3.2 Crop Genetic Resources

In addition to wildlife, biological resources include the genetic resources used to produce agricultural crops. The relationship between agricultural production and biological resources is two directional. While agricultural production may affect wild biological resources, it also depends on crop and livestock genetic resources, some of which are found in the wild. Crop genetic resources are used by breeders to develop new and improved varieties for farmers. This process of genetic enhancement has produced substantial economic benefits. A strong genetic resource base is important for several reasons, among them the fact that a lack of genetic diversity in farmers' fields, if severe, may increase the risk of pest or disease epidemics. Genetic resources are constantly required as inputs into the continuing process of enhancement through selective breeding (including genetic engineering). Therefore, conservation of crop genetic resources is needed, given their critical role in agricultural production.

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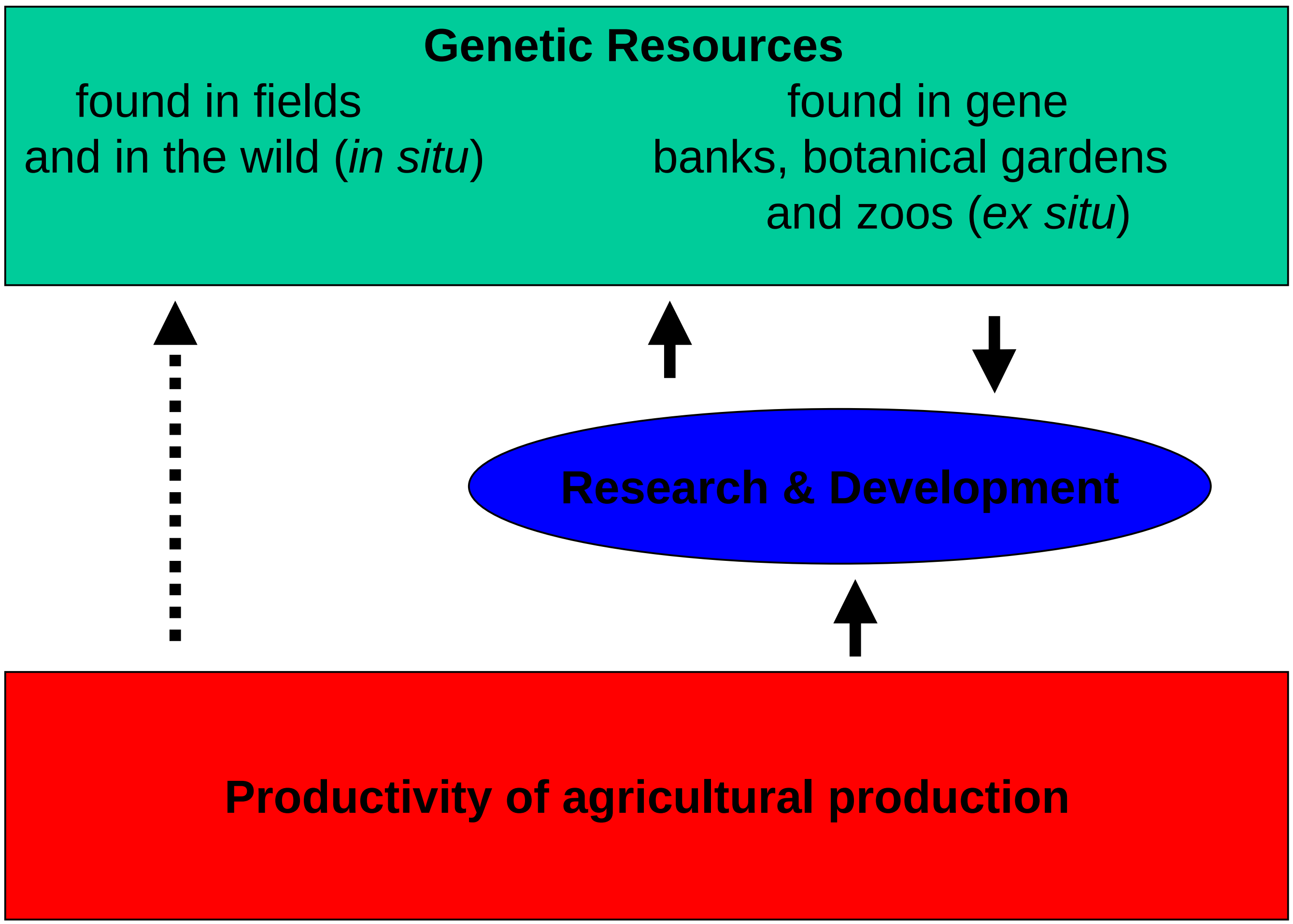
Agriculture's Dependence on Genetic Resources

Agriculture and genetic resources are critically interdependent. All agricultural commodities, even modern varieties, descend from an array of wild and improved genetic resources from around the world. Furthermore, agricultural production depends on continuing infusions of genetic resources for yield stability and growth (figure 3.2.1).

In the U.S., agricultural productivity has increased continuously over the last century (Ahearn et al., 1998). Increases in crop yields have contributed to farmers' ability to produce more food and fiber with fewer inputs. Half the U.S. yield increases of the last 60 years have been attributed to such genetic improvements (Fuglie et al., 1996).

Genetic improvements have arisen in several ways. Before the development of modern varieties, farmers cultivated *landraces* (see box "Use of Landraces and Modern Varieties"). Landraces are varieties of crops that evolved and were improved by farmers over many generations, without the use of modern breeding techniques. These varieties are generally very diverse within species, because each was adapted to a specific environment. The pace of improvement accelerated as modern breeding techniques were developed that facilitated selection of specific desirable traits. Within most types of crops, breeders have crossed different parental material and

Figure 3.2.1-The relationship between genetic resources and agriculture



selected traits resulting in high yields. Quality changes have also been the subject of breeding effort. Other goals of breeding have included rapid and simultaneous germination, flowering, and maturation of crops. Likewise, plants have been bred for uniform stature to ease mechanical harvesting. These advances in yield, quality, and other desired traits have resulted from the use of genetic resources.

Breeders have also sought resistance to pests and diseases, and tolerance to non-biological stresses, such as drought. Because pests and diseases evolve over time, breeders continually need new and diverse germplasm from outside the utilized stock, sometimes using wild relatives and landraces, to find specific traits to maintain or improve yields (Duvick 1986). USDA has estimated that new varieties are resistant for an average of five years, while it generally takes 8-11 years to breed new varieties (USDA, 1990). The economic importance of non-biological stresses can also change over time, although less rapidly than pests and diseases. Plant breeders often rely on landraces or wild relatives as a last resort, but when used, genes from these materials have "often had a disproportionately large and beneficial impact on crop production" (Wilkes, 1991). In short, the plant breeding process is a continual one, in which diverse genetic resources remain a critical input in the agricultural production process.

The advent of biotechnology and genetic engineering may increase the demand for genetic resources. One goal of genetic engineering is to simplify the process of incorporating desired traits in new varieties. The use of genetic engineering and other techniques such as molecular markers may make it easier to incorporate the beneficial characteristics of landraces, and wild relatives of agricultural crops. Genetic engineering also can be used to incorporate traits from very disparate species, exemplified by research that is using flounder genes to prevent frost damage in plants. On the frontier of biotechnology research are efforts to increase the genetic material that breeders can access. Organisms may carry within their DNA many genes that are not expressed as traits, some of which are of interest to crop and livestock breeders. In the future, scientists may be able to determine how these unexpressed genes operate, and make use of them in the breeding of new varieties.

Economic Values of Genetic Resources

Attaching a value to genetic resources is a complex task. Describing the kinds of benefits associated with these resources is easier (table 3.2.1). The simplest value arises from the “direct use” of genetic resources. Direct use values include the use of genetic resources to produce food and fiber, or to help create new varieties of crops and livestock.

Conserved genetic resources may also have economic value even if the resources are not currently being used. The option to exploit resources in the future, for uses not presently known, has considerable value, though this value is difficult to measure. For example, humans presently make little use of many resources found in tropical rainforests. However, by preserving these resources, we retain the option to use them in the future, when they may become important for agricultural or pharmaceutical applications. While we know some new germplasm will be necessary, we do not currently know precisely which resources we will need in the future (Kaplan, 1998). Also, the information about a conserved resource has economic worth. For example, we may not currently need to use a particular species of potato occurring naturally in the Andes. However, information about that species (for example, that it has genes adapted for high altitudes) may be of value to agricultural producers in the future.

Finally, modern molecular biology techniques may reduce the search costs for useful traits in conserved material. "Genomics" refers to investigations into the structure and function of very large numbers of genes undertaken in simultaneous fashion. Many activities may be classified as genomics research, including:

- mapping the genome of an organism;
- sequencing a single individual or several individuals from a given species;
- identifying genes;
- studying genetic variability within species;
- studying genetic similarities across species;
- discovering gene function, and the relationship between gene structure, protein synthesis, and metabolic pathways;
- studying gene regulation, including gene activation and gene silencing;
- studying gene interaction and phenomena dependent on many genes.

Genomics holds great promise for increasing the value of genetic resources. However, the path from mountains of raw genetic sequence data to useful information is not clear. According to Attwood (2000), various difficulties surround the use of genomics. She states that current methods to predict genes in uncharacterized DNA are unreliable. The assignment of gene function based on some degree of similarity between sequences may not be warranted and very few structures are known compared with the number of sequences. The methods for predicting structure are unreliable. Moreover, knowing structure does not necessarily reveal a gene's function. Thus, in the future, conserved genetic resources may have greater value and usefulness as genomics lowers search costs, but it is difficult to predict the pace at which this will take place.

Table 3.2.1—Values of genetic resources for food and agriculture

Value	**Description**
Direct use values	Agricultural inputs: • genes for plant and animal breeding (products include food and fibers, ornamental crops, building and industrial materials) • pesticides useful for agriculture • microorganisms useful for agricultural production
Indirect use values	The role genetic resources play in larger ecosystem (see Chapter 3.1).
Option values	The value of maintaining the option for any direct or indirect use in the future (for example, future agricultural, medical, industrial and climate control needs).
Quasi-option values	The value of information held in conserved resources.
Bequest values	The value of passing resources on to future generations.
Existence values	The value derived from the existence of a resource, apart from any use.

Source: Barbier et al., 1995

Measurement of the Benefits of Genetic Resources for Agricultural Production

Various methods have been used to value genetic material. One fundamental problem arises from the fact that isolating the contribution made by genetic resources is difficult. Breeders use the genetic material to create new varieties. The research effort by breeders has value, as well. Separating the contributions of breeders from the contributions of the germplasm itself is difficult. Thus, many studies have focused on the value of "genetic enhancement," or the value arising from the *use* of genetic material by breeders. Efforts to measure enhancement have largely focused on specific crop breeding programs.

For example, OTA (1987) estimated that genetic improvements have accounted for half the yield gains in major cereal crops since the 1930's. In another study, Thirtle (1985) estimated the contributions of biological advances in U.S. crop production, controlling for changes in other inputs such as fertilizers, machinery, and pesticides. Thirtle concluded that biological improvements contributed to 50 percent of the yield growth of corn, 85 percent for soybeans, 75 percent for wheat, and 24 percent for cotton.

Brennan, *et al*. (1997), examined the contribution of international germplasm to Australian rice improvements. They determined that 64 percent of the improvements came from international germplasm. The total benefits of rice varietal yield improvement from 1962 to 1994 were estimated at $848 million 1994 dollars. Brennan and Fox (1995) also examined wheat and calculated that the total benefits of wheat yield improvement between 1974 and 1993 in Australia were $4.46 billion, in 1994 dollars.

A final example is that of Evenson and Gollin (1997), who sought to value a rice germplasm collection. Evenson and Gollin examined the International Network for the Genetic Evaluation of Rice, an exchange primarily among Asian rice producing nations and the International Rice Research Institute (IRRI). They estimated that without the network, each year, 20 fewer varieties would have been released. The present value of this lost production over a 20 year period (the authors' estimate for the length of time a rice variety is economically viable) was valued at $1.9 billion. The authors estimated that the present value of an added landrace (in a variety introduced by the program) was $50 million (discounted to current net present value at 10 percent.) The authors also find that additional accessions added to the rice collection could also be valuable. For example, the present value of 1,000 additional accessions was estimated to be $325 million (again, discounted at 10 percent).

Benefits from Genetic Improvements

Besides estimating the total value of genetic improvements, it is also possible to estimate the distribution of these benefits. ERS researchers estimated the value of improved crop varieties by modeling the difference in economic welfare for both producers and consumers had there not been crop improvements in five major crops in the U.S. This difference in economic welfare (or loss of benefits) to producers and consumers from an absence of improved varieties provides an estimate of the positive gain in economic welfare brought by crop breeding programs.

These estimates of breeding program benefits are shown in table 3.2.2 and table 3.2.3. Welfare changes from crop genetic improvements are measured in both crop and livestock sectors, as they are calculated from a model that measures changes throughout the agricultural sector. U.S. producers generally lose over $100 million annually from the supply increases due to lower commodity prices. However, lower prices benefit consumers, resulting in an annual increase in consumers' benefits of close to $225 million. Thus, the net economic effect from genetic enhancements is an overall increase in U.S. economic welfare of roughly $115 million per year. Furthermore, at the world level, economic welfare also rises (table 3.2.3).

While worldwide agricultural producers lose more than $600 million annually in economic benefits, again largely due to lower commodity prices, worldwide consumers gain almost $1 billion. Consumer benefits overshadow producer losses and lead to worldwide welfare gains exceeding $300 million per year. The estimated gains and losses attributed to genetic resource preservation and use in the U.S. are felt worldwide. These effects, in terms of dollars, are relatively large when compared with the small magnitude of the yield changes used to generate the estimates.

Table 3.2.2 Estimates of Annual U.S. Benefits from Genetic Enhancements in Major Crops

Commodity	Change in producer benefits	Change in consumer Benefits	Total welfare change
	Million U.S. $		
Livestock	-9	20	11
Poultry	-12	20	8
Dairy	-10	13	3
Wheat	10	7	17
Corn	-37	74	37
Other coarse grains	5	6	11
Soybeans, products	-46	68	22
Cotton	-5	8	3
Other commodities	-5	7	2
Total	-109	223	114

Source: Based on methodology used in Frisvold et al., 1999.

Table 3.2.3 Estimates of Annual World Benefits from Genetic Enhancements in Major Crops in the United States

Region	Change in producer benefits	Change in consumer Benefits	Total welfare change
	Million U.S.$		
United States	-109	223	114
Canada	-17	18	1
European Community	-103	180	77
Other Western Europe	-10	16	6
Japan	-9	66	57
Australia	-13	7	-6
New Zealand	-1	1	0
Centrally Planned	-171	210	39
Developing Exporters	-61	62	1
Newly Industrial Asia	-5	14	9
Rest of World	-119	157	38
Total	-618	954	336

Source: Based on methodology used in Frisvold et al., 1999.

The ERS estimates do not indicate the value of genetic stocks directly. Rather, they measure the value of the crop improvement. However, because genetic stocks are necessary ingredients for making crop variety enhancement, the measure provides (in some sense) an upper limit on the value of genetic material, at least with regard to crop production. These estimates are relatively conservative, compared with the types of estimates reported previously. This may result from the fact that the ERS estimates were developed using a "multi-market" model. The multi-market model allowed prices and quantities to change in many agricultural markets simultaneously. Nonetheless, the estimated benefits in the ERS study, while not exact, are considerable.

Estimates of total benefits from the use of genetic resources, as well as the distribution of these benefits, are sensitive to the economic modeling assumptions employed. For example, the ERS finding that use of genetic resources may have reduced U.S. producer welfare may be the result of the supply and demand assumptions of the agricultural sector model that was used. Furthermore, attempts to value efforts in germplasm preservation or plant breeding may have different results because of different assumptions about what would have happened in the absence of the activity being analyzed. To date, however, practically all published economic analyses of collection of genetic material, conservation in gene banks, or use of genetic resources in plant breeding programs have shown significant economic benefits from these activities.

Genetic Diversity

The loss of genetic diversity in a species, also called genetic erosion, has been identified in many commercially important crops. One reason for this decline in diversity has been the loss of landraces and wild relatives of cultivated crops.

The loss of wild relatives occurs mainly through habitat conversion. Because the economic values of wild relatives can rarely be appropriated (or captured) by land owners, the use of land to preserve habitats for wild relatives remains undervalued compared with alternative uses such as clearing for agricultural or urban use. Although many habitat reserves have been established worldwide, as a rule, wild relatives of agricultural species are covered only by accident (FAO, 1996). Habitat preserves often focus on areas rich in species diversity. These are not necessarily the areas with the greatest crop genetic diversity. While there is some potential for overlap in habitat conservation for wildlife resources and genetic resources, efforts to achieve these two goals often focus on different habitats.

Genetic erosion of crop varieties can be furthered as landraces are displaced by commercially developed modern varieties. When choosing varieties, farmers consider yield potential and consumption attributes. Sometimes landraces offer superior yields and consumption traits, but often they do not. While maintenance of a diverse set of landrace varieties may prove valuable to current or future plant breeding, individual farmers do not directly capture these benefits. Therefore, they have little incentive to account for such benefits when selecting seed for production. Landraces become extinct through disuse if farmers stop planting and maintaining them.

Widespread adoption of genetically uniform crop varieties makes the crop population more susceptible to a widespread disease or pest infestation. Genetic uniformity does not, in and of itself, mean that a variety is more vulnerable to pest and diseases. In fact, modern varieties often are bred for superior resistance, hence their popularity. Nonetheless, as pests and diseases evolve to overcome host plant resistance, genetic uniformity increases the likelihood that such a mutation will be an evolutionary success. The evolved pest or disease has a greater crop base that it can successfully attack, which could increase its efficiency and, therefore, severity. Instead of a particular disease harming only a small percentage of varieties on a limited area of land, the disease now could affect vulnerable varieties accounting for a greater proportion of a crop's production. Genetic uniformity contributed to the spread of the Southern Corn Leaf Blight that led to a 15 percent reduction in the

U.S. corn crop in 1970. Since 1970, the National Research Council (1993) has concluded that the genetic vulnerability of wheat and corn is less of a problem in the U.S. (in part because of efforts to breed in greater diversity). However, the Council also determined that genetic uniformity of rice, beans, and many minor crops is still a concern.

The genetic uniformity of many crops has raised concerns that crop yields and production will become more variable (Swanson, 1996). Individual farmers have limited incentives to consider the consequences of genetic uniformity, and when choosing which varieties to plant may perceive the benefits of uniform varieties to be greater. However, thus far, yields for many major crops have been relatively stable, probably because temporal diversity (or diversity through time) has replaced spatial diversity (diversity across an area) (Duvick, 1984). Although there may be greater spatial uniformity of crops planted at any given time today (compared with 100 years ago), modern plant breeding provides a steady release of new varieties with new traits for pest or disease resistance over time. The ability of plant breeders to keep ahead of pests and diseases through temporal diversity depends directly of the quality of germplasm collections in public gene banks and in private breeder collections. Because many of the benefits of raw germplasm cannot be appropriated, private breeders rely on the public sector to collect, characterize and perform pre-breeding enhancement of genetic materials to make them accessible for private use (Duvick 1991).

Use of Landraces and Modern Varieties

It is a widely held belief that modern agriculture, particularly the transition from landraces to modern varieties as exemplified in the "Green Revolution," has profoundly narrowed the genetic base of modern crop varieties. In the broadest sense, however, genetic alteration and narrowing began with the first domestication of wild plants. The advent of scientific plant breeding, along with changes in crop management practices, almost certainly contributed to genetic narrowing (Porceddu *et al*., 1988). Far less area is planted to landraces worldwide than a century ago. But in many cases improved crop varieties, as exemplified by major advances such as hybrid corn or semi-dwarf wheat or rice, replaced other varieties that were already the products of crop improvement efforts (see Smale, 1997, for example).

Management of genetic resources found in "modern" varieties is related to but distinct from management of genetic resources found in more diverse "traditional" crop varieties (Smale *et al.*, forthcoming). Therefore, knowledge of where different types of crop varieties are currently grown would aid the development of both *in situ* and *ex situ* conservation strategies. However, precise global estimates of landrace use are very difficult to obtain. First, neither industrialized nor developing countries regularly collect detailed information about what crop varieties are being planted by farmers. Second, the limited data which are collected has usually focused on the estimation of areas planted to "modern" varieties, and not to landraces, *per se*. For example, in wheat and rice, "modern" is usually defined as "semi-dwarf." Earlier tall, but scientifically improved, varieties are thus excluded from the definition.

Finally, landrace use is affected by a variety of factors, including whether the crop is a major staple or not, the mode of reproduction (for example, through seed or tubers, cuttings, etc.), and whether the crop is primarily a food or industrial crop. As a result, genetic resource specialists may have detailed knowledge of landrace use, but it is not available in the more aggregated fashion needed by policy makers.

Continued

Use of Landraces and Modern Varieties (continued)

Fortunately, some information is available for the world's three major cereals: wheat, rice, and corn (or maize). These cereals form an important part of the world's food supply, as their direct consumption by humans accounts for over 45 percent of all calories consumed.

Landraces for these three crops illustrate the point that genetic resources of importance for major commercial crops are often found in developing countries. Almost all varieties planted in industrialized countries are results of modern plant breeding (Morris and Heisey, 1998). For example, while wheat landraces from Europe have made important contributions to the modern wheat germplasm pool (Smale and McBride, 1996), today wheat landraces are probably only planted in small isolated areas in Mediterranean Europe.

Furthermore, even in developing countries a large proportion of cropped area is often planted to scientifically bred varieties. In the 1990s, approximately 10 percent of the developing world's wheat area and about 15 percent of its rice area was planted to landraces (figure 3.2.6). Wheat landraces were concentrated in West Asia/North Africa, with some also found in Ethiopia, China, the Indian subcontinent, and small areas in Latin America. The proportion of wheat area planted to landraces varied by wheat type and environment. For example, a considerable percentage of the area planted to durum wheats is still sown to landraces, while the percentage of spring bread wheat area in developing countries under landraces is quite low (Heisey, Lantican and Dubin, 1999). Rice landraces are concentrated in southeast Asia, with some also found in the Indian subcontinent (Cabanilla, Hossain and Khush, 1999). As in wheat, rice landrace use varies by environment, with a much lower percentage of rice area in the irrigated lowlands being planted to landraces than in the more difficult rainfed lowland, flood prone, or upland environments. This may be because modern varieties tend to be bred with irrigated lowlands in mind. In addition, upland rice grown in West Africa often is a different species of upland rice than the rice planted in Asia, and much of the upland West African rice area also consists of landraces (T. Dalton, personal communication).

Corn demonstrates how differences in a crop's mode of reproduction may influence the use of landraces and genetic changes in a crop over time. Wheat and rice self-pollinate, which means that most of the time the pollen that fertilizes a given plant comes from the same plant. As a result, wheat and rice populations tend to be more genetically stable over time. In contrast, corn cross-pollinates, which means that a given plant is often fertilized by a different plant. Because of this feature, corn populations are inherently less stable. Therefore, landraces, improved open pollinated varieties, and hybrids whose seed has been re-used may be very diverse genetically. As a result, it is more difficult to define and measure what constitutes a landrace and what is "improved germplasm" (Morris, Risopoulos and Beck, 1999).

Genetic Resource Conservation

Genetic resources can be conserved either *in situ* (in their natural setting) or *ex situ* (outside their natural setting). *In situ* conservation is the dominant method of conserving natural ecosystems. *Ex situ* conservation is commonly used by agriculturists. However, agricultural resources can also be held *in situ.* Many farmer-developed land races contain significant diversity, and encouraging use of these varieties is one method to conserve agrobiodiversity *in situ*. Wild relatives of cultivated varieties may also be conserved *in situ*, on wild land. More recent approaches view the *ex situ* and *in situ* forms of conservation as complimentary, rather than as substitutes (table 3.2.4).

The preservation of genetic resources varies considerably among different countries. The U.S. uses several policies to promote the conservation of genetic resources.

In Situ: Benefits and Costs

Species preserved *in situ* remain in their natural habitat. Most of the world's genetic diversity is found *in situ*. For agriculturally important species, the greatest diversity in landraces and in wild relatives may be found near their centers of origin, or the places in which they were first domesticated. One of the first scientists to define centers of origin was the Russian botanist N. I. Vavilov in the early twentieth century. Considering some economically important crops for the U.S., corn (or maize as it is known in the rest of the world) and upland cotton were first domesticated in southern Mexico and Central America; soybeans in China; and wheat and alfalfa in West Asia.

Since Vavilov's time, ideas about centers of origin have been refined. Some crops, such as sorghum, sugarcane, and peanuts, were probably domesticated over very broad areas rather than in a well defined center (Harlan, 1971, 1992). Furthermore, useful landraces of some crops have been found in other parts of the world from which they were originally domesticated. *In situ* preservation efforts, as well as germplasm collection activities for *ex situ* conservation, are often focused most closely in and around centers of origin (figure 3.2.4). For example, wheat landraces found at the base of the pedigrees of many modern wheat varieties have come from six different continents (Smale and McBride, 1996). In another example, in what is now the U.S., Native American farmers had selected and reselected corn into many distinct, locally adapted varieties long before European settlements. European farmers in turn adapted these local varieties, beginning in the seventeenth century. By the end of the nineteenth century southern dent varieties from the southeastern U.S. were combined with New England flint varieties adapted to the northeast, to form Corn Belt Dent material adapted to the U.S. Midwest. These Corn Belt Dent varieties later formed the basis of modern Corn Belt hybrids (Duvick 1998).

Because *in situ* conservation of agricultural genetic resources is carried out within the ecosystems of farmers' fields or wildlands, species continue to evolve with changing environmental conditions. *In situ* preservation can provide valuable knowledge about a species' development and evolutionary processes, as well as how species interact. By allowing genetic resources to act as part of larger ecosystems, *in situ* preservation may also provide indirect ecological benefits. However, since restrictions on land use may be necessary, *in situ* conservation can be costly. To preserve agricultural genetic diversity *in situ*, for example, a farmer may have to forgo the opportunity to grow a higher yielding (and more economically rewarding) variety. Or, in the case of wild *in situ* resources, the land may need to be set aside from agricultural production completely.

Table 3.2.4 Benefits and Costs Associated with *In Situ* and *Ex Situ* Conservation

***In Situ* conservation**		***Ex Situ* conservation**	
Benefits	**Costs**	**Benefits**	**Costs**
Genetic resources used to produce valuable product	Costs borne by farmers	Costs generally centralized	Certain types of germplasm not readily conserved
Evolutionary processes continue	May reduce on-farm productivity	Can preserve large amounts of diverse germplasm	Regeneration can be costly, time-consuming
May better meet the needs of certain farmers	Requires land	Germplasm can be more readily accessed by more breeders	Potential for Genetic "drift" can reduce integrity of collection
More efficient for some germplasm, e.g., animals, crops that reproduce vegetatively.	Farmer selections may not preserve targeted diversity	High security storage impervious to most natural disasters.	In practice, many collections are insufficiently funded, organized and documented
Existing wild relatives can be preserved without collection			

One reason that *in situ* biodiversity conservation is not practiced more widely is because the private returns to biological diversity are lower than the social returns (Hanemann, 1988). Private returns are important because resources are generally held at the individual or local level. Thus many decisions that affect conservation of biodiversity, such as land clearing or crop variety selection, are made at the individual or local level. By contrast, many of the benefits of biodiversity conservation accrue at the national or global level. Also, people usually prefer to consume resources in the present, rather than in the future. Together, these factors generate private or individual decisions that differ from those that are socially or globally optimal.

These differing returns contribute to biological resource depletion because agricultural uses compete with alternative uses of land. Since keeping land in its natural state reduces or eliminates the land's earning capacity for its holders, returns to agricultural production form one opportunity cost of wild land preservation. Also, because certain genetic materials are easy to transport and replicate once collected, it is difficult for countries to capture more than a fraction of the value that flows from their genetic resources. Moreover, markets do not exist for most of the other environmental services provided by biological resources. Consequently, keeping land in less intensive uses favorable to the preservation of biological resources is often less profitable to the individual landowner than more intensive agricultural production.

Developing countries often face greater pressures for wild land conversion than do developed countries. Compared with the developing world, the developed world has lower rates of agricultural land expansion. In the U.S., for example, the amount of land used for agricultural production has remained stable since 1945. This does not mean that the same land has been in production. For example urban land expansion has displaced agricultural lands, which have displaced wildlands. Still, expansion of the agricultural production area has not been a significant factor in U.S. biodiversity loss in recent years. Conversion for agricultural use is the primary reason wild lands are cleared in developing countries (Houghton, 1994.) When land is cleared, plant, animal, and microorganism populations generally fall. Therefore, conversion of forest and other wild lands reduces the level of genetic diversity. At the same time, developing countries generally have richer biological diversity, especially in tropical forests. Between 1990 and 1995, the developing world's net loss in forestland was more than 13 million hectares per year. Tropical developing countries had the world's highest deforestation rates (FAO, 1997), due primarily to agricultural land expansion. (See figures 3.2.2, and 3.2.3). Population growth and extensive farming techniques are often cited as factors fostering high rates of land conversion to agriculture. Other incentives for land conversion are thought to include poverty, international trade and debt, land quality, and government policies, including land tenure policies.

Ex Situ: Benefits and Costs

The *ex situ* method removes genetic material from its environment for long-term conservation (table 3.2.4). Botanical gardens and gene banks are examples of *ex situ* conservation strategies. Certain methods of *ex situ* conservation can be used to store large amounts of genetic material at relatively low cost, compared with *in situ* strategies. For example, gene banks hold a large amount of germplasm. The world's gene banks presently hold more than four million accessions, or specific samples of crop varieties. It is estimated that most of the world's cereal landraces are held in gene banks (Plucknett et al., 1987).

However, crop genetic resources must be collected (and samples of only a small fraction of the world's plant genetic resources have been collected thus far). Stored plant materials must be kept under controlled conditions, and periodically regenerated (planted and grown) in order to maintain seed viability. Not all kinds of plant genetic resources are easily conserved *ex situ.* Certain kinds of plant genetic resources lose their varietal identity when they are stored as seed. These plants may need to be kept as living plants, a more costly process that requires additional land and labor. And gene banks in politically unstable areas may be in danger of losing valuable genetic material. Even in stable locations, the relatively modest resources necessary to maintain or improve plant gene banks are not always forthcoming because of the competing demands for public resources.

Figure 3.2.2-Tropical forest loss, 1980-90

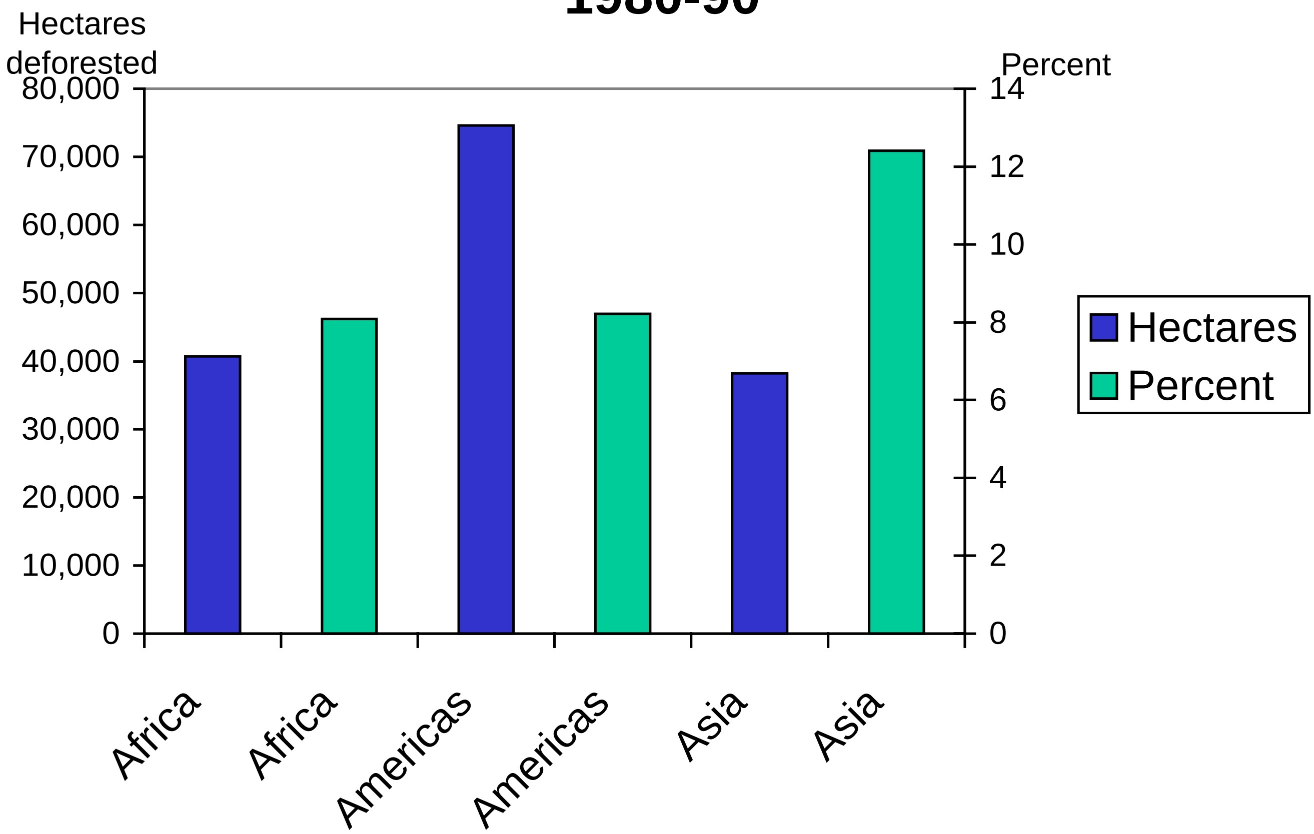
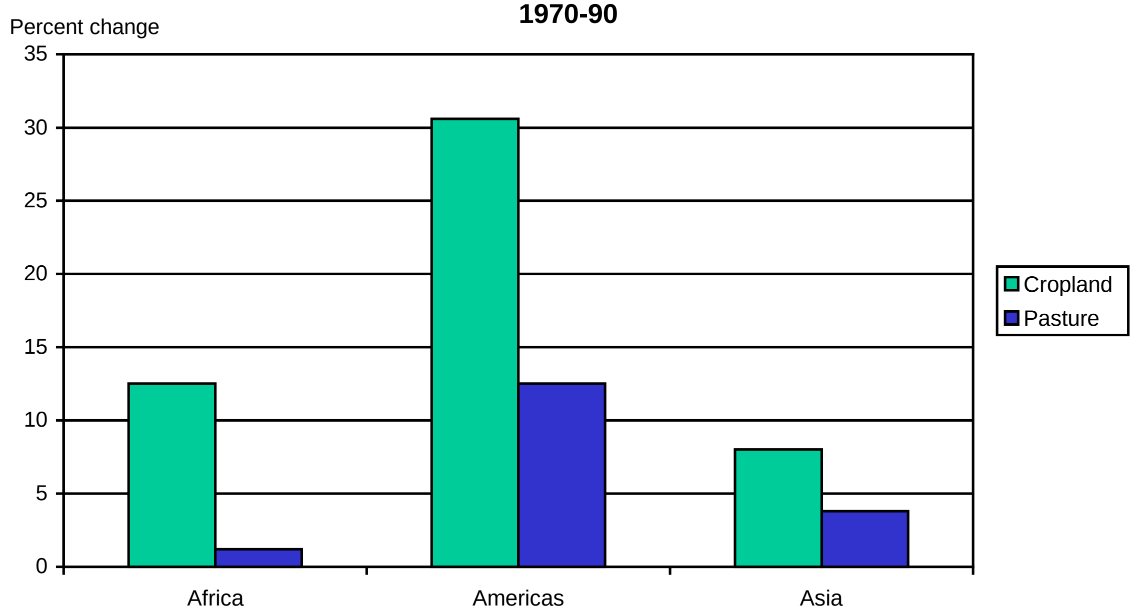


Figure 3.2.3-Tropical agricultural land expansion 1970-90



International Access to Genetic Resources

Access to genetic resources found in other countries is critical to maintaining the rate of varietal improvement. In fact, almost every plant species of major economic importance to the U.S. has been improved with germplasm from elsewhere (figure 3.2.4). (As noted earlier, most commercially important plant species originated outside the U.S.) For example, the genes that provide resistance to yellow dwarf disease in U.S. barley varieties were obtained from a Turkish landrace. Another wild plant originating in the Caucasus related to modern wheat has been the source of important resistance to stem rust disease for U.S. commercial wheat varieties. Both sets of genes have been used to produce important commercial varieties.

Historically, genetic material was regarded as the common heritage of humankind. Developing countries have often provided raw genetic material to public germplasm repositories, both because they often lie in geographic centers of diversity and because they have generally less completely industrialized agriculture and, in Latin America and Africa, more wildlands than developed countries. However, some developing countries believe that the system of unrestricted access to germplasm without compensation is inequitable, especially since material from donor countries can be incorporated into varieties by researchers in developed countries, and then sold by private seed companies (Day, 1997). Observers disagree about whether foregone earnings from sales of raw genetic material by lower-income countries are compensated for by maintaining free access to public germplasm and lower world food prices (Shands and Stoner, 1997; Fowler, 1991).

Figure 3.2.4-Center of origin of selected crops

Note: The pointer locations indicate general regions where crops are believed to have first been domesticated. In some cases, the center of origin is uncertain. Other geographic regions also harbor important genetic diversity for these crops.

Source: U.S. GAO, 1997.

International agreements have been made, which seek to rectify some causes of inadequate preservation of genetic resources, the U.N. Convention on Biological Diversity being the most prominent. The agreements contain provisions that could change the nature of these germplasm exchanges. One change is that the traditional "free flow" of "unimproved" genetic resources and landraces between countries is no longer a given. For example, the Convention can be interpreted to allow countries to sell unimproved genetic resources and landraces, or demand royalties for their use. Changes in germplasm flows and in funding mechanisms could also affect the gene bank system.

Expanding intellectual property rights also have implications for genetic resource conservation. In theory, stronger intellectual property would enhance the incentives for conservation of genetic resources. However, intellectual property law may not cover unimproved germplasm, and farmer developed varieties. (See also AREI Chapter 5.2, Research and Development, for a discussion of U.S. intellectual property rights for biological inventions.) The role of intellectual property rights remains unclear, and has been the subject of much international debate. More wide-reaching intellectual property rights also limit access to genetic resources through free exchange of advanced germplasm or finished varieties, as was formerly the case with many non-hybrid crops.

Using Public Policy to Enhance Biological Resources

Because genetic resources are used in agricultural production, the U.S. must have these resources in order to maintain (and ideally increase) crop and livestock yields. Genetic resources can be found in genebanks, on farmers' fields, in zoos, and in the wild, here and abroad. In the U.S., certain policies promote the preservation of genetic material that will be needed in future agricultural production. This section describes some of the policies used to manage genetic resources.

Overall Policy Objectives

The fundamental goal of plant genetic resources management is to preserve genetic diversity for use in agricultural production. Linked to this activity are efforts to distribute and facilitate the use of germplasm by public and private breeders. Distribution and use of germplasm is one way to promote the incorporation of diverse genetic resources into final varieties.

Germplasm can be held *in situ*, that is, in its natural environment (such as the wild or on a farmer's field). Germplasm can also be preserved *ex situ*, or off site in a genebank, botanical garden, or zoo. Genetic resources found *in situ* can become resources held *ex situ*, if they are collected and preserved.

The U.S. focuses primarily on *ex situ* preservation strategies, especially for domestically held germplasm. However, while we know that genetic resources will be needed in the future, we are unsure which specific resources breeders will require. This uncertainty about genetic resource needs motivates genetic resource managers to collect and preserve a broad range of germplasm. Much of the world's diversity is found *in situ*, outside the U.S. Therefore, various countries are exploring means to conserve *in situ* genetic resources abroad. Finally, because the U.S. relies heavily on foreign countries for new germplasm, the U.S. is also concerned with the preservation and accessibility of that germplasm. Consequently, the U.S. has developed policies or participated in international agreements concerning genetic resources held *ex situ* outside the U.S..

Policies to Protect Genetic Resources

The National Plant Germplasm System, (NPGS) administered by ARS, is the primary player in the effort to secure and utilize germplasm. The public sector plays a unique role in collecting, developing and distributing benefits from genetic material. Much of this work is carried out by the NPGS system. The NPGS system includes national-level centralized facilities, as well as a number of collections throughout the country (table 3.2.5). ARS National Program Staff coordinates the entire system. The National Plant Germplasm Resources Laboratory, in Beltsville, develops and manages the NPGS database (the Germplasm Resources Information Network), coordinates its plant exploration or collecting program, and assists with the international exchange of germplasm. Long-term seed storage is carried out by the National Seed Storage Laboratory. This high security facility maintains the base collection, and backups seed samples for the germplasm found in other NPGS facilities. The other NPGS facilities focus on active collections. Through these crop-specific collections, the NPGS maintains close ties to the State Agricultural Experiment Stations. Many of the NPGS facilities are located on or near Land Grant Universities, which promotes the use of NPGS germplasm. The National Clonal Germplasm Repositories keep germplasm for vegetatively propagated crops, which lose their varietal identity when stored as seed (USDA, 1996).

The NPGS has collections for more than 85 crops. Within a particular crop, the NPGS seeks both breadth and depth. Germplasm can be categorized into three basic types: 1) elite or modern, 2) landraces and 3) wild and weedy relatives (also, some germplasm is "undetermined"). Elite or modern germplasm has been improved by plant breeders. It may be a final cultivar (either recently developed or obsolete), or it may be germplasm that has been modified by a breeder for use in creating cultivars (such as some breeders' lines). Landraces are varieties of crops or breeds of livestock that were improved by farmers over many generations, as they evolved over time. Landraces have been produced without the use of modern breeding techniques. Wild or weedy relatives share a common ancestry with a crop species, but have not been domesticated. Because landraces and wild or weedy relatives often contain unique traits, they increase the diversity of a germplasm collection.

Table 3.2.5—The National Plant Germplasm System

National Germplasm Resources Laboratory, Beltsville, MD	National Plant Germplasm Quarantine Center, Beltsville, MD	National Seed Storage Laboratory, Fort Collins, CO (long term seed storage)

Regional Plant Introduction Stations • Ames, IA, • Griffin, GA • Geneva, NY • Pullman, WA	Crop-Specific Genetic Stocks Collections • Pullman, Washington (pea) • Davis, California (tomato) • Aberdeen, Idaho (barley and wheat) • Urbana, Illinois (maize) • College Station, Texas (sorghum)
Crop-Specific Seed Collections • Salinas, California (endive, lettuce) • Sturgeon Bay, WI (potato), • Urbana, IL (soybean), • Aberdeen, ID (small grains), • Lexington, Kentucky (clover) • Oxford, North Carolina (tobacco) • College Station, TX (cotton)	National Clonal Germplasm Repositories • Hilo, HA, • Corvallis, OR, • Davis and Riverside, CA, • College Station, TX, • Miami, FL, • Mayaguez, PR, • Washington, DC, and • Geneva, NY

Source: USDA, 1996

At the same time, elite material also contains diverse genes, which may be less exotic, but are generally easier to use (NRC, 1993). Thus, curators and breeders will want all three types of germplasm in a collection. In addition to these three basic types, germplasm collections also may include "genetic stocks." Genetic stocks include mutants and other germplasm with chromosomal abnormalities that are used by breeders.

Public germplasm management focuses on a set of activities: collection, preservation ex-situ, characterization and evaluation, and enhancement. The first, collection, involves gathering germplasm from the field, the wild, or from other genebanks. Preserving germplasm *ex-situ* includes general maintenance of germplasm and the use and development of technology to improve the preservation process. Evaluation activities can be broken into three categories: cataloging, environmental specific, and morphological specific. Cataloging involves studying the general make-up of the species (not looking for any specific trait). Germplasm can also be examined for traits that are affected by the environment, such as temperature tolerance or pest resistance. Morphological specific activities focus on traits that usually are not influenced by the environment, such as size or taste. Finally, enhancement seeks to use germplasm to create superior crops and livestock breeds through breeding.

Thus far, the U.S. *ex situ* preservation efforts have resulted in the NPGS becoming one of the world's largest collectors and distributors of germplasm. The germplasm management system has yielded large economic benefits for U.S. and world agriculture. It is important to note that publicly funded germplasm banks provide society with different services than private collections. The NPGS focuses on germplasm that may be needed by both public and private breeders. One goal of the system is to meet the germplasm needs in the long term. Private incentives to collect and maintain such a collection are small, because any economic returns may not be realized until long into the future. Likewise, there is a significant collection of exotic germplasm. As described earlier, exotic germplasm is often difficult to work with, and therefore is not used routinely by private breeders. However, it is a crucial source of needed traits, particularly resistance traits. Also, many forms of germplasm have, in and of themselves, limited appropriability (i.e., private returns are difficult to capture) because such biological resources can be easily reproduced for breeding purposes. Finally, the NPGS collections are kept for national security purposes, so that the US has an adequate supply of breeding material, regardless of any changes in global politics.

These benefits notwithstanding, two problems are found with the present gene bank system (table 3.2.6). First, relatively few wild relatives of domesticated varieties are held in gene banks (GAO, 1997). Second, gene banks, which are an important source of new genetic material for breeders, may not be receiving adequate funding to fulfill their mission (Day, 1997). The NPGS lacks sufficient funding to complete evaluation and documentation, or to perform necessary backups and regeneration of seed accessions (GAO, 1997).

International in situ *resource conservation*—Several instruments have been proposed to foster *in situ* conservation of genetic resources. One method, which targets wild crop relatives, relies on establishing and maintaining protected areas. While efforts to establish protected areas generally have not focused on agricultural biodiversity, this approach could be used to conserve wild crop resources. Improved information about the location, relative scarcity and demand for these resources would greatly assist such efforts. Geographic Information Systems (GIS) offer improved technology for pin pointing key conservation areas, and monitoring the success of protection activities.

Table 3.2.6—Some germplasm collections with insufficient diversity for reducing crop vulnerability

Based on GAO survey of Crop Germplasm Committee members, most collections are considered sufficiently diverse overall. However, nine collections were thought to lack sufficient diversity for reducing crop vulnerability. In addition, many collections lacked sufficient diversity within specific types of germplasm

Collections in which genetic diversity is insufficient for reducing crop vulnerability:

- Grapes
- cool season food legumes
- sweet potatoes
- cucurbits
- tropical fruit and nut
- walnuts
- prunes (peach and cherry trees)
- herbaceous ornamentals
- woody ornamental

Collections lacking specific types of germplasm:

- Wild and weedy relatives: almost 50%, including corn and soybeans.
- Landraces: 12 out of 40 collections
- Genetic stocks: 50%, including alfalfa, peanuts, grapes.
- Obsolete and current cultivars: 5 out of 40 collections.

Source: GAO, 1997.

Farmer participatory breeding programs, which may include some elements of *ex situ* conservation, are a second strategy. In such programs, farmers and breeders work together to improve crop varieties. Breeders gain access to farmer-developed germplasm and farmers' production expertise, while farmers receive training and additional genetic resources. Thus far, the scope of these projects has been limited.

There is the option of simply paying farmers to grow landraces, in cases where landraces cannot complete with modern varieties and are in danger of being lost. Farmers would be paid the difference between maintaining landraces and growing the more productive modern variety. Financing protecting areas and subsidizing production of landraces has been problematic, because thus far, resources have not been sufficient to meet internationally determined conservation goals (see the discussion "International Agreements").

Finally, most of the world's diversity is found *in situ*, consequently the decision to convert wild land to agricultural land can directly affect genetic resources. Land use decisions in any given region are affected by commodity prices, natural and human resources (including access to new technologies), and local, national and global policy. These factors also help determine whether farmers grow landraces or modern varieties. Hence, there is a global link between agriculture and trade policy and protection of the world's genetic resources, though it may not be direct. Consequently, international agreements that affect agricultural production and land use in other countries are also of interest to the U.S. Certain U.S. research institutions and private pharmaceutical firms have also explored "biodiversity development agreements" with diversity-rich countries (see box, "Biodiversity Prospecting"). Genetic resources used for breeding crop and livestock are not generally addressed by these agreements in the U.S. The U.S. position is that publicly held agricultural germplasm is freely exchanged, and not protected by intellectual property. Thus, the public sector probably will not be involved in any agricultural genetic resource bioprospecting efforts. While private firms could enter into agreements to search for useful agricultural germplasm, there appear to be no such agreements involving U.S. companies.

Biodiversity Prospecting

Biodiversity prospecting seeks to address resource losses arises from the fact that the benefits of diverse resources typically are diffuse and longer term, while the opportunity costs of preserving land (and thus, resources conserved in situ) are borne immediately by local communities. Further complications arise from varying property rights structures. Unimproved genetic resources may not be protected by any intellectual property rights, making it difficult to extract rents from resources valued by society as whole, or the producers of final products.

In a biodiversity prospecting agreement (BDA), the users of genetic diversity (usually a private firm) and the holders of genetic diversity (usually a developing country) agree to share genetic resources and the gains from new product development. Generally, there are two related objectives of bioprospecting efforts. The first is to discover and use certain genetic resources. There are many species that have never been sampled or assessed, some of which potentially could benefit agriculture or industry (particularly the pharmaceutical industry). The second objective is to give indigenous people a return for the conservation of genetic resources. These agreements are intended to help countries and local communities capture a greater share of the external benefits of genetic resource conservation. By tying future benefits to maintenance of the resource base they increase a country's incentives for preservation. Many agreements encompass both objectives, and specifically seek to foster resource conservation in situ.

There are limits to what can be achieved through bioprospecting. Prospecting and harvesting activities are not guaranteed to protect in situ resources. In fact, harvesting can damage in situ resources, and synthesis of valuable resources can remove the incentive to continue in situ protection. On a broader scale, incentives for and returns to conservation may differ at the local level (where resources are conserved) and national level (where the agreement may be made.) Moreover, there is evidence that the opportunity costs of preservation are rising rapidly in many tropical regions. Where this is the case, market mechanisms (such as bioprospecting or eco-tourism) that allow countries to capture greater benefits from preservation may have less impact. Other forms of biodiversity protection may be needed. Nonetheless, BDAs can be an important component of a portfolio of conservation strategies. Source countries also need to structure BDAs carefully, to achieve all their objectives.

U.S. Policies Addressing Internationally Held Genetic Resources

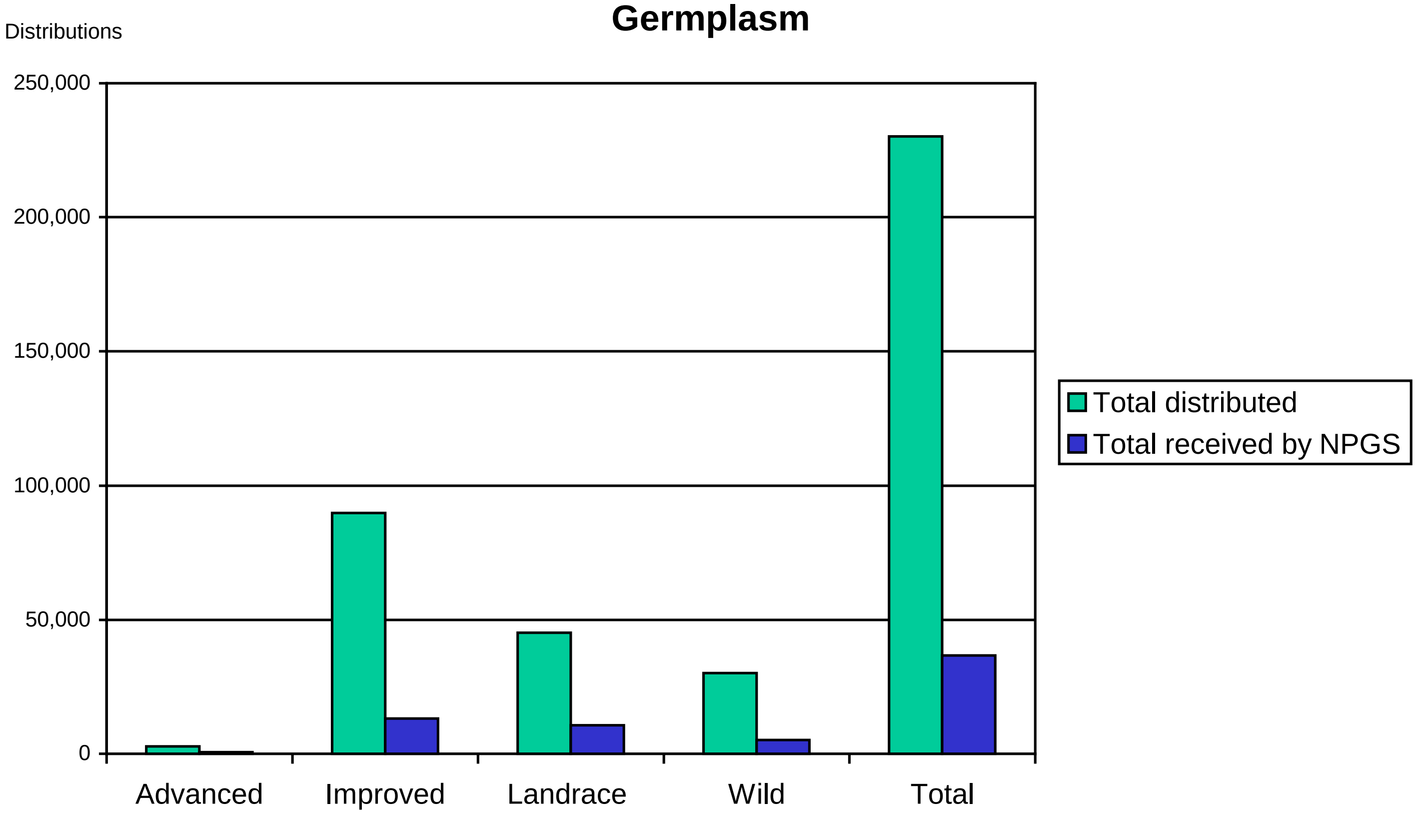
In the U.S., most farmers produce crops and livestock that are not native to this country (NRC, 1993). The U.S. is considered a "germplasm deficient" country, because very few crops and livestock of economic interest originated inside its borders. In contrast, a country can be "germplasm abundant" because it was a center of origin of one or more important crops. Given basic biological conditions and the development of agriculture early in human history, most germplasm abundant regions fall in developing countries. As a germplasm deficient country, the U.S. uses two primary policy instruments to promote the conservation and use of genetic resources found abroad: international agreements and funding international germplasm preservation efforts.

International Agreements—Considerable genetic resources are held ex situ, by a system of international agricultural research centers (also called Future Harvest Centers) funded by the Consultative Groups of International Agricultural Research (CGIAR). The CGIAR is composed of donors from industrialized and developing countries, multilateral development banks, and private foundations. The CGIAR coordinates germplasm preservation efforts for specific food crops. The status of the germplasm flowing into and out of CGIAR member institutions is of interest to the U.S. and other countries.

Despite its germplasm deficient status, past collecting efforts and extensive breeding activities have resulted in the U.S. actually being a net supplier of plant germplasm to the rest of the world (figure 3.2.5). Historically, germplasm has been exchanged freely by different countries. The NPGS supplies germplasm, free of charge, to anyone who requests it. In 1990, a statute was passed confirming the U.S. commitment to unrestricted and free exchange of germplasm. However, due to various economic and political factors, some countries no longer want the traditional free exchange of genetic resources. Despite its status as a net supplier of germplasm, the U.S. continues to rely on other countries as sources of genetic material. Therefore, international agreements that affect the exchange of germplasm are of great importance to U.S. policy makers.

FAO-led International Undertaking—In 1983, a major controversy developed over genetic resources when a majority of countries at the Food and Agriculture Organization (FAO) of the United Nations passed Resolution 8/83, the International Undertaking on Plant Genetic Resources. The Undertaking called for free access to all germplasm, including commercially developed elite varieties and breeding materials (FAO, 1983). Many developing countries argued that in return for the contribution of their unimproved landraces and wild relatives to commercial breeding, private breeders should give them free access to elite breeding materials (Kloppenburg, 1988).

Figure 3.2.5-National Plant Germplasm System Distribution of Germplasm



Some developed countries resisted the resolution, and several did not sign it, arguing that it did not honor the proprietary nature of breeding materials and finished varieties and therefore reduced incentives for private investment in varietal improvements (ASTA, 1984; Brown, 1988). Defenders of intellectual property rights for finished varieties argue that it costs developing countries little to provide germplasm (Brown, 1988) and that genes from unimproved landraces and wild relatives are worth little until breeders incorporate them into elite varieties (Pioneer Hi-Bred, 1984). It has also been pointed out that major beneficiaries of the development of commercial crop varieties have been consumers, particularly in developing countries, who benefit from lower priced and more plentiful food (Shands, 1994b; Wright, 1996). As a result, compliance with Resolution 8/83 was not binding. Virtually every developed country officially indicated to the FAO that they would be unable to support the Undertaking unless significant restrictions to free access to elite lines were included (NRC, 1993). Although frequently portrayed as a simple North-South conflict (Mooney, 1983; Kloppenburg, 1988), several developing countries chose not to adhere to the Undertaking, in particular China, Brazil and many South East Asian countries.

Subsequent meetings of the FAO and a series of talks between opposing factions organized by the Keystone Center began to resolve differences (Keystone Center, 1988, 1990, 1991; FAO, 1987a, 1987b, 1987c, 1989, 1991). Delegates generally accepted that plant breeders' rights legislation represents a legitimate interest and does not necessarily constitute an impediment to access to protected varieties for research and the creation of new varieties. Second, the idea of plant genetic resources as the world's "common heritage" was fundamentally changed by FAO resolution 3/91 acknowledging "the sovereignty of States over their plant genetic resources." Third, another FAO Resolution established a fund for genetic resource conservation. Finally, delegates advocated "farmers' rights" as a means of compensating the contributions of farmers. Under this system, the contribution of farmers to plant breeding would be acknowledged by the creation of the international fund to support plant genetic resource conservation activities, particularly *in situ* conservation programs in developing countries (Brush, 1992; NRC, 1993).

The idea of farmers' rights is different from the existing plant breeder's rights system. In the latter case, breeders can obtain intellectual property protection supported by the force of law for exclusive rights to sell seed. Plant breeders' rights allow new variety developers to capture (to some extent) monopoly rents for a limited period. These rents serve as an economic incentive for new varietal development. In contrast, the farmers' rights system implies a noncompulsory moral obligation to developing countries for past contributions to crop genetic improvements. While plant breeders' rights are aimed at creating incentives for future innovation, farmers' rights proposals focus on retroactive compensation.

The Commission on Genetic Resources for Food and Agriculture oversees the International Undertaking, as well as other international genetic resource efforts including the international network of ex situ collections under the auspices of FAO. Initially, concerns arose over the ex situ collections of the CGIAR. Developing countries and NGOs called for greater control over the unimproved landraces and other germplasm stored in international seed banks, arguing that the CGIAR is biased toward the interests of developed nations, its primary financiers. Thus they have called for a multinational authority, such as the FAO, to control the seed banks. The existing germplasm collections of the CGIAR institutions subsequently were placed under the auspices of the FAO. The CGIAR collections include over half a billion accessions and represent the world's largest single block of *ex situ* genetic materials.

In 1993, the then Commission on Plant Generic Resources called for sovereign rights over genetic resources (consistent with the Convention on Biological Diversity, see below). In 1996, the renamed Commission on Genetic Resources for Food and Agricultural began to establish a Global Plan of Action to conserve of plant genetic resources (FAO, 1996). The Leipzig session of the Commission adopted the Global Plan of Action and the Leipzig Declaration. In the declaration, representatives “assert and renew our commitment to the conservation and sustainable utilization of these resources and to the fair and equitable sharing of the benefits arising from the use of plant genetic resources for food and agriculture, recognizing the desirability of sharing equitably benefits arising from the use of traditional knowledge, innovations and practices relevant to the conservation of plant genetic resources for food and agriculture and their sustainable use.”

Subsequent sessions have developed a Multilateral System to facilitate access to and use of plant genetic resources. However, benefits sharing and farmers’ rights remain contentious issues. To date, it remains unclear how farmers' rights will be implemented, given the difficulty of determining the contributions of and appropriate compensation for farming communities in developing countries. In more recent sessions, intellectual property protection has emerged as further complicating factor. At the Tehran meetings in 2000, a provisional package agreement on IPR was developed. However, the Neuchatel meetings (held later in 2000) saw a loss of momentum in this area, and a continued lack of consensus on mechanics of benefit sharing. Also, the treatment of non-parties (which the U.S.) remains a concern. Finally, other limitations to FAO agreements stem from problems surrounding funding. Contributions to the FAO’s fund for genetic resource preservation have remained insignificant. Questions about how the funds would be specifically used have not been decided. Thus, this multilateral agreement has yet to resolve fundamental disagreements over the equity question or develop an achievable strategy to provide adequate incentives for genetic resource preservation.

The U.N. Convention on Biological Diversity—The Convention on Biological Diversity represents a more recent multilateral attempt to address ongoing disputes over the exchange and use of plant genetic resources, though this was not the primary objective of the Convention. The Convention arose out of concern over loss of ecosystem and species diversity, which stemmed largely from tropical deforestation and other systemic habitat loss. Consequently, many leading representatives negotiating language in the Convention were from environmental rather than agricultural ministries. Language in the Convention related to property rights over genetic materials, intellectual property rights over biological inventions, technology transfer and benefit sharing were drafted with pharmaceutical development more in mind than seed variety development. However, the Convention has several important implications for management of plant genetic resources.

The Convention was designed to promote the conservation and sustainable use of biological diversity and to encourage the equitable sharing of resulting benefits. The Convention was opened for signature at the U.N. Conference on Environment and Development in Rio de Janeiro in 1992. Several provisions of the Convention proved controversial and, in the U.S., there were biotechnology and seed industry concerns that the Convention undermined intellectual property protection. President Clinton signed the Convention in June 1993, but the U.S. Senate has not ratified it. Thus, because the United States has not ratified the Convention, it attends meetings of the COP as a non-voting observer. The Convention came into force for signatory parties on December 29, 1993. The First Conference of Parties (COP) of signatories to the Convention met at the end of 1994 to plan implementation of the Convention. In the Third Conference of the Parties (Buenos Aires), delegates called for a detailed work program specifically addressing agricultural biodiversity.

The Convention has fairly wide reaching implications. Because the International Undertaking is being brought into harmony with the Convention, the Convention’s provisions are being applied to the management of plant genetic resources beyond the confines of the Convention. The International Undertaking’s move to sovereign rights described above reflects the provisions of the Convention. Following the Third COP, subcommittees and working groups have worked to bring closer cooperation with FAO and the administrators of the International Undertaking. However, recently, the primary focus of Convention activities in the area of agricultural genetic resources has been the management of biosafety associated with genetic modified organisms.

Trade-Related Aspects of Intellectual Property Rights (TRIPS)—Plant protection issues (and consequently agricultural genetic resources) were also affected by the Uruguay Round of the General Agreement on Trade and Tariffs (GATT) of 1986. The GATT is a multilateral agreement intended to reduce international trade barriers. An important component of the GATT is settlement of trade-related aspects of intellectual property rights (TRIPs). The GATT has moved closer to more universal recognition of plant breeders' rights. The GATT creates minimum standards for the protection of intellectual property rights over commercially developed seed and plant varieties. Article 27, 3(b) states that, “Members shall provide for the protection of plant varieties either by patents or by an effective *sui generis* system or by any combination thereof.”

On its face, TRIPS seems less directly related to genetic resources than either the International Undertaking or the Convention on Biological Diversity. However, the increasing concerns about IPR in the Undertaking are an illustration of the profound role intellectual property play in the exchange of genetic resources. Many developing countries have adopted IPR legislation that includes provisions for farmers’ rights and benefits sharing for farmer-developed varieties (i.e., landraces). The effects of these IPR policies in the international exchange of germplasm remain unclear. Because the U.S. does not allow for IPR over publicly-held materials, certain germplasm may no longer be transferred to the U.S. genebanks, a difficult complication.

Because the GATT has the power to sanction members who fail to comply with its provisions, in many ways it is the most powerful of three international agreements affecting access to and use of genetic resources. The difficulties stemming from IPR at the most recent International Undertaking session in Neuchatel may be an indication that a more powerful role may be played by TRIPS in the future.

Funding of International genebanks—As noted earlier, CGIAR member institutions have a large collection of germplasm covering a broad array of agricultural commodities. The CGIAR system also facilitates the security and exchange of preserved genetic resources. To support this important source of germplasm as well as broader goals for agricultural research, the U.S. contributed over $40 million dollars to the system as a whole in 1998 (CGIAR, 1999). In fact, the U.S. makes the largest contributions of any single country to this system.

Nonetheless, international gene banks often experience even greater funding shortages than those of the NPGS. The CGIAR system has experienced stagnant funding in recent years, which has affected its germplasm repositories (Pardey et al., 1996). Beyond the CGIAR facilities, individual countries also hold important germplasm collections that are not always backed up in international facilities. Declining domestic funds and/or political instability have adversely affected seed banks in certain countries (for example, in the former Soviet Union) (Zohrabian, 1995).

Authors: Kelly Day-Rubenstein (202) 694-5515 kday@ers.usda.gov and Paul Heisey.
Contributor: John Sullivan.

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"Agricultural Genetic Resources: Building Blocks for Future Crops," *Agricultural Outlook*. November 2000 (Day-Rubenstein). Agricultural genetic resources are used by plant breeders to develop or enhance desirable traits in crops, such as high yields, resistance to disease, drought tolerance, and heightened nutritional value. Genetic improvements from plant breeding account for half the crop yield increases over the past six decades. But continuing evolution of diseases and other pests presents a threat that can quickly undo the gains. Breeders need continually to incorporate diverse germplasm. . In the U.S., most agricultural genetic resources are preserved by removing genetic material from its natural environment for long-term conservation. Given the limited incentives for private firms to hold sufficient levels of all types of germplasm, a strong set of publicly held genetic resources is a major asset in meeting society's goals.

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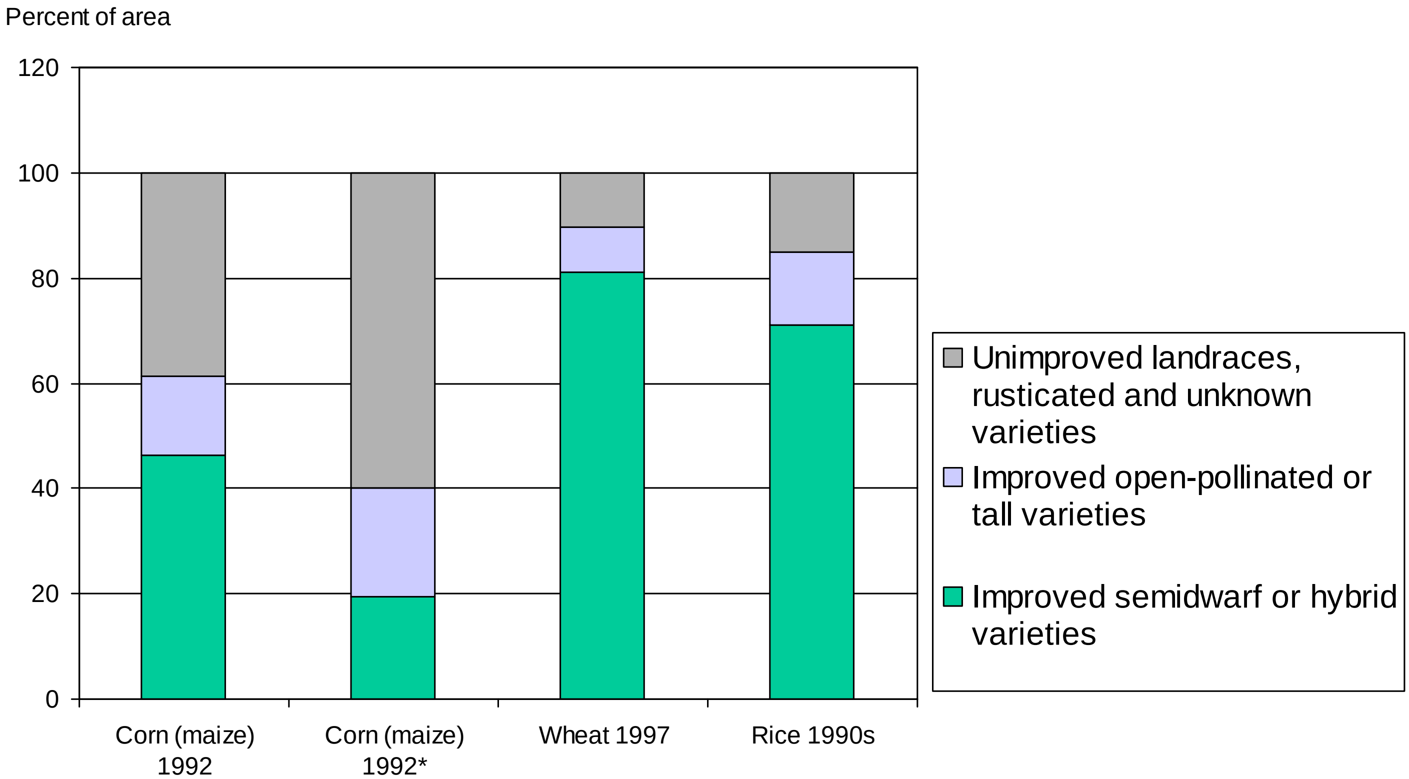
Figure 3.2.6-Developing country cereals area planted to different varieties



*excluding China, Brazil, Argentina, and South Africa

Source: CIMMYT (1994); Morris and Heisey (1998); Heisey, Lantican, and Dubin (1999); Pingali and Smale (forthcoming)