Resolving the challenge posed by agrobiodiversity and plant genetic resources - an attempt

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1 Foreword

Agrobiodiversity is the name of a new discipline that has come into being as a result of the worldwide discussion of biodiversity. Many preparatory studies on the subject exist, but there are few concepts as to precisely what it entails. Those preparatory studies from the area of plant genetic resources (that has already developed to a compact field of study) shall be examined here for their relevance to agrobiodiversity.

The background study for the present publication is the author's assessment paper "Evaluation of *ex situ* and *in situ* methods of maintaining plant genetic resources, including first steps toward solutions and necessity for action". This evaluation was prepared as material for a project prepared for the German Bundestag (**Hammer** 1997). This project "Gene technology, breeding and biodiversity" is available in published form (**Meyer** et al. 1998)

This assessment paper has been almost completely incorporated into the present publication. New information has been included particularly from an article prepared by **Franck**, **Schierholt** and **Hammer** for WBGU (2000). The bibliography has been expanded to facilitate access to publications on a broader thematic basis.

Research on plant genetic resources has a tradition in Witzenhausen. In 1978 appeard the first volume on this topic (**Umlauf** & **Rommel** 1978), the second one in 1993 (**Jutzi** & **Becker** 1993).

In 1998 the new chair for agrobiodiversity was founded forming the basis for intensified research. The first new output, again, highlighted plant genetic

resources as part of the agrobiodiversity (**Hammer** and **Gladis**, 2001). The greenhouse for tropical plants has been developed as an integrated research tool (**Wolff** et al. 2002, **Watson** & **Eyzaguirre** 2002) in this respect.
My special thanks are to **Nancy Arrowsmith** for her mastering the difficult task to translate most of the parts of this book from German.

2 Introduction

The success story of modern agriculture, resulting in an enormous yield increase, is based on four factors:

1. the dominance of a few species within the agricultural system;
2. the dominance of a few productive genotypes within the species;
3. the creation of optimal conditions for the chosen species and genotypes and
4. the ongoing distribution of those agricultural systems, for which points 1-3 are characteristic.

In the discussion of biological diversity, three levels are generally differentiated: genetic diversity (i.e. the diversity within the species), species diversity and the diversity of ecosystems. In this work, primary emphasis is given to the discussion of the functions of gene and species diversity in agriculture, the degree of danger to which they are exposed, and conservation strategies. Agrobiodiversity on the ecosystem and landscape level is only dealt with peripherally, for example in intensively utilized agro-ecosystems.

The large present-day increases in agricultural yield are based to a great extent on the fact that the organic mass production of some components is increased at the cost of others. Take, for example, grain breeding: the ratio of grain to straw has been manipulated to favor grain production. The growing system is so controlled that the largest part of photosynthesis activity per acre is also channeled toward grain production (competition for light, water and nutrients is blocked). But some critics insist that the systems have not actually become more productive in terms of calorie yield per acre (for example **Shiva** 1992).

These processes can also be described in a different manner: because of the active decrease of biological diversity on the plot (soil cultivation, sowing, use of insecticides and herbicides), one single component is actively encouraged. This shows that agricultural production now finds itself in a state of tension with the desire to maintain and conserve biological diversity. On the other hand, 10,000 years of agriculture have also produced diversity that would not otherwise exist, so-called agrobiodiversity. Under this term we understand the diversity of all organisms in agro-ecosystems and the diversity of these systems themselves (for a definition see **Qualset** et al.1995).

While the number of species per agricultural acre as opposed to a fallow comparison acre is almost always fewer in number (therefore, agriculture contributes widely to the death of species), agriculture has also produced amazing genetic diversity (for example, some species often number more than 100,000 different varieties). The dilemma is that “modern” agriculture is in danger of destroying one of its reasons for success: the abundant diversity of existing cultivated plants and animals (**Miller** et al. 1995).

Although the actual extent of this danger is continually discussed, the trend continues, and agrobiodiversity decreases. It is time to answer the following questions:

- What factors influence agrobiodiversity?
- To what extent is agrobiodiversity endangered?
- What functions does agrobiodiversity have in agricultural systems?
- What measures must be taken to maintain agrobiodiversity if necessary?
- Is there need for research and action?

Some definitions are necessary here. Under *agro-genetic resources* we mean that part of biodiversity that "feeds Mankind and is at the same time cared for by Mankind" (FAO 1996b). This definition is not only academically, but also politically important: agro-genetic resources are treated differently in the different international agreements as other components of biodiversity (the Convention on Biological Diversity, IUPGR of the FAO). From this understanding of agro-genetic resources, the priorities of conservation measures are developed by the FAO. For this, there are three possibilities: in Nature (*in situ*), in the field (*on-farm*), and in seed or gene banks (*ex situ*).

Gollin and **Smale** (1999) define agro-genetic resources as "latent biodiversity" and assign it a function as a reserve to be used in times of emergency. It supplements those components of diversity that are actually used in agricultural systems because of their ecological or product characteristics (actual biodiversity). The discussion about the functions, the value and the degree to which agrobiodiversity is endangered must take the different nature of these two groups into consideration. Therefore, one should be careful to differentiate between genetic resources (latent agrobiodiversity) and utilized (actual) agrobiodiversity.

The development of genetic diversity within a species has itself varied over time, from the first beginnings of domestication, which formed a "bottleneck" and strongly limited genetic diversity; to a state of maximal genetic diversity, including a large number of locally-adapted landraces; and finally to the minimization of genetic diversity in the industrial landscape. Agricultural systems of the present day can be classed in these different levels of development.

These developments have dominated scientific discussion since **Frankel** (1970) and others pointed out that landraces and breeds are being lost at an alarming rate. Basic areas of the discussion are:

- Does the process of development and loss of genetic diversity actually take place in this manner? The model is primarily based on observations in Europe and the United States, and these processes are quite precise. But **Brush** (1995, 1999) has discovered, in three case studies based in centers of diversity for maize, potatoes and wheat, that the adoption of modern varieties as well as the use of mineral fertilizer and pesticides did not necessarily correspond with the loss of old landraces. The traditional varieties were maintained because they have characteristic traits missing in modern varieties.
- Does the loss of actual diversity in fields pose a problem or not?
- Can the number of landraces that can be morphologically differentiated be used as a proper measure of diversity? The argumentation is often presented that systematic plant breeding of a variety combines the most positive alleles from many different landraces.
- Is the conservation of the entire genetic diversity (as a resource) a goal worthy of being financially supported?

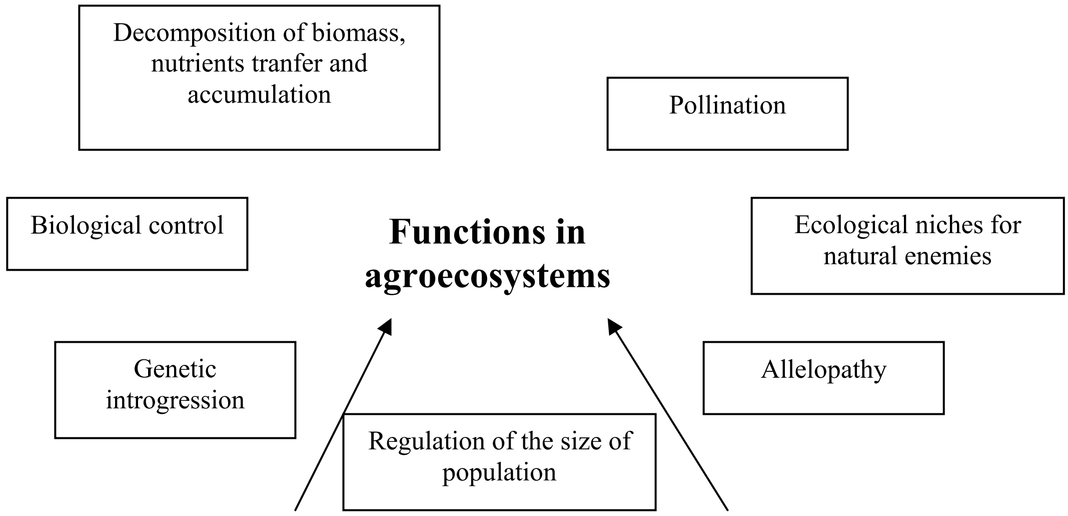
In order to answer these questions regarding genetic and species diversity as part of agrobiodiversity, the functions and present state of agrobiodiversity are compared to the degree of danger faced by agrobiodiversity within the framework of globally important problem complexes. This can be helpful in developing measures for their conservation.

The components of biodiversity do not act very differently in agro-ecosystems than in other ecosystems. The difficulty in studying the "functions" of agrobiodiversity consists in the fact that, up until now, the functions of single diversity components in agro-ecosystems are only accorded importance when they directly influence the productivity of the agricultural system. For example, the ability of the hyper-parasite X to limit the numbers of parasites Z is considered to be a positive contribution toward the diversity component X ("organic control"). But the tendency of plant A (weed) to decrease the number of the cultivated species B is thought to result in yield loss. It is therefore not considered a component with a "function", but is instead classed as a disruptive element.

This leads to the conscious elimination or substitution of a portion of actual biodiversity. For the non-utilization of agrobiodiversity there are three explanations:

1. the contribution of the components is negative,
2. the possible positive contribution of the components has not been discovered, or
3. the positive contribution of the component is not used because it is too expensive or there is a cheaper substitu

Fig. 1:
Functions of biodiversity in agroecoystems (WBGU 2000, p.169, Altieri und Nicholls 1999, Hammer 2001)



In order to better analyze these "functions", **Vandermeer** and **Perfecto** (1995) suggest differentiating between "planned biodiversity" and "associated biodiversity". Those components that are consciously brought into an agro-ecosystem are called planned biodiversity. All the other species that grow in the system (for example, the diversity of soil organisms) are grouped together under the term associated biodiversity. A description of all interactions within agro-ecosystems at the species level is not possible. Therefore, the concept of functional groups was developed. These are:

- Groups of species that have similar ecological functions (for example, species that fixate nitrogen) or destruents
- interactions between species (for example, host-parasite relationships) that are called community processes.

In most growing systems, different cultivated plant species are consciously combined, that is, they are grown in succession or next to each other. On the one hand, different products are grown in this fashion. On the other hand, certain ecological effects are produced, for example erosion protection, loosening of the soil through deep-rooted plants, repression of pathogens or the accumulation of nitrogen (**Vandermeer** 1989). It is quite probable that the ecological stability and the sustainability of the utilization can be markedly increased if systems of cultivation are developed which contain a larger **planned biodiversity** (**Olson** et al. 1995, **Piper** 1999, **Franck** & **Schierholt** 2001).

In agro-ecosystems, we try to create optimal conditions for the consciously utilized diversity components. Interference in the system almost always affects the associated biodiversity. For example, the addition of easily-soluble phosphorus to wheat can cause a two to threefold decrease in mycorrhiza (**Rooper** & **Ophel-Keller** 1997). Often, specific agricultural measures have the largest influence on associated biodiversity, such as the use of the plow on soil fauna or the utilization of agrochemicals on microorganisms and accompanying plants. One could surmise that one species per "task" is enough, because it is important for those community processes to take place that lead to agricultural productivity. But because of the heterogeneity of the system, changing ecological conditions and the diversity of the soil, it is not plausible for such a "one-species" system to function indefinitely. Monoculture systems are more the exception than the rule in Nature. Nonetheless, it has not yet been possible to make general statements proving that a high degree of microorganism biodiversity will stabilize or destabilize the system (**Kennedy** 1999). But there are many examples that the components of **associated biodiversity** help to stabilize the system.

The utilization of identical genotypes for years on end or in large areas, as well as the use of large numbers of domesticated animals in a small area, make agro-ecosystems more liable to infestation by diseases and pests. After the emergence of the Southern corn leaf blight in corn hybrids in the USA during 1969-70, a public discussion took place for the first time outside of specialist groups. The problem of genetic vulnerability came into the focus of public awareness. We speak of genetic vulnerability when one genotype is prevalent in a region and is threatened by a disease, a virus or non-biotic stress and when this is anchored in its genetic constitution (**NRC** 1993).

An important ecological function of diversity on a variety level is to keep this vulnerability as low as possible. At this point, it is customary to point out the advantages of old landraces. But, in fact, very little information about the genetics of landraces exists (**Zeven** 1998). For example, we can see that results depend on the choice of material and method in the case of barley. **Petersen** et al. (1994) found, with the help of molecular markers, a larger genetic diversity in wild barleys (ssp. *spontaneum*) as in an assortment of modern varieties (ssp. *vulgare*). But the diversity within the landrace selections was actually smaller than that of the modern varieties. **Nevo** et al. (1986), on the other hand, found that the cultivated barley varieties of the Middle East had a higher degree of morphological characteristic diversity than wild barley. But the genetic diversity within a species has in fact no influence on genetic vulnerability. The single characteristics and not the degree of relationship are crucial. Single characteristic traits such as resistance qualities are more important than morphological or molecular markers, or degree of relationships or heterogeneity data. The genetic diversity that exists in and within old landraces does not mean better resistance or tolerance *per se*. But, since landraces have been adapted to the specific conditions at each locality through continuous selection over a large period of time, they often have relevant resistances and tolerances.

In countries with a highly specialized seed system, so-called temporal diversity replaces genetic diversity within the area (**Duvick** 1984). A variety is replaced with another after a few years when resistances begin to lose their efficacy. The region biodiversity is replaced by a temporal biodiversity.

The importance of genetic diversity in agro-ecosystems has changed during this process. Systematic plant breeding has combined the most valuable characteristics from genetically diverse material and usually attained a much higher level of resistance (for example through gene-pyramidization). Genetic diversity then fulfils its agro-systematic function, that is, it decreases diseases and vulnerability toward stress, but not in simultaneous, geographically widespread cultivation (see **Becker** 1993).

Instead, it becomes a reservoir for single valuable character traits that can always be recombined in new ways. In short, a genetic resource.

As the example of Southern corn leaf blight shows, decreased genetic diversity can lead to increased incidence of disease and to the massive spread of pathogens. Therefore, there is still need today, in order to secure yields, for a geographically diverse number of varieties.

There are three categories of function that the single components of agrobiodiversity can fulfill, and these are:

1. ecological functions at location (actual biodiversity)
2. functions as producers of varying products or services (actual biodiversity)
3. functions as genetic resources, i.e. as storage places for information or as “raw materials”, for example for breeding processes (latent biodiversity).

While actual biodiversity delivers unmistakably positive contributions toward the productivity of the system and is therefore nurtured by the farmer, this is usually not the case with latent biodiversity (unless the farmer is also a breeder).

Costs for the maintenance of agrobiodiversity that has become a genetic resource become larger as more agrobiodiversity is excluded from active use. At the same time, biodiversity's contributions to the ecosystem have to be substituted. On the level of agricultural production, this occurs in the form of "external inputs" such as pesticides. These become necessary when large areas are cultivated with only a few varieties of a few cultivated species. On the level of the processing industry: the more foods are industrially processed, and not eaten fresh, the larger the demand for increasingly uniform masses of raw materials. For example, missing taste intensity, which is often the result of breeding for higher yields, can be substituted with additives during the processing process.

The less diversity on the other hand there is in the industrial structure, the smaller the diversity of processes and methods of production, which in turn causes a decrease in demand for certain qualities.

The utilization of agrobiodiversity is often directly influenced by measures intended to limit the negative effects of agriculture, as well as trading initiatives that offer high quality fresh products. Because of this, systems of organic agriculture are almost without exception more diverse than conventional systems. Organic food shops often offer several varieties of grains and legumes while normal supermarkets only stock one variety of each.

Wherever there is no interest from the side of agriculture and horticulture for a variety or a species, it is in acute danger of extinction. The component is now demoted to the status of "latent agrobiodiversity" and must be maintained *in situ, on-farm* or *ex situ* or it will be lost completely. The discussion about agrobiodiversity now concentrates itself around two questions:

1. if *in situ* or *on-farm* maintenance or *ex situ* conservation is better and
2. how the benefits, yields and profits from the use of genetic resources should be distributed.

But we must remember that the conservation of genetic resources always remains a preventative measure, even with optimal organization. The biggest challenges is posed by the following question:

How is it possible to develop a diverse agrarian production that *actively utilizes* the functions of agrobiodiversity and therefore also minimizes the negative influences on the environment while generating high-quality, varied products?

How is agrobiodiversity faring? In most of the studied agro-ecosystems, only a small portion of the included species has been identified. Only minimal information is available about soil microorganisms. Non-domesticated plant and animal species have also often not been documented in all their diversity. There is more information about domesticated animal and plant species and their genetic diversity available, but even here, gaps in our knowledge exist.

3 The situation of agrobiodiversity today

3.1 Microorganisms

Domesticated and non-domesticated microorganisms should be differentiated. Non-domesticated microorganisms have often not been documented on a species level, but on a functional level (for example, nitrogen-fixation). A large number of existing species, especially those that live in the soil, has not been described to date. The combination of species in the agro-ecosystem and the relationship of the functional groups to one another are changed through agricultural interventions. For example, up to 44 times the number of denitrifying organisms were found in the soil of a harvested field in comparison with soil that had not been worked (**Rooper** & **Ophel-Keller** 1997). Through the use of agrochemicals, the diversity of some functional groups can be limited to a great extent. But there is usually no danger that whole functional areas (for example decomposition) will collapse if the relationship between the species changes (**Mooney** et al. 1995). An exception is, for example, the highly specific symbiosis of *Rhizobium trifolii* and clover (**Marschner** 1990). There is little information on the genetic diversity of microorganisms in agro-ecosystems (**Kennedy** 1995), with the exception of single pathogens of cultivated plants, which have been studied intensively.

Microorganisms are also used directly for food production. But only a small portion of approximately 1.5 million fungi species, such as yeasts, molds and edible fungi, are used by humans (**Hawksworth** & **Kalin-Arroyo** 1995). Microorganisms are also intensively used for the processing of milk and in the production of wine and beer, for example bacteria such as *Lactobacillus* or molds such as *Penicillium camembertii*. The biotechnological manufacture of nutritional products in bioreactors with the aid of bacteria or fungi is becoming increasingly important. There is also a potential for the transformation of presently unusable plant material with the help of microorganisms into fodder or food.

3.2 Animals

All in all, 50,000 vertebrate animals exist, and some 40 domesticated species play a role in agricultural systems (**Hawksworth** 1995). Cattle (*Bos indicus* and *Bos taurus*), sheep, pigs and chickens as well as domesticated buffaloes (*Bos bubalus*) and goats are present worldwide. Most of the other species are only locally or regionally important (for example, the camel). Even when we stretch domesticated animal species to include the “utilized wild species” such as elephants and falcons, the number of utilized vertebrates still remains small, despite the fact that a large diversity of races exists among the single species (**Hawksworth** & **Kalin-Arroyo** 1995). An overview of worldwide extant and endangered domesticated animal breeds is shown in the table.

TABLE 1: Worldwide extant and endangered domesticated animal breeds (after *Hawksworth* and *Kalin-Arroyo* 1995)

Species	Number of breeds	Rare and endangered breeds
Cattle	783	112
Sheep	863	101
Goats	313	32
Pigs	263	53
Buffaloes	62	1
Horses	357	81
Donkeys	78	11

For more information see **Gladis** & **Hammer** (2002) and **Barker** (2002).

3.3 Plants

An estimated 300,000 to 500,000 species of higher plants exist worldwide, of which roughly 250,000 have been documented (FAO 1996b). Approximately 7,000 species are considered to be cultivated plants (excluding ornamentals and forestry plants). In addition to this, non-cultivated agrobiodiversity such as wild plants, weeds and wild relatives of cultivated plants exist. Of the 7,000 cultivated plant species, only 30 are considered to be “crops that feed the world”. Only 3 “major” species: rice, wheat and maize, supply almost 50% of our worldwide calorie need. Together with 6 other species (sorghum, millet, potato, sweet potato, soybean, sugar cane and sugar beet), they supply 75% of the world’s energy needs. There are also numerous cultivated plant species with exclusively regional importance. For example, tef (*Eragrostis tef*) is of great importance in Ethiopia, but of only marginal international importance (**Rehm** 1989, **Worede** 1993). Further, the group of the so-called “minor species”, “neglected crops” or “underutilized crops” also exists (**Hammer** et al. 2001). These are adapted to special, often extreme locations and are of local or regional importance for human nutrition. “Neglected crops” are cultivated plants neglected by researchers and breeders, for example coriander (**Diederichsen** & **Hammer** 2003), or yams. “Underutilized species” are species that are little used as agricultural crops, such as *Lupinus albus* in the Mediterranean.

The theory of **gene centers** or centers of diversity was developed by the Russian scientist Vavilov (1926). A region is designated as a gene center for a species if a large portion of the genetic diversity within the species can be found here. At first, Vavilov considered the gene centers to be identical with the centers of origin for a species. In the meantime, this theory has been further developed, among others by **Harlan** (1971), who defined centers and non-centers in order to differentiate “regions of origin” from secondary regions, populated at a later date with the species. According to our knowledge, a gene center can therefore, but must not be identical with the region of origin of this species (see **Hammer** 1998a). For example, a large spectrum of barley landraces, but not one single wild barley, exists in Ethiopia (**Zohary** 1970). This points to the fact that barley cannot have been domesticated there (the region of origin is actually to be found far away in the Middle East). Gene centers were defined for the most part for cultivated plants. They still offer us an important starting point in the search for genetic variability for these species, and have also served as a common goal for collecting and data seeking expeditions.

In the gene center for maize (*Zea mays*) in Mexico, there are regions in which one parent of origin of maize, Teosinte, still coexists with maize. Therefore, introgression in the maize material is possible, making further evolution of corn possible (**Miller** et al. 1995). This kind of introgression of genetic material is only one possibility of the further evolution of cultivated plant species. Other possible evolutionary developments are, for example, recombination, epistasy and mutations (**Rasmusson** & **Phillips** 1997).

Regions with high genetic variability of one species can usually be found in areas where smaller fields and agricultural structures were prevalent because of the diversity of the natural terrain. These are often isolated, diverse, and hilly landscapes with marginal, very heterogeneous soil and climate conditions. Different landraces for each local situation were selected here (**Zohary** 1970, **Brush** 1995). Up until today, traditional agriculture has persisted here, because the natural terrain prohibits modern intensive agricultural practices (**Putter** 1994, **Ladizinsky** 1998, **Vavilov** 1997).
In biodiversity literature the term "hotspot" is used for rich areas (**UNCED** 1992, **Myers** & **Mittermeier** 2000, **IUCN** & **WWF** 1994). So far there is no larger treatment of hotspot in relation to gene centers.

The **loss of plant genetic resources** on the level of varieties or species (gene erosion) can only be visualized through the use of examples, since a comprehensive summary does not exist.

In many regions, the loss of genetic diversity is alarming. One reason for this is the transition from traditional agriculture to intensive or industrial agriculture. Landraces and also cultivated plant species fall into disuse and are removed

from the agricultural system. The total loss of this material can only be prevented by maintaining them as “genetic resources”.
A precise evaluation of the situation regarding agrobiodiversity is not possible because of lack of systematic comparison studies. Larger studies have only been done on the situation of *ex situ* collections of animal and plant genetic resources, and even here, only for the most important species (**FAO** 1996b, **Soulé** 1986, **Cohen** et al. 1991, **Allan** 2001, **Lawrence** 2002). For the improvement of *status quo* descriptions, and prognoses for possible losses, a worldwide inventory should be made as quickly as possible.

Genetic diversity within the cultivated plant species is distributed very differently according to region. Because both the creation and the conservation of this diversity are dependent on human intervention, several important political and economic questions about fairness in distributing the resulting tasks and duties develop from this situation.

Agriculture uses only a small portion of the total species spectrum as planned biodiversity, but, within the years of its existence, has produced an enormous diversity of varieties and breeds within the most important utilized species.

There are strongly varying reasons for the decrease of agrobiodiversity produced by Mankind. The **FAO** (1996b) lists as the most important reasons: population growth, wars, and extremes of weather, especially drought. A number of other factors are added to these (see also **Hammer** 1998a).

From this list, the following problem groups that have a direct influence on agrobiodiversity can be summarized:

Agro-ecosystems are defined as systems that were created to produce certain products and services. The demand for the products and service of an agro-ecosystem, therefore, has a decisive influence on the **structure of this system**.

Despite the fact that only a few **species** were suitable for agriculture from the very beginning (**Diamond** 1998), these were not all utilized, at least not to a large extent. One major reason for this is that many species yield similar products, for example, starch, fat, protein, milk, meat, wool, bedding for animals, firewood, and so on. But in most regions, one species, usually the highest-yielding under local conditions, is the main provider of such a product group. For example, in one region, either wheat, rice or corn is usually grown as the main starch supplier (**FAO** 1996b).

New technological developments allow us to change agricultural products during the processing phase so much that only a few basic raw materials are necessary. It is possible, for example, with the aid of biotechnological methods to produce iso-glucose from starch. In the USA, a large part of the present demand for sugar is met with iso-glucose made from cornstarch. This has led to a strong decrease in the importance of cane sugar (**Knerr** 1991).

Another approach attempts to supply widely differing quality products with a regionally well-adapted variety. For example, different oil qualities are produced from canola (rapeseed, *Brassica napus*) in order to avoid importing oils or growing other oil plants. Transgenetic canola with a high laurin acid oil content can be used to substitute coconut or palm oil (**Sovero** 1996), and reduce the demand for these oils in the industrial countries.

Varieties are usually not grown because they are optimally and ecologically adapted to local conditions, but because they supply a certain product quality. With growing demand for better storage, keeping and transport qualities, a definite reduction in varieties has resulted. One example is strawberries. Several especially tasty varieties have disappeared from agricultural production because they spoil quickly after harvest.

The demand of retailers and the processing industry for large amounts of uniform wares also contributes to the reduction of variety diversity. For example, only 5 brewing barley varieties supply most of the worldwide demand for malt. There are several suitable genotypes in various regions of the Earth that are probably better varieties in terms of agronomy, but the number of varieties is limited to lower prices for the trade and malt industries (**P. Franck**, personal information). Because of this, there is little interest in increasing diversity.

Agro-political measures often lead to a marked reduction of the diversity offered for sale. Guarantee sales and dumping prices divorce supply from demand, and the transfer of information on new and desired product qualities is limited.

Often, there are relationships of **substitution between ecological functions** of agrobiodiversity and external input (for example fertilizer or pesticides). That means that external inputs can take over functions of agrobiodiversity and vice versa. In homogenous, high-input agricultural systems, ecosystem functions that are missing because of low agrobiodiversity are replaced with intensive management and external inputs. This happens (to a certain degree) in intensive grain monocultures without crop rotation. Most of the functions that are taken over by different species in a more complex system are replaced by external inputs, such as mechanical soil loosening or the addition of nitrogen fertilizer.

Because of this, those components of agrobiodiversity whose functions can be substituted at lower cost are particularly endangered. The influences of these measures on species diversity in agricultural systems are obvious. For example, in former years many different fodder plants were grown in German fields (oats, barley, beans, clover, lucerne, fodder beets and potatoes). Now, corn is usually the only fodder plant, possibly supplemented by soybean meal as a protein component. Each of the species has lost the race in its own fashion. For example, lucerne's other function has now been substituted with a chemical-technical means of fixing nitrogen, causing it to lose its value in crop rotation as well. Fodder beets have become unprofitable because of increased labor costs.

On the variety level, there are many examples for diversity loss due to changed management intensity. For example, the use of grains with shorter straw prevented lodging while allowing larger amounts of nitrogen to be added to the soil (**Becker** 1993). Short-strawed varieties were so much more successful than longer-strawed varieties that they almost completely displaced them in just a few years, at least in those areas where fertilizer application was possible and financially feasible.

But we presently do not know many functions and interactions of substituted agrobiodiversity. As a result, we cannot evaluate the value of a substitution in the long term, or what results the removal of one of the components is actually going to have on the diverse system.

On the **species level**, plant breeding is more profitable if the species is widely cultivated. On the other hand, the species itself becomes more able to compete if breeders work it on intensively.

Worldwide breeding in both private and publicly-financed institutions therefore concentrates on relatively few species. The correlation between the investment in breeding research and yield increase is positive and usually quite narrow. The production of intensively-bred wheat increased in the developing countries yearly by some 5% between 1963 and 1986, while millet only increased by 1% (**Becker** 1993).

Biotechnology and gene technology only seem to strengthen this trend. Worldwide investments concentrate on maize, rice, soybeans, and canola. Other important species such as wheat, barley and sunflowers follow, at a considerable distance. Some breeding activities exist for the important “minor crops”, but on a very reduced scale. They are usually financed by public funding. Many species that are important basic foods in less agriculturally-productive areas are not bred at all and are also not being systematically conserved and maintained (**Brown** et al. 1989, **Spellerberg** & **Hardes** 1992, **Fiedler** & **Jain** 1992, **Given** 1993).

On the **variety level**, the main reason for genetic diversity loss throughout most of the world is the substitution of local varieties through newly-bred varieties (**FAO** 1996b). All the regional reports of the Global Plan of Action came to this conclusion, with the exception of Africa. The “Green Revolution” contributed and still undoubtedly contributes to the loss of genetic diversity, even if the case is not as cut and dried as **Wood** & **Lenne** (1997) state it in the equation “Green revolution = Loss of genetic diversity”. This loss was not effected by the high-yielding varieties of the first or second green revolution. Those areas in which the green revolution was and still is most successful are, according to **Wood** & **Lenne** (1997), agriculturally privileged areas, and usually not centers of diversity.

Landraces of different species are often only preferable to modern varieties or able to compete economically under unfavorable eco-climatic conditions. Most of the studies have come to the conclusion that yield (or yield potential) is, next to the harvest product, the most important criterion for the choice of a variety by a farmer (**Heisey** & **Brennan** 1991). But **Brush** (1995) found that many farmers would grow high-yielding varieties without completely giving up traditional landraces. This is usually because the landraces possess a certain valuable quality such as high protein content or taste.

Nonetheless we must assume that the substitution of older varieties by newer ones will continue. It is crucial that this continuing substitution does only lead to genetic erosion in connection with increase speed. Genetic erosion can be partly avoided by making sure the genotypes that are now termed "genetic resources" are conserved in a timely and sustainable manner and that all useful genotypes are considered as genetic resources.

Beyond the immediate reasons given for changes in agrobiodiversity, the reasons listed in this introduction include:

- weather extremes and climatic instability (**Jackson** et al. 1990)
- rarity and loss of resource quality (**Yonezawa** 1986)
- pollution (**Frankel** & **Soulé** 1981)
- population growth (**Hanson** et al. 1995)
- political unrest and wars (**Fowler** & **Mooney** 1990, **Blom** et al. 2000).

Different political bodies attempt to regulate these occurrences. **Agricultural and economic measures** set the framework for market and technology developments in the agricultural sector. Areas of action of these political bodies are, among others, the protection of intellectual property rights (for example, variety protection, patent law), research support, agricultural price politics, subventions, food administration and law or foreign trade policies. Most of the countries of the world try to regulate the agricultural economic area more than any other. Because of the diversity of possible agricultural and economic policies, it is obvious that the influence of these political areas on agrobiodiversity is very complex.

4 Biodiversity and plant genetic resources – parallels and differences

Amazing parallels exist between biodiversity and plant genetic resources. Both are concepts that have evolved in the last few years and have attained impressive political importance in this short time. Both are global issues and both are necessary for attaining sustainable development. Both have given rise to a phenomenal increase in scientific knowledge, although the dissemination of this information is still in an initial development stage.

The term biodiversity was first employed in the mid 80s during the conference "The National Forum on Biodiversity" in Washington. Lectures given during this conference are collected in book form under the title "Biodiversity" (**Wilson** 1988). Two other publications from 1980 are generally considered to be the precursors for these lectures (**Lovejoy** 1980, **Norse** & **McManus** 1980).

The IUCN (International Union for the Conservation of Nature) has supported the idea of a global convention on biodiversity since 1981. In 1987, the United Nations Environment Program (UNEP) called for a suitable international agreement. By 1992, the Convention on Biological Diversity (CBD) was already signed in Rio di Janeiro.

At the beginning of the 70s, the Food and Agriculture Organization (FAO) in Rome began to intensify its interest in the genetic basis for plant breeding. A conference was held in 1961. The follow-up conference took place under the

"International Biological Program" and the term "genetic resources" was first used at this conference (see **Hawkes** 1997). The conference papers were published in 1970 (**Frankel** & **Bennett** 1970) and formed the basis for further developments. In 1983 the "International Undertaking on Plant Genetic Resources" (FAO 1983) provided the legal framework for work with plant genetic resources, underlining the principle of free access to material as an "inheritance of Mankind".

Because of the Convention on Biological Diversity, the more global concept of biodiversity came into the foreground of interest. The field of plant genetic resources, on the other hand, was forced to distance itself from its underlying principles and suffered a setback.

Both areas have only marginally taken each other into consideration. While biodiversity was principally influenced by the thoughts of nature conservationists, plant genetic resources developed under the influence of agricultural research, especially plant breeding.
The modi operandi of the two groups differ, especially the methods used to conserve diversity. Supporters of biodiversity use primarily *in-situ* methods, while those supporting plant genetic resources employ more traditional *ex-situ* approaches. Further differences have developed from the specific working methods of each group. At first, ecological aspects predominated among the adherents of biodiversity. Later, surveys of the diversity of species were added. Plant genetic resources was committed first and foremost to genetic diversity, and tended to overlook ecological aspects as well as work on species diversity.

5 Agrobiodiversity

Agrobiodiversity can be found at the dividing line between these two disciplines. Because of this, it suffers from the drawbacks listed above, but is also blessed with the unique opportunity to help fill the gaps opened up between the two areas of knowledge.

Agrobiodiversity includes all biological diversity in agriculture. In our present study, zoological and soil biology problems have been placed in the background. But the botanical side is analyzed in depth, especially because of the presence of missing elements in the basic concepts of this discipline. In other words, agro-biodiversity goes way beyond the concept known as "domestic biodiversity" (see **Jeffries** 1997). It also includes the genetic resources of the future, and involves elements of biodiversity such as, for example, the large number of relevant wild plants.

TABLE 2: The three levels of biological diversity (after *Heywood* and *Watson* 1995, *WBGU* 2000, *Hammer* 2001)

Ecological diversity	Genetic diversity	Organismic diversity
Bioms		Kingdoms
Bioregions		Phyla
Landscapes		Families
Ecosystems		Genera
Habitates		Species
Niches		Subspecies
Populations	**Populations**	**Populations**
	Individuals	Individuals
	Chromosomes	
	Genes	
	Nucleotides	

Weeds are a logical part of the system. Agrobiodiversity as a whole, as well as biodiversity as a whole, deal with a wealth of different species, differing ecosystems and a marked variability within the species (**Persson** 1996). Ethical, ecological, aesthetic and economical aspects play a role here, as they do in agriculture. Agricultural production and agro-biodiversity must arrive at a balanced relationship in order to guarantee the future of agriculture.

Ethno-biodiversity studies the interaction between plants, animals, human societies and the inanimate world (Szabó 1996) and is based on ethnobotany and ethnobiology. Ethnobiodiversity and agrobiodiversity overlap in most areas. From the viewpoint of agrobiodiversity, ethnobiodiversity can make worthy contributions to the many areas of interaction between the two disciplines.

5.1 Diversity of Species

Although species diversity has played a special role in biodiversity research (**Peet** 1974, **Lucas** & **Synge** 1978, **Vane-Wright** et al. 1991, **Pitman** & **Jorgensen** 2002), the species diversity of cultivated plants (which constitute the basis of plant agrobiodiversity) has not been given much study until now. Up-to-date results of this research have been put together in Table 3.

TABLE 3: Number of cultivated plant species worldwide (according to *Hammer*, 1995a)

Author	**Year**	**Number of species**	
		proven	**estimated maximum number**
MANSFELD	1959	1,430	1,700-1,800
VUL'F (before 1941)	published 1987	2,288	
VUL'F & MALEEVA	1969	2,540	
Mansfeld, 2. Edition Ed. SCHULTZE-MOTEL	1986	4,800	
Mansfeld, 3. Edition (Ed. HANELT & IPK)	2001	More than 6000	–
Total estimate			**7,000**

Cultivated plants are included in this compilation as defined by Schultze-Motel (1986), i.e., species from field and garden cultivation, which are or have been grown as food, fodder, medicine, oil, fiber, seasoning, or as green manure crops, shade trees or hedge shrubs. Strictly excluded are all species grown solely as ornamentals and forestry plants. According to present experience, the number of ornamentals is probably quite high and probably exceeds that of all other cultivated plants. These plants have been subject in recent years to constant, rapid development.

The percentage of cultivated plants among the total number of higher plants is quite small and does not exceed 3%.

In early years, it was customary to make intensive inventories and to consult various literature sources in order to determine the number of cultivated plants. In the 80s of the last century, gathering expeditions for plant genetic resources were also included in these studies. The checklist method (**Hammer** 1991b) was further used to calculate species diversity. The number of species included in the new edition of the Mansfeld inventory (**Hanelt** & **IPK** 2001) has increased not only in hitherto poorly-researched areas such as Cuba (**Hammer** et al. 1992-1994) and Korea (**Hoang** et al. 1997), but also in intensively studied areas such as Italy (**Hammer** et al. 1992, 1999).

In comparison to the seminal work documented by Vavilov, a much larger number of species of cultivated plants were documented southern Italy and Sicily alone (see Table 4).

TABLE 4: Comparison of the number of species of cultivated plants in southern Italy (*Hammer* et al. 1992) with those of the Mediterranean gene center of diversity (*Vavilov* 1935) (according to *Hammer* 1996b)

Crop group	**VAVILOV (1935)**	**HAMMER et al. (1992)**
Grain plants	16	3
Fodder plants	11	56
Oil and seasoning plants	7	3
Fruit	2	26
Vegetables	30	38
Seasoning plants and plants with ethereal oils	15	14
Plants containing dyes and tannins	2	2
Plants for different uses	1	63
Total	**84**	**205**

This drastic increase in the numbers of species results from in-depth field research, taking into account seldom-cultivated or endangered cultivated plants. The most important cultivated plant species for the global economy are relatively easy to inventory. We may still be in for some surprises with regard to of local or endangered species, especially if the relatively humble first steps in this field result in a task force working on both a national and international level (see **Hanelt** 1997).

Our knowledge of the number of genetic resources species is even smaller than our knowledge of how many cultivated plants exist today.

A pilot study in Germany counted 1055 species that were considered to be wild genetic resources (see Table 5).

TABLE 5: Central European wild plants, classed in utilization groups (according to *Schlosser* et al. 1991, *Hammer* 1995a)

Utilization group	Number of wild plants	Number of adventitious plants
Ornamentals, grasses for ornament and lawns	280	46
Medicinal or seasoning plants, plants supplying cosmetic basic ingredients or additives	228	32
Trees and shrubs for gardens and landscaping, wind and landscape protection, ornamentals	188	33
Fruit trees, wild fruits including plants supplying nutlike fruits, rootstock for fruit trees	78	16
Fodder plants	72	17
Plants for re-cultivation, soil improvement or erosion control	58	15
Vegetables, wild vegetable plants	41	11
Forest trees and shrubs	35	2
Technical cultures, special uses	19	8
Plants containing oils and fats	19	6
Plants containing starches and sugars	5	4
Plants supplying protein	2	1
Number of species in study = 1055	**980**	**148**

Through consequent use of the gene pool concept of **Harlan** & **De Wet** (1971), especially for the relatives of fodder plants (**Hammer** & **Willner** 1996), a much larger number of plant genetic resources can be estimated for Germany. Further developments in the areas of species and genus crosses will increase the gene pool even more. From the figures for plant genetic resources in Germany, we can extrapolate the number of plant genetic resources worldwide (Table 6).

TABLE 6: The structure of plant genetic resources (PGR) in Germany and the world (according to *Hammer* 1995a, 1999)

Germany	**Absolute**	**% of higher plants**
Number of higher plants (A_2)	2,500	100
Number of plant genetic resources (B_2)	1,150	46
Number of cultivated plants(C_2)	150	6
World	**Absolute**	**% of higher plants**
Number of higher plants (A_1)	250,000	100
Number of plant genetic resources (B_1), calculated	50,000 – 115,000	20 – 46
Number of cultivated plants(C_1)	7,000	2.8

The abundance of species studied by agrobiodiversity therefore goes beyond all present expectations. This fact has to be considered, and the consequences taken into account for the study of agrobiodiversity as well as for the development of strategies to protect and conserve this wealth.

5.2 Infraspecific diversity

Earlier, special attention was paid to the infraspecific variability of cultivated plants and their wild relatives. The marked diversity within this area was already noted by Darwin, who reported unusual variability under domestication. It was his hypothesis that cultivated plants are more variable than their wild predecessors (**Schwanitz** 1960). This seemingly attractive viewpoint has come under increasing criticism in recent years, because of the discovery of hitherto unsuspected variability within wild species. To further complicate things, few studies exist which directly compare the variability of large numbers of cultivated and wild plant groups.

In some studies on flax, a wider variability of the generative plant characteristics of cultivated forms, and a greater variability of the vegetative characteristics of wild plants was found (**Diederichsen** & **Hammer** 1995). The pressure of domestication seems to be responsible for these differentiated results. Differing results are also found according to the species and the methods used.

Studies of the allozymes of cultivated plants have shown that populations of cultivated plant groups were genetically more heterogeneous (**Hamrick** & **Godt** 1997). On the other hand, the genetic variability of wild wheats and barleys has been shown through molecular studies to be higher than that of cultivated varieties (see **Petersen** et al. 1994). This is considered to be caused by the founder effects of domestiication. Differing degrees of correspondence can be found between the morphological and molecular data according to species (**Dulloo** et al. 1997), which results in the need for further clarification of the problem (see for example **Newbury** & **Ford-Lloyd** 1997). But the value as genetic resources of those wild species related to our cultivated plants is fully established (**Mills** et al. 1993, **Hoyt** 1988, **Anikster** et al. 1991, **Hawkes** 1991).

Traditionally, morphological characteristics are used to classify the infraspecific variability of cultivated plants. This method was particularly developed by the Russian School of **Vavilov** in order to organize massive plant collections. The way in which the world wheat collection is categorized is exemplary: it takes into account the intraspecific variability of 27 wheat species, including wild species (**Dorofeev** et al. 1979, **Filatenko** et al. 1999).

Table 7 illustrates one selected example. The infraspecific variability of einkorn is, in comparison with other spelt grains, fairly small. Such systems of classification give a good overview over the variability of forms within one species and are available for the most important cultivated plants. Recently, despite the accelerating gene erosion of many species, new plant groups have been discovered which broaden the hitherto accepted form spectrum (for example, einkorn, see **Szabó** & **Hammer** 1996 or club wheat, see **Al-Maskri** et al. 2003).

Such systems offer a unique outline of the most important, morphologically visible variability within a species. They offer a unique means of making the biodiversity of the most important cultivated plant species visible, which unfortunately is not available for wild plants. It seems strange that this method, which is already available, is rarely taken into consideration in our modern era of biodiversity. It is not only an appropriate tool for gene banks, but is also an indicator of the challenges facing us. Other methods will be developed in the near future that can be adapted to the conditions and needs of agrobiodiversity. But they are not yet easy to use and do not provide an accurate summary of the system.

Fig. 2:
Infraspecific variability of *Coriandrum sativum* and historical documentation of the pathways of its distribution (Diederichsen & Hammer 2003)

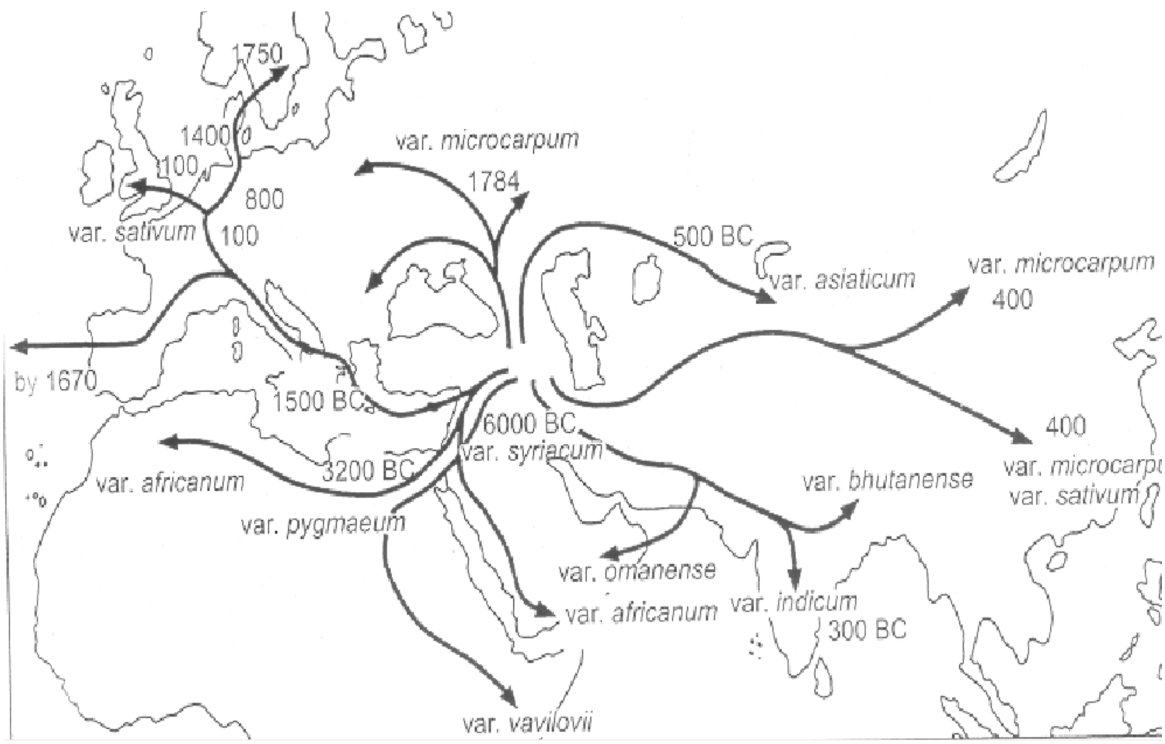


Fig. 3:

Genepool-system according to Halan & De Wet (1971) indicating the possible use of plant genetic resources for plant breeding

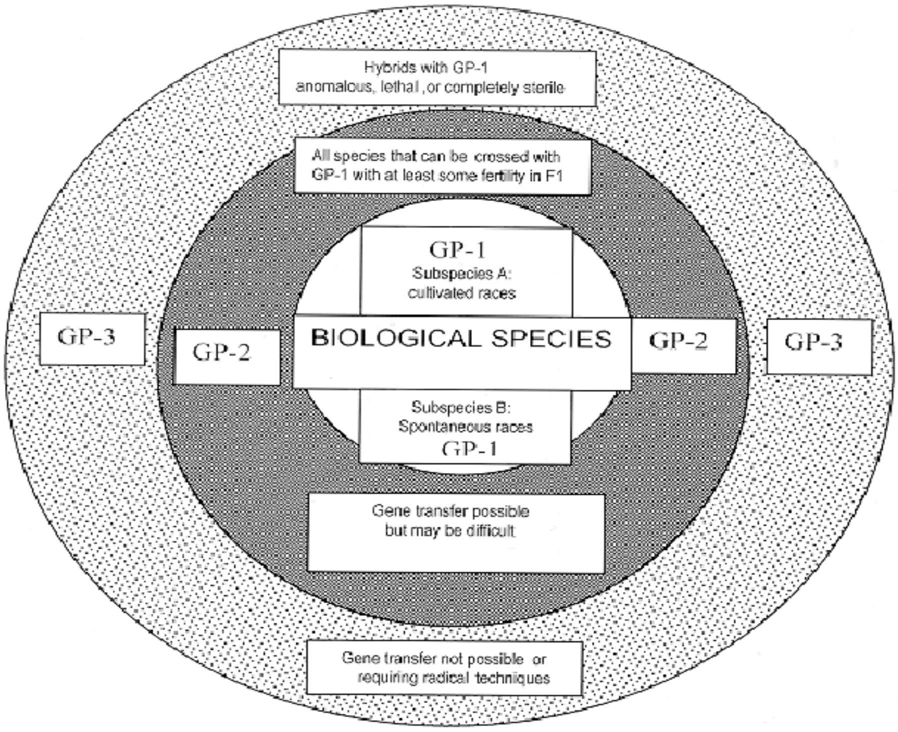


TABLE 7: Matrix of the signs of infraspecific variability of einkorn, *Triticum monococcum* convar. *monococcum* (according to *Szabó & Hammer* 1996)

1	2	3	4	5	6	7	8	9	
x				x		x			var. *monococcum*
					x	x			var. *tauricum*
	X			x		x			var. *flavescens*
	X				x	x			var. *pseudoflavescens*
			x		x	x			var. *sofianum*
x				x			x		var. *macedonicum*
x					x		x		var. *pseudomacedonicum*
	X			x			x		var. *vulgare*
	X				x		x		var. *atriaristatum*
		x			x		x		var. *symphaeropolitanum*
			x		x		x		var. *nigricultum*
x				x				x	var. *hohensteinii*
	X			x				x	var. *hornemanii*
	X				x			x	var. *pseudohornemanii*

1= glume color white, 2=glume color brown, 3=glume color black on white background, 4=glume color black on brown background, 5= awn color same as spike color, 6=awn color black, 7= glume dull, 8= glume shiny, 9= glume hairy

5.3 Ecosystem diversity

In Central Europe, agrarian ecosystems are currently approaching a stage of strongly reduced biodiversity (**Kühbauch** 1998). In the developing countries, the situation is much more positive (see e.g. **Lamola** 1994). The Central American house garden "*conuco*" can be cited as an example, which serves as a home for numerous differing species as well as providing niches for infraspecific variability. In Cuba, more than 1000 cultivated plants have been catalogued, and most of these can be fond in the traditional "*conucos*". The *conucos* may therefore be characterized as an evolutionary environment suited to the continued development of cultivated plants, as well as a center of maintenance for agrobiodiversity (**Esquivel** & **Hammer** 1998, 1992).

A network of house gardens in the tropical and subtropical regions (**Anderson** 1952, **Kimber** 1973, **IBPGR** 1985) can contribute greatly to the maintenance of agrobiodiversity. A first step is presented by **Watson** and **Eyzaguirre** (2002).

5.4 Centers of diversity

Vavilov (1926) (see also **Zeven** & **de Wet** 1982, **Hawkes** 1983) developed the theory of centers of diversity. He was able, through ambitious research expeditions, to discover certain areas of the earth that produced an unusual diversity of species and forms of cultivated plants. He also considered these centers to have been the places of origin of cultivated plants, but this hypothesis could not be confirmed in all cases.

The centers of diversity were basically defined for the most important cultivated plants and included areas with traditional agriculture. For decades, these areas were the most important sources of genetic variability. Above all, resistance and quality characteristics, sorely needed for the improvement of cultivated plants in breeding programs, could be obtained from these centers.

Fig. 4:
Global biodiversity hotspots according to *Wilson* (1992), *Jeffries* (1997)

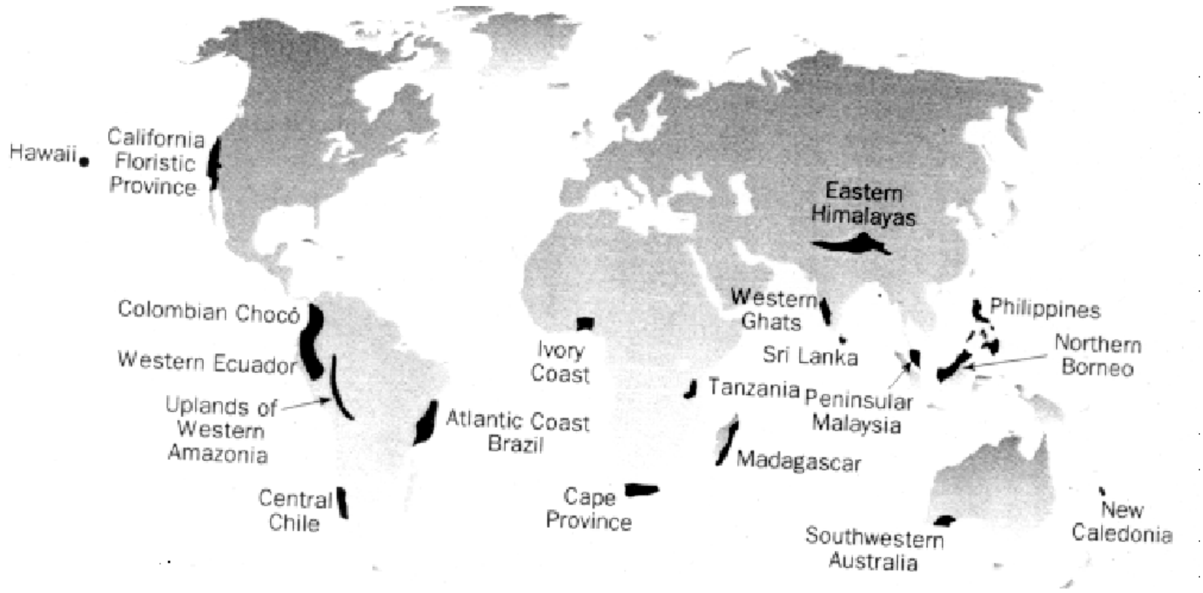
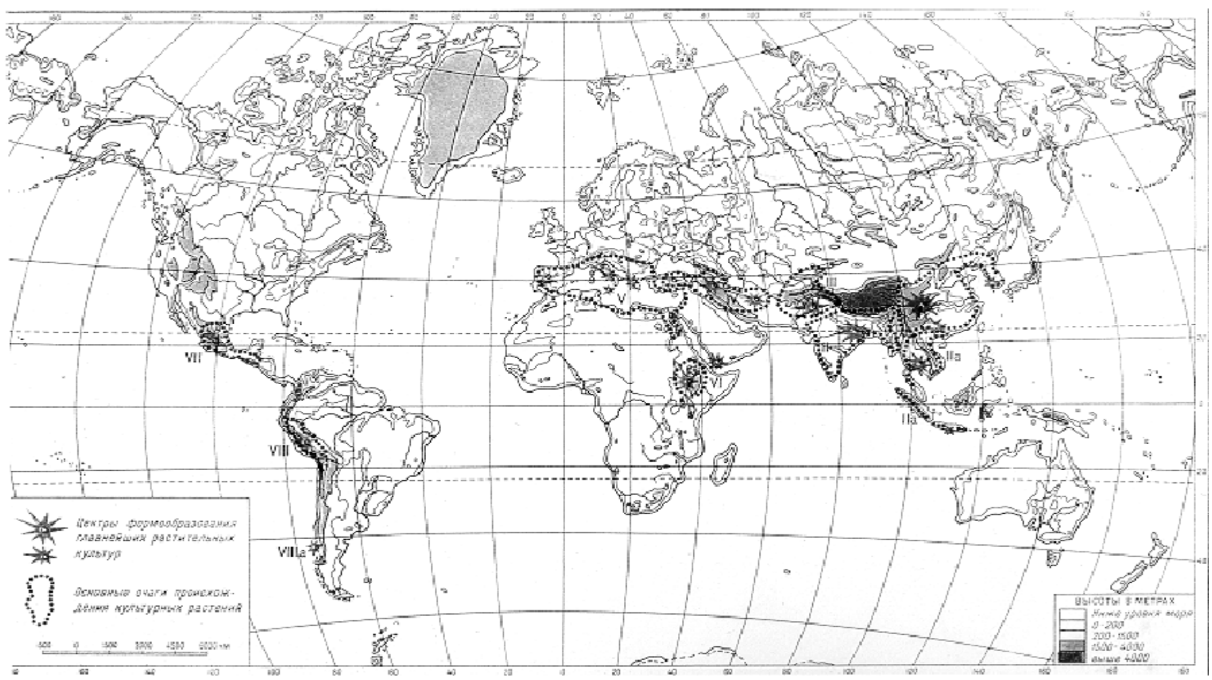


Fig. 5:
Gene centres of crop plants (developed from Vavilov, 1926)



The theory of the centers of diversity has been widely changed and expanded. **Harlan** (1951) pointed out the lack of detailed information in centers of diversity and suggested a course of "anatomical" studies. But it was also **Harlan** (1971) who finally worked out a new global hypothesis. As a counterpart to **Vavilov's** concept of pure centers of diversity, he presumes the existence of centers as well as non-centers. Further studies have completed the efforts to define the “hotspots", as the centers of diversity are now called in modern biodiversity discussions.

In any case, it has become obvious that the discussion about the centers of diversity for cultivated plants will be a long one. Similar to the discussion on infraspecific variability, there has been no concerted search for common physical traits and patterns (see **Groombridge** 1992, **Heywood** 1995).

There are probably few obvious common traits because the biodiversity of agricultural ecosystems is less varied, with fewer species involved, than those of the richly structured habitats of wild plants, established where there is little or no agriculture. Nonetheless, there are areas where the two meet, such as in Southeast Asia or in the western part of South America. Another convergence, which cannot be found from studying the maps, is west tropical Africa, which is particularly blessed with different cultivated plants (see **Dalziel** 1995). Vavilov did not point this out, because the cultivated plants Europeans consider typical are missing there, but it was indicated by his collegue **Sinkaya** (see **Filatenko** et al. in print). Cuba leaves a similar impression (**Hammer** et al. 1992-1994). Despite the great number of endemic plants found here, Cuba is not included in the "hotspots". New thoughts about agro-geography (**Franklin** 1993, **Sauer** 1993) can be of special use for such comparisons.

5.5 Loss of diversity

With the development of scientific plant breeding, one phenomenon soon became obvious: the resulting high-quality and homogenous products (new varieties) were quickly and widely distributed. They began to suppress the variable landraces that are the source for the further development of breeders' varieties (**Röbbelen** et al. 1989, **Ahokas** & **Manninen** 2000). The value of landraces as original breeding material was soon accepted (**von Proskowetz** 1890, **Schindler** 1890). Soon afterward, the first large collections were put together. In particular, mention should be made of the varied activities of **N. I. Vavilov** (**Vavilov** 1935), which then resulted in the world's largest collection.

In the centers of diversity that he studied, **Vavilov** was able to observe and document the unbroken result of an evolutionary process that had lasted thousands of years. The threat to this diversity only became visible much later, as, for example, when **Harlan** reported on decreasing landrace cultivation in Turkey (1950). The loss of diversity soon escalated, and the term gene erosion was coined (**Bennett** 1968). Studies on cultivated plants played a major role here as well. Because of this, it is unusual that few concrete figures were determined, except for some situational descriptions and approximations. **Saouma** (1993) reports a 75% loss of the genetic diversity of cultivated plants since the beginning of our century. This is also supposed to include species loss, but such estimations do not hold up under scrutiny.

5.5.1 Loss of species

The discussion of species loss plays a vital role in biodiversity. There are occasional reports of the extinction of cultivated plant species in some areas. For example, the one-flowered vetch (*Vicia articulata)* was widely cultivated in the fifties, but cannot be found now in southern Italy and Sicily (**Hammer** et al.

1992). In 1999 the species was found as a rare crop in an island close to Sardinia (**Laghetti** et al. 1999). *Cucurbita ficifolia*, the fig-leaf gourd, suffered a similar fate, and was seen in 1997 in the Aeolian Islands and Stromboli, cultivated in isolated areas as a vegetable squash. For wild plants that would be a typical example of a place-specific "Lazarus-Taxon".

We have to ask ourselves if there are any cultivated plants that are truly and completely extinct (see Table 8). In order to encourage and enliven discussions on this subject for cultivated plants, three characteristic examples are given here.

TABLE 8: Estimated number of species of extinct or endangered cultivated plants and plant genetic resources in Germany, Europe, and the whole world (according to *Hammer* 1998a)

	Cultivated plants	Plant genetic resources
Germany	20	142
Europe	67	640
World	940	13,500

5.5.1.1 Anacyclus officinarum – German pellitory

German pellitory probably originated, like other members of this genus, in the Mediterranean area. It may be an annual sport of Roman pellitory, *Anacyclus pyrethrum* (**Tittel** 1986). It was once cultivated as a field crop in Europe, among other places, near Magdeburg, in Vogtland and in Czechoslovakia.

The ethereal oil of the root was used in folk medicine as a tincture against toothache. The roots were once an official drug (*Radix Pyrethri gemanii sive communis)*. After the discontinuation of the plant as a commercial crop, it was commonly believed that the species could at least be encountered in botanical collections. It occasionally turned up adventitiously (**Hegi** 1929). Today, *Anacyclus officinarum* is still being offered in the *Indices seminum* of some botanical gardens. In the early fifties, **Ludwig** (1954) in Gartenbauwissenschaft 1(19) 413 (see **Tittel** 1986) already pointed out that most of this material was in fact *Anthemis altissima*. Later attempts of the author to obtain German pellitory were doomed to failure. Even **Humpries** (1979), the author of a monograph on the genus *Anacyclus*, tried in vain. At least he was able to identify some garden material that had great similarity with the vanished species. We were able to obtain some of this material *(Anacyclus radiatus*) and through simple selection bred a plant group with phenotypical similarity to *Anacyclus officinarum* in much the same way as zoological gardens work with certain animal breeds. This plant is now an exhibit in agro-historical museums. But we can say with a good deal of certainty that the real German pellitory is extinct.

Fig. 6:
Documentation about the loss of a crop plant species (*Anacyclus officinarum* L.) from Jeffrey in Hanelt and IPK (2001)

Anacyclus officinarum Hayne, Arzneigew. 9 (1825) t. 46
G. Deutscher Bertram; Russ. Nemeckaja romaška.
Described only from cultivated plants, nowadays obviously extinct; probably an annual derivative of *A. pyrethrum* (L.) Link.
Formerly cultivated in Central Europe (Germany and former Czechoslovakia) for its ethereal oil, and formerly officinal (Radix Pyrethri germanici sive communis, Deutsche Bertram-Wurzel). In more recent times mostly confused with Anthemis altissima L. (Ludwig in Gartenbauwissenschaft 1, 19 (1954) 413).

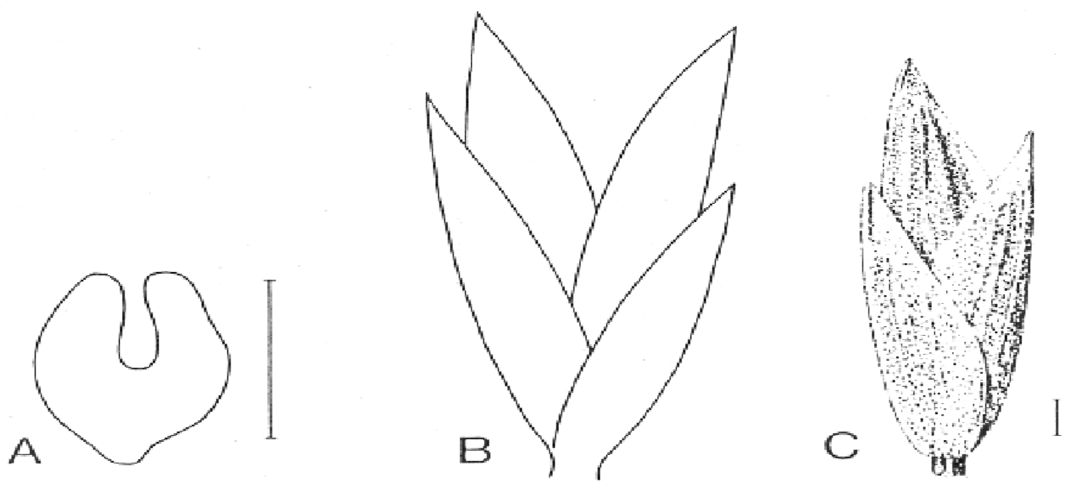
Ref.: Hegi VI (2), 1929; Humpries 1979, 83; Sokolov 1993, 352 pp.

5.5.1.2 Bromus mango - "Mango"

This is not the mango fruit, but a traditional grain from Chile that was still being cultivated at the beginning of the last century (**Gay** 1854). Local Indians prepared flatbread and a fermented drink from it. Around 1830, it was only being grown on two farms on the island Chiloe. During the first year of cultivation, it was used as a fodder crop, and the grain was harvested in the second year. This traditional crop was cultivated in places far away from those farms that grew the European grains preferred by the local populace. The description of this New World grain awakened great interest in scientific circles because it had previously been believed that only maize and some of the so-called pseudo-cereals (for example *Chenopodium quinoa*) were domesticated for use as grains.

After many futile attempts to discover the plant, reports that suggested that the species had survived were considered sensational (**Cruz** 1972). A similar species was found, cultivated by one farmer only, but this turned out to be chess (*Bromus secalinus)*, introduced from Europe (**Muñoz Pizarro** 1944). **Reid** (1988) then reported that *Bromus mango* had been found at several places in Argentina and Chile. This material was distributed in scientific circles, and it was possible to ascertain without a shadow of a doubt that it was in fact another species, *Bromus burkhartii* (**Scholz** & **Mos** 1994). *Bromus burkhartii* is not closely related to *Bromus mango*. We can therefore speak with certainty of this species being extinct. Seeds of herbarium samples are not viable any more. It is often possible for cultivated plant groups to survive as wild plants or weeds, but there has not been any proof of this yet for *Bromus mango* (see **Bush** et al. 1995).

Fig. 7:
Bromus burkartii, a species missinterpreted as Bromus mango (after Scholz & Mos 1994)



Scale = 1 mm

5.5.1.3 Silphion of classical times

There is still much disagreement about the identification of this plant. In any case, it is an *Umbelliferae* from the area of Kyrenaika, which was a very important trade center. The plant existed only in this area, and the Greek city-state Kyrene had a monopoly on its sale from the 7th to the 1st century B.C.

Pliny reports that the thickened juice of the plant (the so-called laser) was such an important medicine that it was worth its weight in silver coins. The various parts of the plant were appreciated in different ways. The young sprouts were boiled, fried and steamed and were considered a delicacy by the Romans. They were also employed as a seasoning herb. The fruit was used as a spice and the roots were preserved in vinegar and prescribed as medicine (**Beuttel** 1951).

Although we have a very good idea what the imposing plant looked like from precise pictures on coins and from written descriptions, it has been impossible to positively link the plant with any living sample (see among others **Schnabel** 1996).

Bishop Synesius of Kyrene gave us an eyewitness account of the plant towards the end of the 4th century. He confirmed that silphion was almost extinct and could still be found in gardens (**Beuttel** 1951). This proves that this important plant species fell a victim to over-harvesting and exploitation. The last historical sightings of the plant in garden situations confirm reports that silphion was cultivated. Other stories tell of fruitless efforts to domesticate the plant (**Steier** 1927). In any case, silphion can be taken as an early example of a plant species that was once an important resource, but then disappeared.

Fig. 8:
The mysterious Silphium (after *Keith* 1965)

These three examples point to a whole group of reasons for species loss: overuse, neglect and lack of use, mistaken identification, and displacement by other species. Since there are few concrete references to loss of cultivated plants species, but these are indicators for more extensive gene erosion, an estimate of the extent of the erosion can help to focus attention on the entire problem.

5.5.2 Loss of genetic diversity

To the present day, studies about the gene erosion of cultivated plants usually concentrate on the infraspecific part of the problem. Concrete surveys form the exception to the rule. For example, **Hammer** et al. (1996) were able to document the extent of gene erosion of two countries in the Mediterranean area. Existing land races were collected in southern Italy in 1950 (**Maly** et al. 1987). In the 80s, new collecting expeditions were carried through in these areas, and the loss of land races or their continued existence was documented (see **Hammer** et al. 1992). Crops as well as garden plants species were compared. In Albania, the first collecting expedition took place in 1941 (**Stubbe** 1982), and the comparison expedition followed in 1993 (**Hammer** et al. 1994). Only crop plants were studied.

In Albania, no land races for einkorn (in 1994, one sample was finally found), rivet wheat und common vetch could be discovered. In the case of barley, the rate of gene erosion was 20%, and 87.5% for common wheat.

In southern Italy, a large number of species were available for comparison. Following expeditions in the 80s took place during 4 years, so that the findings can be assumed to be more reliable. Landraces of grains such as Byzantine oats and wheat had disappeared. Among the legumes, chickpeas and lentil landraces were missing, as were onions, tomato, radish and eggplant among the vegetables. For barley, gene erosion of 75% was found, but it was only 25% for rye.

Even with commonly grown garden beans, gene erosion of 68.7% was discernable, and it was 66% for peas. For cabbage and zucchini the erosion added up to 66.7%, and with lettuce it was 50%. For all grains, a loss of 71% was calculated. The legumes have much better chances for conservation: only 62.1% gene erosion was measured. Vegetables, which are usually considered to have favorable chances due to richly-structured gardens, showed an amazingly high average erosion rate of 81.6%. Altogether, high gene erosion for most of the landraces of varying species was characteristic, with a resulting high loss of genetic variability.

Studies of gene erosion among the land races of South Korea were published by **Ahn** et al. (1996). In 1985 and 1986, 7000 agricultural experts collected 5,171 seed samples of 57 species. In 1993, the collecting was done again. The results were devastating. On an average, only 18% of the original landrace material still existed. Practically no land races of rye, rapeseed, peppers, spinach, vegetable burdock were found. A very small percentage of landraces was found, among others, for peas (ca. 4%), castor beans (ca. 5%), Job's tears (ca. 2%), and multiplier onions (ca. 4%).

A systematic approach for measuring genetic erosion has been elaborated by **Guarino** (1999, see also **Serwinski** & **Faberová** 1999).

5.5.3 Ecosystem loss

Despite varying socio-ecological and economical conditions, the results for the Mediterranean studies (**Hammer** et al. 1996) were quite similar: for southern Italy 72.8% and for Albania 72.4% gene erosion (according to the calculation scheme: gene erosion = 100%, minus gene integrity, i.e. the still extant land races). Surprisingly enough, there were no significant differences between crop and garden plants, although this could have been expected due to the marked differences between the respective ecosystems.

But computations of the yearly loss rates showed 2.45% for Albania and 3.88% for southern Italy. Maybe this points to a certain threshold or limit for the introduction of new varieties, and a chance for the conservation of landraces. Despite this, radical political and economic changes can still strongly influence gene erosion. The new collecting activities in Albania are based on this assumption.

The study of 220 land races with 147 forms in South Korea (**Ahn** et al. 1996) showed a median gene erosion of 74%. The results varied between the different areas only minimally: in Sangjoo-Kun the erosion was 74%, in Geumung-Kun 76%, and in Gochang-Kun 73%. Species important for nutrition were conserved better, and also showed a more marked genetic integrity. The alarmingly high yearly loss rate of approximately 9% is a danger sign, which should be taken seriously.

In other areas of the world, for example in Central Europe, a much higher level of gene erosion has already been attained than in these countries. Despite all worries about the high level of gene erosion in these countries, a maintenance level of some 25% is still an encouraging signal for us to think about *in situ* conservation mechanisms.

6 Critical assessment of measures

The prospects for the future look fairly bleak. Because of this, many scientists have come to believe that only maintenance in *ex situ* collection can stem the tide of erosion. A large number of gene banks are working in this direction on a global scale. Altogether, the accomplishments of the gene banks should not be underestimated (see Table 12). A large amount of biodiversity knowledge is coupled to the gene banks. Because of this, the importance of the gene banks is growing. But how can gene banks take up the challenge posed by new discoveries about biodiversity? One answer could be the integrated gene bank model. On the basis of preparatory studies published in 1993 and 1994 (see **Hammer** 1993c, 1994, 1995a), this idea was subsequently opened up for discussion (**Hammer** 1996a & b).

The concept assumes the existence of an inner structure that guarantees necessary gene bank functions such as collection, maintenance, characterization and documentation of plant genetic resources. The gene banks must also take into account modern developments in the field of biology and support an integrated *ex situ*/*in situ* approach. This last point seems to be of great importance, as pointed out directly by biodiversity research findings. A paradigm shift was necessary to attain a breakthrough (**Hammer** 2003). **Kuckuck** (1974) already demanded that grain fields with different grains, together with related wild plants and weeds, be protected in the centers of diversity of cultivated plants so that such evolutionary processes can continue.

Kuckuck's suggestions, which should be understood as a reaction to the dangers posed by the "Green Revolution", were not given much attention. In the following years, new attempts were made. **Perrino** & **Hammer** (1984) suggested that fields of emmer and einkorn should be protected in an appropriate manner in southern Italy. Here, again, in order that such stands can be seen in their overall evolutionary importance. New information about cases of introgression of wild into cultivated plant groups and vice versa were taken as further proof of the importance of *in situ* maintenance for the evolution of cultivated plants, for example rye in Italy (**Hammer** et al. 1985a), barley in Libya (**Hammer** et al. 1985b), and cabbage races in Italy (**Perrino** & **Hammer** 1985).

But the breakthrough was made in tropical and subtropical areas (for example **Esquivel** & **Hammer** 1988, **Altieri** 1989, **Brush** 1989). Because gene erosion was not as advanced there, an on-farm maintenance in house gardens (**Esquivel** & **Hammer** 1992) and other suitable ecosystems was more easily accomplished (**Brush** 1995).

It is a well-known fact today that only a small portion of cultivated plant species can be maintained in gene banks. In the most active gene banks, the number of species maintained is estimated to be 2000. The large remaining number of species (see Table 10) must be conserved through *in situ* measures (**Lleras** 1991, **Maxted** et al. 1997, **Damania** 1994, **Bush** et al. 1995). This means on-farm measures for the most part, since we are dealing with cultivated plants.

An integrated gene bank should therefore support such measures in an appropriate fashion and scientifically promote them. According to its capacities, it should take such measures into account while collecting endangered land races.

This newly developed principle has been formulated for southern Italy by **Hammer & Perrino** (1995). The following steps were taken into account (according to **Hammer** 1996b):

Endangered and rare plant material (only found singly). A sample should under all circumstances be included in *ex situ* maintenance. This is naturally also true for plant groups for which there is no record or which have only recently or rarely been found in this area.

Rare material (found at more than 10 places). The further development of this plant group must be carefully followed. On-farm maintenance should be arranged with especially interested farms. For added security, duplicates should be included in *ex situ* conservation strategies.

Fairly widespread material (found at more than 100 places). Ideal for on-farm maintenance. In individual cases, duplicates can be stored in the gene banks as a security measure. The situation must be controlled regularly.

Common material. Special measures are not needed here. Maintenance is guaranteed through general cultivation practices.
The necessary intensity of the measures will probably keep gene banks from implementing them, except in individual cases. But these cases can be expanded and studied.

Additional impulses must come from research. Universities must include agrobiodiversity in their programs. Parallel to this, capacity has to be made available for agrobiology. Lists of endangered species only exist for wild plants at present, and not for cultivated plants (see **Walter** & **Gillett** 1997, **Hammer** 1999). There is a tremendous amount of catching up that has to be done before an even remotely equivalent level can be attained. It is still a completely open question just how the nature conservation system can be included in the problem of agrobiodiversity, or if a parallel system should be established. There is a need to concentrate capacities. The very active group of the segetal plant researchers (in Germany see, among others, **Lohmeyer** & **Sukopp** 1992, **Schneider** et al. 1994) and the large number of interested lay people should be included.

International activities are also important. There has been a lot of thought given for quite a while to neglected and underutilized cultivated plant species, which constitute the larger part of cultivated plant species worldwide. A first project was initiated in the USA (NATIONAL ACADEMY OF SCIENCES 1975), in which 36 representative cultivated plant species were chosen. The project on "underutilized and neglected crops", financed by the German government, forms the basis for further international cooperation in this area and is one of the high points of this movement (**Heller** et al. 1996-1998). Table 9 documents the present status of the work.

TABLE 9: Monographs published to date on neglected and underutilized cultivated plants in the framework of a IPK/IPGRI project (according to *Hammer & Heller* 1998)

Species	**Botanical name**	**Authors**	**Year**	**Pages**
Physic nut	*Jatropha curcas*	J. HELLER	1996	66 pp.
Yam bean	*Pachyrhizus spp.*	M. SØRENSEN	1996	141 pp.
Coriander	*Coriandrum sativum*	A. DIEDRICHSEN	1996	83 pp.
Hulled wheats	*Triticum spp.*	S. PADULOSI, K. HAMMER & J. HELLER, ed.	1996	262 pp.

Species	Botanical name	Authors	Year	Pages
Niger	*Guizotia abyssinica*	A. GETINET & S. SHARMA	1996	59 pp.
Pili nut	*Canarium ovatum*	R.E. CORONEL	1996	57 pp.
Safflower	*Carthamus tinctorius*	LI DAJUE & H.-H. MÜNDEL	1996	83 pp.
Chayote	*Sechium edule*	R. LIRA SAADE	1996	58 pp.
Bambara groundnut	*Vigna subterranea*	J. HELLER, F. BEGEMANN & J. MUSHONGA, ed.	1997	166 pp.
Breadfruit	*Artocarpus altilis*	D. RAGONE	1997	77 pp.
Cat's whiskers	*Cleome gynandra*	J.A. CHWEYA & N.A. MNZAVA	1997	54 pp.
Tef	*Eragrostis tef*	SEYFU KETEMA	1997	50 pp.
Sago palm	*Metroxylon sagu*	M. FLACH	1997	76 pp.
Oregano	*Origanum spp.*	S. PADULOSI, ed.	1997	176 pp.
Black nightshades	*Solanum nigrum*	J.M. EDMONDS & J.A. CHWEYA	1997	113 pp.
Traditional vegetables	various species	L. GUARINO, ed.	1997	171 pp.
Carob tree	*Ceratonia siliqua*	I. BATLLE & J. TOUS	1997	92 pp.
Grasspea	*Lathyrus sativus*	C. CAMPBELL	1997	92 pp.
Buckwheat	*Fagopyrum esculentum*	C. CAMPBELL	1997	93 pp.
Peach palm	*Bactris gasipaes*	J. MORA-UURPI, J.C. WEBER & C.R. CLEMENT	1997	83 pp.
Andean root crops: Arracacha, yacon, maca and ahipa	*Arracacia xanthorrhiza, Polymnia sonchifolia, Lepidium meyenii, and Pachyrhizus ahipa*	M. HERMAN & J. HELLER, ed.	1997	256 pp.
Chenopods Asia	*Chenopodium album*	TEJPARTAP, B.D. JOSHI & N. GALWEY	1998	67pp.
Lupines	*Lupinus spp.*	W. COWLING, B. BUIRCHELL & M. TAPIA	1998	105 pp.
Aibika	*Abelmoschus manihot*	S. PRESTON	1998	97 pp.

For further conclusions, especially concerning the complementarity of *ex situ* and *in situ* measures to maintain agrobiodiversity, see the following explanations. A special comparison of the differences between the varying forms of maintenance is also necessary here (see Table 31).

The forms of diversity as well as the methods of conservation (*ex situ*, *in situ* or on-farm) play a role in conservation strategies. Cultivated plants, related wild species and weeds must each be considered separately. Small islands may play a certain role in the conservation of landraces (**Hammer** et al. 2002)

The gene banks play a special role in the conservation of the genetic diversity of cultivated plants. Since the greatest genetic diversity is present within the most important cultivated plant species and these are very well represented in the gene banks (see Table 13), the special experience accumulated by the gene banks should find general acknowledgement for conservation measures. **Zeven** (1996) has already pointed out problems that have not been solved up until now with other methods of maintenance for such material.

For wild species, *in situ* maintenance is all cases preferable, if problems of availability are excluded. Weeds take a place situated between these two positions.

This division of conservation measures into three areas of plant genetic resources has been the direct result of biodiversity research to date. Agrobiodiversity can also be taken into account here and confirmed as a special category.

The conservation of agrobiodiversity in a large part of worldwide *ex situ* collections is itself endangered. Therefore, priority should be placed on securing and providing financial support for existing collections. The regular regeneration of material is essential and must be made possible.

Collections that have been developed by different non governmental organizations (NGOs) (for example community gene banks in developing countries, or NGO collections in industrial and developing countries) should be included in funding considerations, as well as the gene banks at the research centers of the Consultative Group of International Agricultural Research (CGIAR). These collections should be networked in a global initiative leading to increased efficiency and cooperation. The existing collections must be supplemented according to the prevention principle (**Noah's ark principle**). Priority should also be given to the expansion of species collections in the centers of diversity. A **Red List** for endangered cultivated plants should be put together as a basis for the creation of suitable conservation measures and for their financing. The maintenance of endangered domesticated animal species and breeds must be included as a further important part of the efforts to conserve agrobiodiversity.

Since *in situ* or *ex situ* conservation is often the only possibility of preventing the total loss of certain agrobiodiversity components, these measures must be supported. Because of the decentralized distribution of these measures, the international political will to effect changes is particularly important. In many cases it is necessary to **avoid disturbing** locally-organized *in situ* or *on-farm* maintenance and utilization measures to maintain agrobiodiversity. In the past, disruption has often occurred through restrictive regulations about the exchange and distribution of seed or through agricultural advisors burdened with one-sided views about "modernization".
In order to bring valuable genes from genetic resources into elite material and to expand its genetic basis, sizeable and publicly funded pre-breeding programs (if

possible with ties to gene banks) are necessary, together with basic evaluative work on genetic resources.

In the area of utilization of agrobiodiversity, the financing of secondary evaluations of genetic resources or the characterization of presently utilized agrobiodiversity has priority. Especially the study of resistances and specific characteristic traits should be given closer attention.

6.1 Comparison of the measures

In the last few years, conservation measures have often been critically evaluated. During this process, there have been difficulties of comprehension and communication between supporters of in situ and ex situ conservation. Originally, ex situ practitioners considered it a given fact that cultivated plants and their related wild species could only be maintained in situ as an exception to the rule. Today, in situ methods are widely accepted.

Many supporters of the in situ strategy consider ex situ methods to be at best a transitional method leading to further in situ maintenance (Lande 1988). The differing standpoints have been formulated in various international documents and treaties.
Weber (1996) has compiled a comparison of the advantages and disadvantages of in situ conservation as opposed to ex situ (Table 10). This special view of the matter from the perspective of the user gives preference to on-farm conservation as a specialized form of in situ strategy.

It is important that criticism of ex situ maintenance includes the limited possibilities of evolution available with this method. In gene banks, conservation of the material is handled in such a manner as to exclude natural evolution. This has to do with long-term seed storage on the one hand, which strongly reduces the metabolism and therefore strongly limits evolution. On the other hand, gene banks often have to grow the plant material in areas that are far removed from its place of origin, and this can easily result in changes in population composition.

TABLE 10: Advantages and disadvantages of *in situ* as opposed to ex situ maintenance (from *Weber* 1996)

Advantages
- Accessions can be observed as plants - Comparison of different accessions *in situ* is possible - Natural developments can influence plants - New variants can evolve - Passage of time can be observed and studied - Easy maintenance of vegetatively reproduced forms
Disadvantages
- *On-farm* maintenance only possible for a relatively small number of accessions - Risk of loss is increased - Access for breeding research is not as easy - High costs for *on-farm* maintenance

Additional points of criticism are that insufficient equipment and facilities are available to gene banks, that long-term storage is overrated, and that the necessity of reproduction is underrated.

Ex situ as well as in situ conservation are also highly dependent on political and economic influences. This seems to be particularly relevant for the gene banks, and could be observed in Eastern Europe toward the end of the last century, when the work of several of these institutions was reduced due to lack of money and employees. Only international help was able to prevent catastrophic breakdowns (see Frison & Hammer 1992).

Ex situ collections are not and are never going to be the universal means of preventing the results of gene erosion. The collections will always be limited and gene banks will only be able to include a portion of all genetic resources.

From the side of the user, the major criticism of in situ conservation lies in the difficulty of obtaining access to the material for basic and breeding research.
The on-farm concept is in its beginning phase. Because it assumes planned conservation in the framework of agricultural or garden production, but follows a fairly static approach with regard to the choice of varieties, problems are bound to occur. For example, this form of conservation will become similar to ex situ maintenance if financial subsidy is not available.

6.2 Utilization of plant genetic resources and costs for their conservation

Plant genetic resources are generally considered to be of great value. In particular, the work of Mooney (above all, 1979, see also Wells 1992, Pistorius & van Wijk 1993) has made their potential economic value evident. Profits in the billions range are possible. For example, a gene is attained through breeding for disease resistance and therefore a breakthrough is made toward newer wheat varieties, which are more stable in yield. Such a breakthrough is, however, tied to two requirements that can easily be overlooked:

1. The resistant material must be located with great expenditure of time and effort from extensive collections. Between the first discovery of the material and the launching of a new variety, roughly 20 years pass by, even if modern breeding methods are employed (see Table 11).
2. Therefore, such utilization of plant genetic resources is generally dependent on a high expenditure of time and money. This is even true in the developing countries, where the development from plant genetic resources to new varieties can be accomplished much more quickly because of the lower level of breeding expertise (see for example **Castiñeiras** et al. 1991).

TABLE 11: Connection between the first discovery of gene bank material with resistance characteristics and the registration of varieties developed with this material (according to *Hammer* 1991)

Crop	Beginning of the studies/Source	Variety/Year
Summer barley	1954/NOVER & MANSFELD 1955	'Trumpf'/1973, 'Nadja'/1975
Winter wheat	ca. 1960/NOVER 1962	'Compal'/1981, 'Fakon'/1981
Pea	1969/SCHMIDT & LEHMANN 1990	'Sima'/1987, 'Bornella'/1987

In any case, plant genetic resource material can be very useful. But it is extremely difficult for gene banks to prove where their material originated, among other reasons because of the long time span between the discovery of the material and its development into a new variety. One of the very few exceptions is the data listed in Table 12 from the gene bank Gatersleben. For all 56 varieties, it could be proven that they originated from gene bank material. A calculation of the value of this utilized material does not exist up until now, but should be fairly high.

TABLE 12: Varieties registered from 1973 to 1990 proved to have been developed with material from the gene bank Gatersleben (according to *Hammer* 1991)

Crop	Number of Varieties
Spring barley	30[1]
Winter barley	3
Spring wheat	1
Winter wheat	12
Dry soup pea	2
Fodder pea	3
Lettuce	1
Vegetable pea	4
Total	**56**

[1] 5 of these for variety mixtures

The loss of one species is estimated at being worth $203 million (Farnsworth & Soejarto 1985). These authors have calculated a total financial loss for the USA through the loss of plant species at $3,248 billion dollars up to the year 2000. Presently, 33,730 plant species are characterized as being extinct or strongly endangered (Lucas & Synge 1996). The plant genetic resources of cultivated plants with their proven economic importance certainly make up a large part of this number, even if the present loss of infraspecific variability of cultivated plants cannot be compared with the much more dramatic species loss of wild plants.

The value of plant genetic resources utilized from ex situ conservation is, despite all the difficulties encountered, much easier to estimate than that obtained from in situ maintenance. The potential should, however, be roughly comparable.

It looks much different when we talk about costs. The high costs for ex situ maintenance are highly visible, and it is possible to obtain an overall picture from the concrete figures for material and equipment listed in the global report. According to Plän et al. (1994), the conservation of one seed sample costs approximately 0.50 German marks a year (calculated according to Smith 1984 & Parez 1984). In all probability, only the mere storage costs are included in this calculation. According to published data (Thoroe et al. 1994), the entire volume of finances for the gene bank Gatersleben in the year 1992 (payroll, investment costs, overhead) came to 4,790,800 German marks. Taking 100,000 samples into account (see Table 16), the costs for the maintenance of one sample comes to approximately 50 German marks. Included in this estimation are not only the costs for the maintenance of the material, but also research, without which the collection cannot be vitally maintained over a longer period.

The economics of plant genetic resources, with relation to gene banks, is going to establish itself as new research area (see von Braun 1996, Virchow 1999). The basis for these considerations is usually the search for larger budget-cutting possibilities. But since gene banks have often already been degraded to the role of harvest silos, such examples are highly unsuited for a general estimate of costs. The economic conclusions reached by such studies could further burden the already unstable situation of global ex situ conservation.

For in situ conservation (including on-farm conservation), there are not yet good cost analyses available. It is obvious that this area also has to be provided with adequate financial support. Competition for financial means between ex situ and in situ measures is not likely because the sources of money for these measures diverge widely from one another.

In conclusion we can state that from the differing perspectives of user and conservationists, but also other groups, the advantages and disadvantages of the basic conservation strategies become visible. The advantages of in situ conservation are undisputed in order to maintain a large wealth of species, at the same time guaranteeing further evolutionary adaptation.

The possibilities of easily gaining access to the material are positive aspects of ex situ maintenance. Also, a vast amount of material of the most important plant groups, mostly in the infraspecific area, can be safely conserved. Above and beyond this, systematic documentation and characterization can be carried out more easily.

On-farm conservation should be seen as mixture of both approaches, in which the economic aspects of the measure come to the foreground.

There are specific advantages and disadvantages for different conservation strategies. Concentrating on one strategy to the exclusion of all others cannot do justice to present demands for the conservation and utilization of plant genetic resources.

The evaluation of plant genetic resources from a financial viewpoint is still in the beginning phase. Ex situ measures are relatively expensive. No useful estimations of the costs of in situ measures exist to date.

6.3 Evaluation of measures to conserve plant genetic resources

Plant genetic resources have awakened increased interest in the last few years throughout the world (**WCED** 1987). As was once again emphasized at the world nutrition summit of the FAO and United Nations of 1996 (**Fresco** & **Rabbinge** 1997), they are an important part of the nutrition of a steadily increasing world population. Above and beyond this, the need for plant raw materials, fodder for animal production, material for the preparation of pharmaceuticals and other additives and preservatives can be securely satisfied on a long-term basis by the use of plant genetic resources.

The term “resources” points to the “market value” of plant genetic resources, which has now come to mean for the most part only the commercial aspect (**Pearce** & **Morgan** 1994). The sustainability of plant genetic resources, which distinguishes them from non-renewable raw materials, has up until now played almost no role in general discussions. Another issue that has not been discussed thoroughly is the international origin and development of plant genetic resources, and especially of cultivated plants, which make political and geographical assignment almost impossible.

Plant genetic resources, once the "common heritage of Mankind" (but exploited by the industrial nations within a large commercial framework) are now termed "national heritages". But, as with every other inheritance, this inheritance also involves duties, for example for the conservation of these resources, a task which Third World countries have trouble carrying out.

Different measures are available for the maintenance and conservation of plant genetic resources. On a global scale, *in situ* maintenance is preferred. *Ex situ* measures are interesting for special tasks. Because of the relative novelty of modern conservation concepts, there is no qualified use of the two basis models, and we are far removed from integrated approaches.

The rapid increase of gene erosion forces us to take urgent action if we want to save a large part of our plant genetic resources from extinction. But neither the extent nor the mechanisms of gene erosion have been sufficiently documented and researched. And it will take a long time until the little we know is processed.

But we can begin to estimate the extent of plant genetic resources. An overly utilitarian approach will not permit us to make necessary global predictions. That is why it is important to incorporate questions of biodiversity in our considerations.

6.3.1 Plant genetic resources

With the beginning of scientific plant breeding, or when the science of heredity was developed, less than a hundred years ago, it became possible to directly intervene in the development of cultivated plants. Processes that once took hundreds or thousands of years to develop could then be carried out within decades or even years under human influence. The new varieties were widely distributed and are now supplanting traditional, well-adapted land races from cultivation with increasing rapidity. At the end of the last century, plant breeders with a feeling for future developments already pointed out that this process was threatening the genetic base for further breeding development (see **Proskowetz** 1890 & **Schindler** 1890, also **Lehmann** 1990). Land races were then gathered together, which resulted in fairly large collections, above all in the USA and in Russia (**Plucknett** et al. 1987).

In particular, the Russian scientist N. I. Vavilov amassed an unbelievable collection of diversity in a Leningrad institute (now St. Petersburg) by systematically collecting material in the centers of diversity he had defined (Vavilov 1926). He stimulated worldwide collecting activity. But these activities are still primarily used to make plant genetic resources available for plant breeding instead of protecting them against the results of gene erosion (e.g. **Peeters** & **Martinelli** 1989).

Only after the Second World War did a definite change of attitude take place. Besides obtaining material, the aspect of conserving material from threatened loss played a larger role.

In 1961 in Rome, the FAO became more intensively involved with the origins of cultivated plant improvement through breeding (**Hawkes** 1997). A second conference was organized within the "International Biological Program". And it was here that the term "genetic resources" first turned up (**Hawkes** 1997, see also **Flitner** 1995). In 1970, the documentation of the conference was published (**Frankel** & **Bennett** 1970). It became a milestone publication for the most important movements utilizing and protecting plant genetic resources, and placed the genetic diversity of cultivated plants and their related wild relatives in the center of world-encompassing surveys.

The "International Undertaking on Plant Genetic Resources" (FAO 1983) gave the legal framework for the collection, exchange, use, and protection of plant genetic resources.

"Plant genetic resources" is basically a political concept (**Hammer** 1996), and as a result, a great deal of activity dealing with plant genetic resources can be expected on a political level. Scientific questions were and still are accorded less intensive attention.

According to the revised International Undertaking 1983 of the FAO (First Draft CPGR/94/WG 9/3, February 1994), plant genetic resources were defined as the entire generative and vegetative reproductive material of species with economical and/or social value, especially for the agriculture of the present and the future, with special emphasis on nutritional plants. The following categories were named:
modern varieties
old varieties
landraces
wild and weedy species, near relatives of cultivated plants
genetic material (breeding lines, mutants, etc.).

According to the Convention on Biological Diversity (IUCN 1993), biological resources and genetic resources were considered to be distinct.

Biological resources are:
Genetic resources, organisms or parts thereof, populations or other biotic parts of ecosystems with potential or actual use or worth for Mankind.

Genetic resources are:
All genetic materials of actual or potential value.

In the European Union ordinance (EG Nr. 1467/94) on the Conservation, Description, Collection and Utilization of Genetic Resources for Agriculture (June 20, 1994), a definition of plant genetic resources for agriculture is given.

Included are:
agricultural plants including grapevines and fodder plants,
garden plants including vegetables and ornamentals, medicinals and scented plants,
fruit plants,
forest plants,
mushrooms as well as microorganisms as far as they are or could potentially be useful in agriculture.

In the German country report for the preparation of the 4th International Technical Conference of the FAO on plant genetic resources (**Oetmann** et al. 1995), the definition used was based on the FAO's definition. It goes somewhat further than the Convention on Biological Diversity:

"Plant genetic resources are plant materials, reproduced generatively or vegetatively, with current or potential value (for nutrition, agriculture and forestry), including land races, related wild forms and species and specific genetic material of cultivated plants."

This is the definition used in the ensuing pages.

6.3.2 Biodiversity

The loss of biodiversity belongs to one of the central problems of Mankind, next to other important matters such as climate change and securing an adequate supply of drinking water. The diversity of living beings has fascinated Mankind for a long time. At first, diversity was catalogued, described and classified so that it could be widely utilized. Conserving diversity only became an issue in the last century.

The first comprehensive portrayal of biodiversity was published in 1982 (**Anon.** 1997a). It was quite broad in scope, due to a global approach to biodiversity.

Scientific precision came somewhat later, when, for example, **Heywood** (1995) logically separated the different aspects of biodiversity from one another. He differentiated

diversity of species
genetic diversity (see **Wilkes** 1989) and
ecosystem diversity.

Generally it is assumed that agriculture is a major factor in the reduction of biodiversity because it is primarily interested in producing a maximum yield from few chosen organisms. As an important expression of human activity, it is obvious that agriculture plays a role in this direction. The unusual twist is that agriculture itself is to a large extent dependent on biodiversity.

This leads to interesting interactions as well as mistaken evaluations by proponents of pure conservation or mere utilization strategies.

The scientific basis of the biodiversity concept can be greatly improved (**Akeroyd** 1996). The term was coined in 1980 by **T.E. Lovejoy** to denote abundance of species. Genetic and ecological aspects were added by **E.A. Norse** and **R.E. McManus**. In 1981, the "U.S. Strategy Conference on Biological Diversity" was held. The actual breakthrough only was achieved in 1988, when the conference files of the "National Forum on Biodiversity", held in September of 1986 in Washington, were published. Since then, there has been a flood or articles on this problem, but unfortunately they have not led to a consensus on the basic concept and its different aspects (**Watson** et al. 1995a, **Anon.** 1997a).

But the existing concept has proved to be politically extremely effective (**Jeffries** 1997, **Kato** 2000). As soon as 1992, a Convention on Biological Diversity was signed (BUNDESMINISTERIUM DER JUSTIZ 1993) at the conference of the United Nations on Environment and Development in Rio di Janeiro, and became effective in Germany by 1993. A particularly important, legally binding framework for dealing with biodiversity had been created. Which does not mean that further administrative measures are superfluous (**Huele** 1994).

6.3.2.1 Ex-situ measures

Because of rapidly increasing gene erosion, it was already necessary at the beginning of the last century to employ *ex situ* measures in order to secure landraces and other plants (**Coats** 1969). Larger collections developed out of the working collections of the plant breeders, and were often brought together in specialized institutions.

Only in the seventies of the last century was the term "gene banks" coined for these collections. Gene banks have always considered themselves to be collections of plant genetic resources that conserve plants "*in toto*" (as seed and

plants “*in vivo*” and “*in vitro*”) (“Genbanken in der Züchtung”, **Nevers** 1991). At approximately the same time, the term “gene bank” was also introduced for the storage of isolated genes by molecular biologists (“Genbanken in der Gentechnik”, **Nevers** 1991). This parallel use of terminology has sometimes led to misinterpretations and mistakes.
Gene banks are establishments for the collection (see **Guarino** et al. 1995), maintenance, study and supply of the genetic resources of cultivated plants and related wild plant species. These genetic resources are made available as original material for plant breeding and as an object of study for various branches of science (**Knüpffer** 1983). This definition characterizes the traditional work of gene banks.

Gene banks with collections of plant genetic resources have gained special knowledge through intensive work with these plants over the decades. They are theoretically capable of solving even the most difficult problems relating to the conservation of rare and endangered plants, even if it involves pioneer work (**Weisser** et al. 1991).

Botanical gardens have even longer and more intensive experience in this direction, especially with the cultivation of wild plants. In recent years, botanical gardens have been increasingly integrated in conservation strategies (see, among others, **Fessler** 1981, **Hecker** 1981, **Heywood** et al. 1991, **Rauer** et al. 2000). Their work can overlap with that of the gene banks, for example when a wild plant is also a genetic resource.

An increasing exchange of knowledge has been taking place in the last few years between gene banks and botanical gardens. Botanical gardens contribute their skill in cultivating complicated plant groups, while the gene banks offer specialized information, such as work with intraspecific variability, the long-term storage of seeds and the use of modern methods (among others, in-vitro cultures and cryo-conservation). As it is unmistakably stated in the German "Report for the preparation of the 4th International Technical Conference of the FAO on Plant Genetic Resources from 17-23 June 1996 in Leipzig" (**Oetmann** et al. 1995), there is no doubt that botanical gardens and arboreta have to be integrated in a holistic system of conserving and utilizing plant genetic resources

As a further important *ex situ* measure, the amazingly large special collections of cultivated plants of non-governmental organizations such as Arche Noah (**Arrowsmith** 1993) or Seed Savers Exchange (**Whealy** 1993) have been brought together in recent years. The special collections of pomological groups and similar organizations have existed for quite some time and also should be mentioned here. The conservation of endangered species is included in their deliberations (**Seal** 1992).

6.3.2.2 In-situ measures

In-situ measures are the central element of the Convention on Biological Diversity. Numerous plant genetic resources can be maintained in this fashion.
Especially for cultivated plants, there has been talk of "on-farm" maintenance (**Wood** & **Lenne** 1997), which is neither defined in the Convention on Biological Diversity nor in the FAO undertaking (**Begemann** 1995). It refers to the conservation of cultivated plants in their natural environment, which means being traditionally raised by farmers and gardeners (**Hammer** 1995a, **Maxted** et al. 2002). The use of this method for cultivated plants and other co-domesticated species is a very new conservational tool and it must therefore be subjected to intensive studies (**Altieri** 1994, **Frankel** et al. 1995).

The UNESCO program "Man and the Biosphere" (MAB) (Anon. 1970) is also supposed to offer a scientific basis for the sustainable utilization and conservation of the natural resources of the biosphere, and it includes plant genetic resources. The program assumes that Mankind influences maintenance and utilization strategies. In biosphere-parks, it is possible to implement both *in situ* and on-farm measures. But up until now, this program has not been used much in this direction.

In the “Global Plan of Action” of the FAO for the conservation and sustainable use of plant genetic resources (FAO 1996c), *in situ* measures are also considered to be of greater importance. In the final analysis, we are talking about the method of conservation that takes the natural evolutionary developments into full consideration and therefore guarantees a continual adaptation of the material to continually changing conditions.

6.3.2.3 An inventory of in situ plant genetic resources

The work of **Harlan** & **De Wet** (1971) has formed a valid scientific basis for the definition of plant genetic resources. It starts with gene pools (**Ingram** &**Williams** 1993). All crop species belong to a primary gene pool together with such material with which they produce completely fertile crosses through hybridization (in the sense of the evolutionary definition of species). All those plant groups that contain certain barriers against crossing belong to the secondary gene pool. The tertiary gene pool includes groups that can only be crossed with the help of radical new techniques. In the era of gene technology, it is basically possible to transfer hereditary material of every species to any other species. The entire plant kingdom therefore belongs to a quartiary gene pool, which has to be newly defined (**Gladis** & **Hammer** 2002). Because of this, the importance of biodiversity appears in a completely new light.

Up until now, there have been few attempts to apply the principles of **Harlan** & **De Wet** (1971) on large amounts of material. For the *Triticinae* (similar to wheat), an increase above all of the tertiary gene pool through the development of necessary hybridization techniques could be proved by **Bothmer** et al. (1992). For example, the tertiary gene pools of wheat and barley overlap.

The number of species, especially those belonging to the tertiary gene pool, will therefore continue to grow. This refers of course to cultivated plants.

Only recently has a **global** estimate of the number of plant genetic resources species been made (**Hammer** 1995). Beginning with numbers for Germany and Europe (see the following section), an extrapolation on the basis of the number of higher plants (global and country-by-country), of cultivated plants (global and country-by-country) and all plant genetic resources in Germany was made (Table 10, according to **Hammer** & **Gladis** 1996).
The estimated 115,000 species let us see for the first the extent of genetic resources of higher plants. It is obvious that the large number of the species can only be maintained in their natural habitat. With increasing scientific knowledge, the number of species that includes plant genetic resources (according to their definition) will increase even more.

For **Germany**, the number of naturally occurring plants that are characterized as plant genetic resources (see Table 13) was determined in special studies (**Schlosser** et al. 1991, **Hammer** & **Schlosser** 1995).

The number of species has also increased in this case (**Hammer** & **Willner** 1996, appendix 2 and 3 in **Oetmann** et al. 1995).

Grains belong to ***Gramineae***, the most important cultivated plants for human nutrition. But they are also of great importance as fodder plants. Of the 10,000 species, 4,000 can be considered to be plant genetic resources. Because of intensive effort to expand the gene pool of the most important grain species (see von **Bothmer** et al. 1992), this number should probably be increased.

The *Gramineae* are present worldwide. With very few exceptions (for example couch grass *(Agropyron repens)* and green bristle grass *(Setaria viridis)*, wild relatives of grains do not occur in Germany. The relatives of fodder grasses, however, number more than 100 species. Because of this, German flora can be classed as abundant in *Gramineae* species.

Many fruit plants belong to the ***Rosaceae*** that include approximately 3,100 species.1,240 species can be classed as plant genetic resources, although this number is at the upper end of the scale. The family includes many weedy species, which have produced relatively few cultivated plants.
The family is spread out throughout the world, with a central area in the temperate and warm areas of the Northern Hemisphere. Although Germany cannot be considered to be one of the primary domestification centers for most *Rosaceae* species, numerous wild species that are closely linked to cultivated forms can be found here. Through introgression, gene exchange does occur fairly often.

The *Rosaceae* as well as the *Gramineae* are with more that 100 species well represented in Germany.

The ***Leguminosae*** are not only rich in fodder plants, but also in pulses, important for human nutrition. It includes roughly 16,000 species. Approximately 6,400 of these species can be classed as genetic resources. The large number of fodder plants in this family may include some species not be included in this estimate.

The *Leguminosae* are widely distributed, with centers of diversity in the Mediterranean climate zones. The fodder plants have many near relatives in the German flora, while this is only true to a small extent for the pulses (for example, different *Lathyrus* species).

With approximately 90 species, the *Leguminosae* belong to the most numerous naturally occurring plant genetic resources in Germany. This large percentage is due, once again, to their almost universal suitability as fodder plants. Related species occur mostly in the Mediterranean area and in West Asia.

There are many vegetable and oil plants that belong to the large ***Compositae*** family, which includes more than 20,000 species altogether. According to our calculations, approximately 8,400 of these species belong to the group of plant genetic resources. This large family has, despite appearances, produced relatively few cultivated plants.

The main distribution of this family is in the temperate regions of the world. Because of this, the portion of *Compositae* genetic resources in Germany is relatively high. But near relatives of the most important cultivated groups are fairly rare here.

The approximately 70 species of genetic resources from this family that occur in Germany are potentially valuable. They are employed in many different ways that go far beyond the customary primary use of members of the *Compositae* family. Medicinal plants are especially numerous.

The ***Cruciferae*** include approximately 3,000 species that are distributed mostly in temperate zones. Of these, roughly 1,200 species are genetic resources.

Considering the great number of very useful cultivated plants within this family, this number seems to be realistic or even a little too low.

Similar to the *Compositae*, the *Cruciferae* have produced an especially large number of vegetable and oil plants. But the percentage of important cultivated plants is much higher among the *Cruciferae*. The approximately 60 species from this family that occur in Germany have qualities as vegetable and oil, medicinal, fodder and ornamental plants.

The ***Umbelliferae*** family includes roughly 3,100 species and is mostly found in the northern temperate zone as well as in tropical mountains. The major uses are as vegetable, medicinal and seasoning plants. Some 1,240 species can be assigned to the genetic resources.

The relationships between native German genetic resources and the most important cultivated plants are often very close. A little more than 30 German species are genetic resources.

The ***Solanaceae*** are widely distributed throughout the world with ca. 2,600 species. The most important members, potatoes, tomatoes and peppers, all come from the New World. They are mostly used as vegetables, but there are also numerous medicinal plants within this family. Some 1,000 species can be classed as genetic resources. There are practically no relationships between German wild plants and the most important cultivated plants of this family, which is logical if we consider the mainly neotropic source of the cultivated plants.

Nonetheless, some 10 native German species can be listed among the genetic resources, but they are mostly medicinal plants.

A very large number of **other families** include genetic resources. According to the "Mansfeld-Verzeichnis" (**Schultze-Motel** 1986), there are some 230 families that include cultivated agricultural and garden plants, excluding ornamentals. Cronquist's (see **Mabberley** 1987) system of angiosperms includes a total of some 380 families. In roughly 60% of these, plant genetic resources can be found. This percentage is almost certainly higher, because in the meantime new species and in some cases even new families have been added. Ornamental and forestry plants are not included in the Mansfeld inventory.

The **number of plant genetic resources** in the sense of the basic definition used here is very high worldwide. It includes, according to our present knowledge, some 40% of the botanical species of higher plants (see Table 13). As scientific knowledge progresses, this number will certainly be increased.

TABLE 13: Number of species of wild plants, plant genetic resources (PGR) and cultivated plants in Germany, Europe and the world (according to *Hammer* & *Gladis* 1996, estimated, see *Hammer* 1995, *Moore* 1982, *Hammer* 1999)

	Higher plants	PGR among higher plants	Cultivated plants among higher plants
Germany	2,500	1,150	150
Europe	11,500	5,290	500
World	250,000	115,000	7,000

Up until now, it has often been overlooked that Germany is not deficient in native genetic resources. This is especially true for ornamentals, medicinals, seasoning plants, trees (including fruit trees), and fodder plants. Vegetables, plants containing starch or sugar, and, above all, protein kernel plants, which are of the greatest importance for human nutrition, are less numerous. The primary domestication and a large part of the further evolution of members of these groups have occurred outside of Central Europe. If we concentrate on these cultivated plants of world importance when looking at genetic resources, we will get a distorted picture of the situation.

When looking at single plant families, the differing utilizations can be seen, for example, use as fodder plants or protein pulses. Their evaluation as genetic resources must therefore also be differentiated. These examples from Germany show that one region can be classed as poor in one utilization area, but rich in another.

6.3.2.4 An inventory of plant genetic resources in situ/on-farm

On-farm conservation is a relatively new concept. **Kuckuck** (1974), for example, suggested that valuable grain fields be protected in their areas of origin in a suitable manner and that evolutionary processes, including the wild relatives present there, continue to evolve, but this proposal did not get much attention. Even in the 80s, the time was not yet ripe to accept a plan to conserve fields of einkorn *(Triticum monococcum)* and emmer *(Triticum dicoccon)* in southern Italy with the support of the European Union (**Perrino** & **Hammer** 1984). Only further research can make the evolutionary importance of on-*farm* situations evident, for example by proving introgression.

A change in the way of thinking about *on-farm* conservation began in the tropical and subtropical areas, especially in the centers of diversity of cultivated plants (for example **Altieri** & **Merrick** 1987, **Esquivel** & **Hammer** 1988, **Brush** 1989). In these areas, gene erosion is less advanced, and traditional agriculture is practiced in house gardens (**Esquivel** & **Hammer** 1992) or in small fields (**Brush** 1995).

The rapid progression of **gene erosion** is decreasing the numbers of presently cultivated landraces and older breeding stock with ever-increasing speed. According to an estimate of the FAO (**Saouma** 1993), 75% of the genetic diversity of agriculturally cultivated plants has been lost since the beginning of this century. The same number was later mentioned in the FAO World Report (FAO 1996a). This estimate is only approximate in nature and was not reached through analysis of concrete examples.

But it is remarkable that first studies made by comparing landraces in 1941 and 1993 in Albania and in 1950 and 1983-86 in southern Italy (**Hammer** et al. 1996) were just as high. For Albania, the result was gene erosion of 72.4%, and, for Italy, of 72.8%.

Because of this data, we have a framework for a **global** assessment of still extant material. But we must realize that the conservation conditions for the traditional material are very different *on-farm* throughout the world. As seen above, the Mediterranean areas can easily be compared with each other. A study in northern Italy, unfortunately without earlier data for comparison, showed much more rapid gene erosion (**Hammer** et al. 1991).

The presence of traditional landraces, as well as greater species diversity in agriculture and gardening has been estimated to be much higher for the tropical and subtropical areas. This was documented in Cuba (**Hammer** et al. 1992-1994): more than 1,000 species were proven to be in cultivation. Studies in the Mediterranean and in Eastern Asia, both of which belong to the traditional centers of diversity discovered by **Vavilov**, documented about half of the number of species (see Table 14).

TABLE 14: Summary of the checklists of cultivated plants database. The years refer to the respective publications for Cuba (*Esquivel* et al. 1992) and Korea (*Hoang* et al. 1997). Figures for areas in preparation are still incomplete (after *Knüpffer* and *Hammer* 1999, *Hammer* et al. 2000)

Country or region	Cuba (1992)	Korea (1997)	East Asia[1] (in prep)	Albania (in prep)	Italy
Taxa	1044	605	996	433	687
Species	1029	578	940	418	665
Genera	531	378	529	255	380
Families	117	111	147	82	105
Synonyms	729	497	686	225	495
Vernacular names	1669	714	2889	264	15621

[1] The database under construction for East Asia contains information on China (at present 552 species and 694 folk names), Japan (448 and 497, respectively) and Korea (875 and 986, respectively). Relevant information has also been collected during a mission in Japan (**Tomooka** et al. 1999).

It is possible to discern a north/south dividing line, with relatively high values for tropical and subtropical areas, and lower values for the North. No precise calculations exist, but the relatively intact home gardens of South and Central America (**Budowski** 1985), Southeast Asia (**Suemarworto** & **Suemarworto** 1979, **Wiganda** 1981), and Africa (**Chweya** 1994) support such a hypothesis.

Germany is one of the leading industrial nations, and has few old landraces in cultivation. This supports the theory of a north/south axis. Some NGOs cultivate plants in an *on-farm* similar situation. Landraces are also cultivated in living museums and agricultural-historical museums (**Sukopp** 1983), as well as in other suitable situations (**Hammer** 1994). But only a very small proportion of traditional varieties and species are grown in Germany. Gene erosion for plants cultivated in fields and gardens is estimated to be at least 90% over the last 100 years.

But gene erosion is different from species to species, for more traditional material is grown in German gardens than in large agricultural fields. A more specific estimate is therefore necessary for the sake of clarity, based on differing plant groups.

Landraces of **grains** are only rarely cultivated in Germany, and then for the most part by organic farmers (**Schmidt** 1995), in exhibition gardens and biosphere parks, or they are cultivated for unusual uses (for example, emmer and spelt for special bakery and other products).
We cannot expect the cultivation to be appreciably increased. Because of this, *on-farm* conservation is limited. With very few exceptions (grouped under the term pseudo-cereals, for example, buckwheat, Polygonaceae), all species belong to the Gramineae.

Many **meadow plants** have been recruited from local genotypes that developed in native ecosystems. They form the larger part of the genetic resources in this group. On the infraspecific level, the wealth of eco-geographically and morphologically differentiated material almost defies measurement (**Hammer** & **Willner** 1996, see also **Oetmann** 1994).

Because of this, most of the material can be said to be growing under *on-farm* conditions. 148 species from 18 families have been documented. Additionally, there are 30 species from 12 families that are adventive plants (**Hammer** & **Willner** 1996). But the larger part consists of Gramineae and Leguminosae.

The cultivation of traditional **pulses** is analogous to the situation with grains: it is quite limited. Some plant groups may be found cultivated in gardens as vegetables.

There is little possibility of increasing the relatively sparse cultivation of traditional material. All of the pulses belong to the Leguminosae family. Wild relatives are seldom found among native German plants.

In house gardens and small gardens, a certain amount of traditional **vegetable** varieties are cultivated. Several older varieties are also available commercially that are not protected by law, but have been registered with the Bundessortenamt (**Oetmann** et al. 1995).

The informal sector is especially interested in the cultivation of vegetables, so that some capacities for *on-farm* cultivation are available here. In general, vegetable breeding is developing positively at present, with emphasis on diversity and quality, and this in turn supports the cultivation of a larger degree of diversity.

A certain increase in the cultivation of traditional material is possible, mostly through the activities of the NGOs. Vegetables belong to different plant families. The Cruciferae, the Umbelliferae and the Liliaceae are particularly rich in vegetables, and these also have native wild relatives.

For **oil and fodder plants**, the same conditions apply as for grains. The situation is further complicated by the typically narrow spectrum of species and varieties present in Germany. This does not allow any predisposition towards diversification.

The expected tendency toward diversity through the help of the special subsidies for renewable resources sponsored by the European Union government has not been substantiated. There is also little hope that the cultivation of traditional material can be increased because of these measures.

Numerous species from different families belong to this group. Wild native relatives also exist.

The **medicinal and seasoning plants** are not normally domesticated. The cultivated varieties are often simple selections of wild material. A large spectrum can still be found cultivated in gardens. This group is also interesting for demonstration or exhibition plots, historical gardens and NGO activities. Through these measures, a certain increase of *on-farm* conservation possibilities has been documented.

A great number of species from very divergent families belong to this group. The most important families are the Labiatae, the Compositae and the Umbelliferae. A large amount of material has been developed from related native plants. Similarly to the other crop groups, there is little traditional material of **potatoes** now being grown in German fields. But small farmers and NGOs are expressing great interest in old varieties.

A certain increase in the cultivation of traditional varieties is possible. But the cultivation and conservation of material is narrowly limited because of phyto-pathological problems. Potatoes belong to a tuber-bearing section of the large genus *Solanum*. Only few native species of this genus are of interest as a genetic resource for the breeding improvement of potatoes.

Landraces of **beta-beets** have already, with the exception of very few vegetable forms, disappeared from cultivation.
An increase of land cultivated with traditional material is not to be expected.

The relevant beets belong to the genus *Beta*. The species *Beta vulgaris* is the only one in cultivation, with its many forms. In Germany, a population of wild original material can only be found in Helgoland.

Old **fruit** trees can still be found in many locations in Germany. But the conservation of these trees is especially endangered because of their advanced age. Agro-historical museums, NGOs and other groups and individuals participate in the cultivation of traditional varieties. Subsidized government programs for the conservation of orchard meadows are also positive developments (**Büttner** & **Fischer** 1995).

Many initiatives for the cultivation of fruit trees lead us to expect a substantial increase in the amount of traditional material actually being grown. The informal sector will certainly become more important in this area. Our fruit trees belong for the most part to the family of the Rosaceae. There are fairly numerous wild relatives.

Old **ornamental plants** can be often found in gardens, which offer them a suitable and richly structured sanctuary. The number of gardeners interested in ornamentals is so large that their chances of conservation can be considered relatively good. The number of species in this group, from different families, is very large. Many native relatives exist.

According to first estimates, we can **conclude** that the plant genetic resources that are presently in field and garden cultivation account for approximately 25% of the diversity that was cataloged during the first half of this century. This estimate includes a certain species loss, but above all, genetic loss within the richly categorized cultivated plant species. There is a definite north/south dividing line with regard to the number of resources found *on-farm.* Fewer are available in the industrialized countries.

This is also the case for Germany, in which the cultivation of traditional varieties is altogether minimal. Gene erosion has attained a total extent of over 90% here. Cultivation of traditional material must, however, be looked at on different levels. The situation for grasses and fodder plants is, for example, better than for other groups. A variety of fruit trees are also present in different cultivation forms.

Crop plants are generally limited in their variability, while the conditions of garden cultivation create niches that serve as plant sanctuaries. This is a general observation that also holds true for Germany. An increasing number of informal sector members are joining the traditional agricultural and horticultural growers. Their motives for planting traditional varieties are varied, and often go beyond the purely economic.

6.3.2.5 An inventory of plant genetic resources ex situ

Collections of plant genetic resources were already amassed towards the end of the 19th century, when breeders with foresight kept a growing number of promising breeding material. Successful modern varieties were already widely distributed and threatened to displace traditional landraces from their original growing areas.

At first, breeding collections developed, and they soon became centralized. The most famous example is the Vavilov Institute in St. Petersburg, as it is presently called. The first collections of this institute were already gathered toward the end of the last century.

It was only much later that the *ex situ* conservation of plant material in gene banks became a worldwide movement. At this time, gene erosion was already so widespread that some of the landraces were literally rescued at the last moment, to be conserved under gene bank conditions.

Botanical gardens and arboreta have a much longer tradition of *ex situ* conservation and reproduction. But these institutions usually specialize in wild plants and cannot take care of the great numbers of morphologically similar landraces, at least to the casual observer. The collections of most botanical gardens are put together on a species level and require a different conservation method than the maintenance and reproduction of the infraspecific variability of cultivated plants in gene banks. Gene banks are especially concerned about avoiding unwanted cross-pollination in their collections.

Globally there are more than six million accessions in *ex situ* collections. Of these, some 600,000 samples are maintained within the Consultative Group on International Agricultural Research (CGIAR). The remainder is being taken care of by regional or national gene banks (see Table 15). Twelve countries control more than 45% of all global material in their national gene banks (FAO 1996a).

TABLE 15: Number of worldwide *ex situ* collections and their material (according to FAO 1996a)

Region	**Number of gene banks**	**% world**	**Number of accessions**	**% world**
Africa	124	10	353,523	6
Asia	293	22	1,533,979	28
Europe	496	38	1,934,574	35
Near East	67	5	327,963	6
North America	101	8	762,061	14
Latin America and Caribbean	227	17	642,405	12
Sum	**1,308**	**100**	**5,554,505**	**100**
CGIAR system			593,191	
Total sum			**6,147,696**	

Only 30 crops make up the major part of the conserved plant material (Table 16). That means that most of the remaining 7,000 species of cultivated plants and many other valuable genetic resource species are not always included in the gene bank collections.

TABLE 16: The 30 most important cultivated plants of the world and the present number of *ex situ* accessions (according to *FAO* 1996b)

Crop	Number of accessions in collections	Crop	Number of accessions in collections
Wheat	784,500	Fava bean	29,500
Barley	485,000	Manioc	28,000
Rice	420,500	India rubber	27,500
Maize, Corn	277,000	Lentil	26,000
Beans	268,500	Garlic/Onion	25,500
Soybeans	174,500	Sugar beet	24,000
Sorghum/Millet	168,500	Oil palm	21,000
Cabbage	109,000	Coffee	21,000
Vigna	85,500	Sugar cane	19,000
Peanut	81,000	Yams	11,500
Tomato	78,000	Banana/Plantain	10,500
Chick pea	67,500	Tobacco	9,705
Cotton	49,000	Cocoa	9,500
Sweet potato	32,000	Taro	6,000
Potato	31,000	Coconut	1,000

Despite the fact that the CGIAR centers are strategically situated in the centers of diversity of cultivated plants, most of the material can be found in those gene banks of the industrial nations (see, for example, Table 17) that have the financial capacity to maintain large collections. On top of this, the utilization of the material is energetically promoted in the industrialized countries. There is a dividing line here, but in a north/south direction. This fact can be read indirectly from Table 18. Only a small percentage of native plant genetic resources are attributed to the industrial nations, while this number is very high in the developing countries.

TABLE 17: Germany's largest crop collections as compared to world collections (according to *FAO* 1996a)

Crop	Total accessions in gene banks worldwide	Rank of German collections	Percentage of the total world collections (%)
Wheat	784,500	5	6
Garden beans	268,500	5	3
Cabbage	109,000	3	9
Tomato	78,000	5	4
Potato	31,000	3	13
Fava bean	29,500	2	18
Onions and relatives	25,500	1	18
Sugar beets	24,000	1	25

TABLE 18: Percentage of local material in national gene banks (according to *FAO* 1996a)

Region	Country	Percentage (%)	Region	Country	Percentage (%)
Europe	Belgium	12	Near East	Iraq	>95
	Bulgaria	75		Iran	22
	Germany	20		Cyprus	100
	Moldavia	40	America	Brazil	24
	Romania	71		Columbia	55
	Slovakia	8		Ecuador	52
	Czech Republic	16		USA	19
Africa	Angola	100	Asia	China	85
	Ethiopia	100		Korea (North)	20
	Cameroon (tuberous plants)	75		Korea (South)	18
	Cameroon (fruit)	25		Sri Lanka	67
	Malawi	100			
	Mauritius	100			
	Nambia	100			
	Senegal	10			

The genetic resources maintained ex *situ* in *Germany* are numerous. As early as 1943, the Institut für Kulturpflanzenforschung (now called the Institut für Pflanzengenetik und Kulturpflanzenforschung, Institute for Plant Genetics and of Cultivated Plant Research Gatersleben) was founded, and a large collection established. It now includes some 100,000 samples (Table 19) from almost 2,000 species and more than 70 families. Since 1992, parts of these collections have been maintained in Groß Lüsewitz (potatoes), Malchow/Poel (fodder plants), Gülzow (rye and triticale), as well as Dresden-Pillnitz (fruit). This last collection has been taken over by BAZ (see following section) in 2002.

TABLE 19: The collections of the Gatersleben gene bank and its affiliated stations 1996 (according to *Anon*. 1997b)

Crop group	Number of plant accessions
Grains, including maize and millet[1]	38,100
Grasses[2]	5,447
Potatoes[3]	5,238
Beta beets	362
Pulses, legumes	15,782
Fodder plants[2]	4,468
Tobacco	473
Oil and fiber plants[2]	5,338
Medicinal and seasoning plants	3,293
Vegetables including squash	12,599
Mutants (*Lycopersicon, Glycine, Antirrhinum)*	2,503
Fruit[4]	2,673
Ornamentals	1,700
Gene bank Gatersleben total	**97,967**

1. including the collection in Gülzow-Güstrow (now transferred to Gatersleben)
2. including the collection in Malchow/Poel
3. Station Gross Lüsewitz
4. Station Dresden-Pillnitz (now transferred to BAZ, Dresden – Pillnitz)

The collection of genetic resources of the Bundesanstalt für Züchtungsforschung (BAZ, the Federal Institute for Breeding Research), located in Braunschweig (it originally belonged to the Bundesforschunganstalt für Landwirtschaft, the Federal Institute for Agricultural Research), was established as the central gene bank of Western Germany in 1970. It contains some 57,000 samples of 948 species from 58 families (see Table 20). Since 2002 this material is going to be transferred to Gatersleben.

TABLE 20: The collections of the gene bank Braunschweig (according to *Begemann & Hammer* 1993). From 2002 the collections are going to be transferred to Gatersleben

Crop groups	Number of Accessions[1]
Grains	29,467
Legumes	9,030
Oil and fiber plants	3,222
Beets and potatoes	6,265
Fodder plants	2,797
Tobacco	43
Other	1,155
Agricultural crops	**51,979**
Vegetables	2,237
Medicinal and seasoning plants	1,090
Mutants and others	1,814
Horticultural crops	**5,141**
Total Braunschweig gene bank	**57,120**

[1] The data is according to Seidewitz (1991) up to the 15th of August 1991. The legume collection (large and small seeds) is included under legumes. The root crops with the exception of beets and potatoes are included in vegetables. Wild species have been classed under mutants and others.

The gene bank at the Institute for Grapevine Breeding (Institut für Rebenzüchtung of the BAZ) in Siebeldingen was moved in 1947 from the Kaiser-Wilhelm-Institute for Breeding Research to Siebeldingen. It was integrated in 1993 into the BAZ, which was in turn founded in 1992. It maintains 2,500 vine samples from 32 species.

All of the German gene banks maintain some 2.5% of the world gene bank collections, although their facilities are almost exhausted. In comparison, the USA controls roughly 4,5%, but the facilities are calculated for 16%.

The development of regional forest gene banks began for the most part after the founding of the federal and regional working group on the “Conservation of forest gene resources” in 1985. They can be found in Arnsberg, Escherode, Graupa, Hannoversch-Münden, Teisendorf, Trippstadt and Waldsieversdorf. Approximately 68,000 samples of some 50 trees and shrubs are maintained here.

More than 70 botanical gardens and arboreta exist in Germany, and these often specialize in certain plant groups. For example, the Europa-Rosarium Sangershausen maintains a rose collection of roughly 450 wild species and 6,500 new as well as older varieties. The botanical gardens contain numerous plant species, many of them exotic.

The German gene bank collections contain a little less than 20% native material. The rest of the material comes from other collections, from collecting expeditions and from further sources. The large portion of non-native plant material, usually adapted to northern temperate climate zones, is characteristic for the collections of many industrial nations (see Table 15). The percentage of material in both German collections, classed according to plant groups and levels of cultivation, are listed in Tables 21 and 22.

TABLE 21: Material in the *ex situ* collections Gatersleben and Braunschweig (according to *Oetmann* al. 1995, selection)

Crop	**Percentage of the collection Gatersleben**	**Percentage of the collection Braunschweig**
Grains	39	53
Grasses and fodder plants	13	6
Pulses	17	16
Vegetables	10	7
Oil and fiber plants	7	7
Potatoes	5	6
Beta beets	2	4
Fruit	2	-
Ornamentals	1	-

TABLE 22: Characterization of the *ex situ* collections Gatersleben and Braunschweig according to the cultivation class (according to *Oetmann* et al. 1995)

Cultivation class	Percentage of the collection Gatersleben	Percentage of the collection Braunschweig
Present-day varieties and breeding lines	33	42
Old varieties and landraces	48	35
Wild material	15	15
Mutants	4	1
Miscellaneous accessions	-	7

Grains are well-represented in the collections because of their importance as genetic resources, above all for human nutrition. Gatersleben maintains approximately 39,000 samples, while Braunschweig's collection numbers some 30,000.
Grains are an ideal group for *ex situ* maintenance. They are mostly self-pollinating (except for rye and maize), and their caryopses are suitable for long-term storage (except for rye and oats). That is why they are over-proportionately represented in worldwide collections.

For the most important grains, approximately 90% of existing variability is still present in the collections. The related wild species are becoming more important for breeding and must be integrated in the collections in order to make them available to breeders, but also to protect them.

Ex situ collections for **grasses and fodder plants** are quite limited in number. Gatersleben has 13,000 samples, while Braunschweig's collection comes to 4,000. **Hammer & Willner** (1996) published a precise analysis of the collections in the custody of Gatersleben.

Grasses and fodder plants tend toward cross-pollination. The seeds are not ideally suited for long-term storage. For most of the perennial species, maintenance in field gene banks is the chosen method, which, however, requires a large amount of space. This is why this group is often underrepresented in gene bank collections.

It has been estimated that less than 10% of the entire variability is included in German collections. The domestication of grasses has not advanced very far, so that differences between wild and cultivated material are often negligible.

Pulses, like grains, are included in the German collections in a wide range of variability. Some 17,000 samples can be found in the gene bank Gatersleben, and over 9,000 in Braunschweig.

Pulses are to a large extent self-pollinating, and do not pose problems for *ex situ* maintenance. The seeds are extremely well-suited for long-term storage, with a few exceptions, such as soybeans. Related wild species are very rarely found in Germany.

Approximately 80% of the entire range of variability is included in the gene banks. The cultivated material has been highly domesticated. Wild forms play a steadily increasing role in the improvement of many species of this group.

There is much demand for plant genetic resources from the extremely varied group of **vegetables**. With 10,000 accessions, the gene bank Gatersleben has one of the largest collections in the world. The Braunschweig collection consists of approximately 4,000 samples. The painstaking pollinating and ecological details necessary for the pollination and reproduction of vegetable collections have been summarized by **Gladis** (1989).

Vegetables belong to one of the most difficult groups for conservation under *ex situ* conditions. They generally cross with each other, are often perennials, and the seeds of some species such as lettuce and onions only remain viable for a short time.

Because of the technical and biological difficulties encountered during reproduction, there are relatively few vegetables generally available in gene bank collections. Next to highly domesticated species, there are also those that have almost no cultivated features. For the breeding improvement of highly domesticated species, there is a constant need for wild material.

Although the **oil and fiber plants** are usually grouped with the typical crop plants, and their gene erosion is especially dramatic, it is not adequately represented in most collections. Some 7,000 samples are maintained in Gatersleben and 4,000 in Braunschweig. Rapeseed (canola) plays a central role for Europe and therefore makes up the largest part of the collections.

The plants that belong to this group are usually annual and their seeds are suited for long-term storage. Because they are cross-pollinating, labor-intensive isolation measures are necessary. This is probably the reason why these plants are underrepresented in many collections. Another reason is that landraces are not being collected quickly enough to counter the rapid pace of gene erosion.

Approximately 50% of the variability of this group is present in all the collections. For most of the highly domesticated species, a certain reservoir of wild plant groups exists. These have, however, not yet been studied intensively enough.

The group of medicinal and seasoning plants has been analyzed precisely in Gatersleben: in 1993 the collection included 2,690 species from 269 genera. **Hondelmann** pointed out the importance of the Braunschweig collection in

1990. A comparison of both collections (**Hammer** 1995b) came to the surprising conclusion that the two gene banks maintain quite divergent material, although they are both situated in the same cultural-ecological-geographical area. Because of the differing collection strategies, the duplicates in the two collections do not account for more than 20% of the material. However, if we look at the wealth of total variability in this group, the collections are fairly modest.

The group is very heterogeneous, including many cross-pollinating plants, and is therefore difficult to maintain in gene banks. Because of this, gene banks the world over are maintaining relatively little material in view of the immense number of species available. In Korea alone, over 500 cultivated species have been confirmed (**Hammer** et al. 1997).
Much less than 10% of the entire variability of this plant group can be found in gene bank collections. Only a few species are highly domesticated, and genetic closeness to wild plants is therefore very marked. Despite this, the collection and documentation of landraces has generally been neglected. The study of wild members of this group is in the initial stages of its development.

Potatoes and their close wild relatives are numerously represented in the German collections. In the gene bank Gatersleben (the station Gross Lüsewitz), there are 5,000 accessions, and in Braunschweig, they number 3,500. The collection in Braunschweig contains more wild species. As a result of German-Dutch gene bank cooperation, this collection is being transferred to Holland.

Cultivated potatoes are usually propagated vegetatively and must therefore be grown out repeatedly. In recent years, they have been increasingly maintained *in vitro*. In both cases, the process is labor-intensive and therefore expensive. Wild potatoes can be propagated by seed. There are intensive international programs to collect both cultivated varieties and wild species.

In Gatersleben, there are approximately 300 accessions of **beta-beets** in the collection, and in Braunschweig, the number is 2,000. In Braunschweig, special expertise with this group has evolved over the years (see **Frese** 1995).

Beta-beets are mostly biennial and cross-pollinating, and their *ex situ* maintenance is therefore difficult. The seeds can be stored long-term with good results.

Sugar beets are only seldom grown as landraces. But there are niches in garden cultivation for the vegetable beet varieties, so that *in situ* material can be found here. Some 80% of the variability is presently in *ex situ* collections. Wild forms are mostly needed for the breeding improvement of the sugar beet.

More than 2,500 **fruit** samples can be found in the special collection of the BAZ in Dresden-Pillnitz. The collection of numerous **grapevines** in Siebeldingen has already been mentioned (see also **Dettweiler** 1995).

Fruit and grapevines must usually be maintained in field gene banks. This is labor-intensive and places large burdens on the gene banks.

Altogether less than 50% of the existing variability is contained in *ex situ* collections. Fruit trees are for the most part highly domesticated. Wild material is of primary importance for resistance breeding and for grafting stock.

A small collection of **ornamental plants**, including approximately 1,000 forms, can be found in the gene bank Gatersleben. Important *ex situ* collections are established in botanical gardens and arboreta. Private individuals and organizations have also put impressive collections together.

Ornamentals have widely differing growing needs. Perennials are usually kept in field gene banks.

Only a small portion of the very varied material can be found in *ex situ* collections. Beyond the highly domesticated older varieties, there are a number of newer and potentially valuable varieties and species.

Forest plants are an exception in so far as they can be cheaply produced and maintained through modern methods of production, which allows for the combination of the conservation of genetic resources and production for forest use. The fact that they are an exception to the rule has caused much discussion (see **Kleinschmit** 1995). Because of this, forest cultivation does not find a special place in this study. But a few important studies are listed here (**Muhs** 1994, **Kleinschmit** 1994, **Kohlstock** 1993).

The *ex situ* forestry collections have already been commented on briefly.

In **conclusion** for the most important crops, approximately 60% of the closely related wild varieties and all the variability of the cultivated forms are included in *ex situ* collections. Most of this material is maintained in gene banks. But we must not take this statement at face value, and should look at it more closely. While a large proportion of the material for such crops as spiked grains and sugar beets are present in *ex situ* collections, grasses and fodder plants as well as medicinal and seasoning herbs are not as well-represented. The utilization as well as the distribution and importance of the different groups are responsible for the differences.

With *ex situ* conservation, there is a typical north/south dividing line, with abundant collections in the industrial countries and much smaller facilities in the developing countries.

Crop plants are generally better represented in gene banks than garden plants. Strangely enough, there is a correlation between the presence in the collections and the ease of reproduction. Crop plants are mostly annual and usually self-pollinating, and are simpler to reproduce.
Collections of wild plants in gene banks are relatively small. There is often great need for wild material related to highly domesticated species as a source for character traits. These are necessary for further development of the cultivated plant groups. The availability of the material is of primary importance for inclusion in gene bank collections. Occasionally, aspects of conservation also become relevant. For example, *Aegilops* material (a close relative of wheat) is maintained in gene banks, particularly those species that are listed in the "Red Book of the Union of Soviet Republics" (**Hammer** 1980). It is imperative to also incorporate the knowledge obtained by botanical gardens for wild plants.

Ornamental plants are often maintained *in situ* in botanical gardens and arboreta. The activities of NGOs also play an increasingly important role in this area.

Ex situ collections in Germany have assimilated more than 90% of the existing variability of native cultivated plants. In addition to this material, a large number of samples come from other geographical zones, but are usually not available there any more. Programs of repatriation can help to resolve this problem (for example, Albania and Georgia, see **Beridze** 1996). Nonetheless, the material must be also maintained *ex situ* as an international undertaking and to secure the reproduction of the material.

6.4 General possibilities of conserving plant genetic resources

For the conservation of cultivated plants as a separate group of genetic resources, a paradigm has developed (**Hammer** 1993b). According to it, effective conservation can only be effected by gene banks and similar institutions, because increasingly intensive agricultural production is feasible only through the use of modern varieties.

Only much later were considerations made about *in situ* maintenance for the wild relatives of cultivated plants.

On-farm conservation is the newest concept and still needs the most conceptual input.
Without doubt, there is no single solution to the conservation of cultivated plants that can do all things for all plant groups. Integrated models should therefore be developed to allow differentiated and cautious progress.
But the aforementioned rapid increase in gene erosion does not leave us much time for in-depth development. Because of this, improvisation must be included among the virtues necessary to resolve the problems arising from the conservation of cultivated plants.

The ***ex situ* conservation** of large numbers of cultivated plants depends on the longevity of the seeds. Most species belong to the orthodox seed type with a logarithmical progression of shelf life as humidity and storage temperature are reduced (**Hammer** & **Hondelmann** 1997). The duration of seed viability can be estimated fairly precisely by taking these aspects into account (**Ellis** & **Roberts** 1980). The life expectancy is determined through genotype. The germination rates of seeds of various plants can be seen in Table 23. Care should be taken that viability not sink under 85% (if the original rate is set at 100%), so that gene mutations will not occur in the seed during storage. The most important cultivated plants in the northern temperate zone all belong to this orthodox group of seeds.

TABLE 23: Estimated reproduction intervals for seed that is stored at -20°C and 5% moisture content (according to *Roberts* 1973, *Ford-Lloyd* & *Jackson* 1986). These theoretical figures are often much higher than those dictated by practical knowledge. For example, according to our experience, barley has to be regenerated before 35-40 years have passed

Species	Variety	Prognosticated interval before regeneration (years)
Barley	'Proctor', 'Golden Promise', 'Julia' (middle figure)	70
Rice	'Norin'	300
Wheat	'Atle'	78
Fava bean	'Claudia Superaquadulce'	270
Pea	'Meteor'	1,090
Onion	'White Portugal'	28
Lettuce	'Grand Rapids'	11

The storage of seeds of the recalcitrant group is more difficult. The seeds cannot be dried without damaging them. Under normal conditions, they only live for a short time. Trees often belong to this group, and tropical plants are also frequently recalcitrant.

A special method of conservation is cryo-conservation, which allows for an extremely long storage of many species. This method is especially advantageous for the storage of vegetative material from *in vitro* culture.
Field gene banks in which material is grown out are advantageous for long-living, primarily vegetatively-reproduced material such as fruit trees.

In vitro maintenance is used for vegetatively-reproduced species as well as for some recalcitrant species and other hard–to-maintain accessions. This method involves high input and outlay and can therefore only be implemented for relatively few plant groups.

Apart from the last, more difficult methods, the conservation of the orthodox seed of plant species is relatively simple. Because of this, mistakes are often made in underestimating the tasks of a gene bank (it is indicative that long-term refrigeration units for seeds are often wrongly referred to as gene banks). If the technical prerequisites for the cold storage of seeds are available, the major problem of the gene bank lies in the reproduction of the material. Annual self-pollinators are easier to reproduce than cross-pollinators, which must be subjected to additional security and isolation measures when many different samples of one species are to be reproduced.

For wild plants without domestication features, reproduction is even more complicated because the seeds shatter, they ripen over a longer period, and they exhibit other difficult characteristics. For the last twenty years, gene banks have had to do pioneer work with wild plants (see **Hammer** 1980, **Lawrence** 2002), because a large demand has developed for them for various breeding and breeding research tasks. Botanical gardens have more experience in this area (**Raven** 1987).

The methods of *ex situ* conservation have been summarized in Table 24.

TABLE 24: Methods of *ex situ* conservation for various plant genetic resources (according to FAO 1996b)

Storage technology	Storage material	Function
Low temperature (-18°C), 3-7% moisture content	Orthodox seeds	Long-term storage (basic collection), working collection
Dried seeds at cool temperatures	Orthodox seeds	Active and working collections, medium-term storage
Ultra-dried seeds at room temperature	Orthodox seeds with long-term viability	Medium to long-term storage (active and working collections)
Field gene banks	Vegetatively-reproduced species, species with recalcitrant seeds, species with long reproduction cycles and minimal seed production	Short or medium-term storage, active collections
In-vitro culture under slow-growth conditions	Vegetatively-reproduced species, some species with recalcitrant seeds	Medium-term storage, active collections
Cryo-conservation at -196° C with liquid nitrogen	Seeds, pollen, tissue or embryos that are suitable for *in-vitro* regeneration after freeze drying	Long-term storage

Wild plant material is usually conserved in its natural habitat. Compared with the relatively small number of cultivated plant species (see Table 10), the plant genetic resources of wild plants are quite numerous. General protective measures can therefore be of great importance to a large number of plant genetic resources. The different categories of land use practiced in Germany are summarized in Table 25. Problems related with ***in situ* conservation** are also discussed by **Anon.** (1996).

Specific forest conservation areas exist according to the nature conservation law as well as forest law. Besides, conservation areas in which forests have a certain importance also exist. In Germany, at least half of the wooded area is protected under one of these categories (**Oetmann** et al. 1995). These are positive requirements for the conservation of forest genetic resources, as well as for other plants that are part of the wood, or grow in it, such as fruit trees, as well as medicinal, seasoning and fodder plants.

TABLE 25: Categories of land use in Germany (1993), (according to Statistisches Jahrbuch für Ernährung, Landwirtschaft und Forsten 1994, Nationaler Waldbericht 1994, *Oetmann* et al. 1995)

Type of use	Millions of hectares	Area %
Agriculture	17.2	48
Agricultural cropland	11.7	32
Agricultural meadow and pasture	5.3	15
Agricultural perennial cultures	0.2	1
Forest	10.7	30
Other[2]	7.9	22
Total	**35.7**	**100**

[2] Buildings, open spaces, space used for transportation, wetlands, waste lands

Other possibilities for conservation exist in large protected areas (see Table 23). Included in these are national parks, biosphere reserves and Nature parks, which can be divided into areas of varying protection, as well as riparian or wetland areas of international importance according to the Ramsar convention.

Nature and landscape protection areas (Table 26) can easily be integrated into national protection policies.

Presently, we are seeing an increase in the number of protected areas. A networking of the various protective zones is being enacted within the framework of integrated protection strategies. This helps to promote the protection of biotopes, which is the prerequisite for effective species protection (see **Schlosser** et al. 1991).

In Germany, positive conditions for various protection measures exist through legal frameworks, Nature protection agencies, universities, and Nature protection organizations. Numerous volunteers take care of and oversee the protected areas.

An inventory with regard to plant genetic resources is urgently needed. Such studies exist for the area of former East Germany (see **Schlosser** 1982, **Schlosser** et al. 1991). Otherwise, they are missing. For the area of Saxony-Anhalt, such a concept has been completed (**Anon.** 1995b).

Table 26: Protected areas in Germany (1992) (according to Data on the Environment 1992/93, *Oetmann* et al. 1995)

Large protected areas

	Category of protected area			
	National park1	**Biosphere reserves1**	**Wetlands (Ramsar)1**	**Nature parks**
Number	8	9	29	ca. 67
Area (hectares)	180,302	628,690	ca. 134,240	5,569,447
Area (%)	0.5 %	1.8 %	0.4 %	15.6 %

Protected natural and landscape areas

	Category of protected area	
	Protected natural areas	**Protected landscape areas**
Number	ca. 4,880	ca. 6,206
Area (hectares)	ca. 617,000	ca. 9,039,871
Area (%)	1.7 %	25.3 %

1 not including the sandbanks or wetlands of the North or East Sea

As an exceptional form of *in situ* conservation, ***on-farm*** **maintenance** is limited to agricultural and garden plots. Conservation must therefore take place during agricultural production. Modern varieties, which often are more productive than the landraces, compete for this space with landraces or wild plants. Therefore, financial or other incentives have to be built into the system to safeguard future conservation.

These requirements can be more easily attained in developing countries. Subsistence farming tolerates a multitude of cultivated plant species and forms in mixed culture and should be considered a living conservation reservoir (see **Esquivel** & **Hammer** 1988). The evolutionary development of cultivated plants is guaranteed (see for example **Ceppi** 1994). In some cases, local farmers and gardeners can be encouraged to improve their cultivated plants through breeding (for example **Sperling** et al. 1993, **Eyzaguirre** & **Iwanaga** 1996, **van der Heide** et al. 1996). This process corresponds to the millennia-old farmer's breeding tradition, which has culminated in the unbelievable variety of landraces presently available to us (**Baumann** 1991).

In Germany, smaller niches can be found in small garden plots and some less intensively-used agricultural areas. Special programs for the preservation of fruit orchard meadows and fallow strips on field borders are further examples.

6.5 A possibility of combined approaches

On an international level, first attempts within a larger framework have been made (**Frankel** & **Soulé** 1981, **McNeely** 1992, **IPGRI** 1993). Ideas for **combined approaches** of gene banks (*ex situ*) and nature conservation (*in situ*) have been developed (**Hammer** 1993a). The "International Board of Plant Genetic Resources" in Rome, at first quite conservative in its approach, had to react in 1984 with a paper on basic concepts of integration (**IBPGR** 1984). Each of the large gene banks in Germany adapted differently to the new needs.

The gene bank in Braunschweig was already working at an early date with the "Stiftung zum Schutze gefährdeter Pflanzen" (Foundation for the Protection of

Endangered Plants) to put the seeds of endangered wild plants into long-term seed storage (**Dambroth** & **Grahl** 1981, see also **Dambroth** et al. 1990). The subsequent release of the plant material in protected areas was a definite part of the program (see **Spiess** 1990).

In Gatersleben, the need to conserve weeds of the convergent type of development was determined (**Hammer** 1985, **Spahillari** et al. 1999). Intensive cooperation with organizations was also undertaken to catalog and study genetic resources in protected areas (**Schlosser** et al. 1991).

In an international framework, Gatersleben has also developed a far-reaching concept. It repeatedly stresses the importance of *in situ* conservation, especially in those cases in which introgression has left its mark due to rapid evolution (see **Hammer** & **Perrino** 1995). For example, the presence of wild rye in the vicinity of rye fields (*Secale cereale*) in southern Italy has caused such developments (**Hammer** et al. 1985). Conservationists also have misgivings about the genetic integrity of the wild plant group, for transference of characteristics takes place in both directions. Research on cultivated plants, on the other hand, follows the phenomenon of introgression with great interest. Seed producers are not as positive about these developments (for example, introgression with carrots and sugar beets).

A high point of the integrated approach was the attempt to place the entire small Italian island of Linosa under protection. It has a characteristic natural flora, and autochthonous agriculture is practiced here as well (**Hammer** et al. 1997). It presents a unique opportunity to study various possibilities for an integrated approach.

Altogether, the model "biosphere reserve" (see **Goerke** & **Erdmann** 1994, **Euromab** 1993) seems to be predestined for a mixture of *in situ, ex situ* and *on-farm* measures. A pilot project is being established at the Landesanstalt for Großschutzgebiete Brandenburg. In the biosphere reserve Schorfheide-Chorin, Elbtalaue and Spreewald, old landraces of different plant types are being maintained and reproduced. Most of this material came from the gene bank Gatersleben. Through this method, the evolutionary development of varieties under agricultural production, which is usually painfully missing, can be observed.

Meadow orchards are another illustration of an integrated approach. It has been suggested that they be divided into levels of utilization intensity, which show the combination of possible and differing conservation strategies (**Büttner** & **Fischer** 1995).

Rank 1: Meadow orchards are left to natural succession and therefore satisfy the function of a natural biotope (Nature conservation, genetic resources of fruit trees and other plants).

Rank 2: Meadow orchards are subject to extensive cultivation; the fruit production is given lower priority (landscape protection, genetic resources of fruit trees and other plants).

Rank 3: Production of fruit, primarily for industrial use, is given top priority, and all other measures are subordinate to this goal. Insecticides and fungicides are used only as needed (fruit production, maybe fruit genetic resources).

Rank 4: Pulling up of trees and new plantings according to a determined method of production, either for landscaping or for the production of cider fruit or a field gene bank (Rank 2 or 3).

Field flora reserves can also play a special role for the protection of both segetal species and genetic resources (**Schuhmacher** 1982, **Oldfield** & **Alcorn** 1991, **Illig** & **Kläge** 1996). The appropriate landraces and weeds are supplied by *ex situ* collections.

Partial aspects of *ex situ, in situ,* and *on-farm* conservation are definitely present in Germany. But, up until now, no appropriate organizational form has existed to oversee these developments. **Bommer** & **Beese** (1990) argue in their concept for a „Fachausschuss Pflanzengenetische Ressourcen Artenschutz" (Committee for plant genetic resources and species protection), with the following responsibilities:

- to set priorities for species protection,
- to develop utilization concepts for agricultural extensification programs to ensure Nature and species conservation,
- to promote the interdisciplinary exchange of thoughts with ecological, genetic and taxonomic working groups,
- to develop cooperation with the committee for forest gene resources,
- to develop standards for data storage and exchange,
- to include botanical gardens in *ex situ* conservation, and
- to insure the participation of the German Republic in international Nature and species conservation programs.

This concept forms a useful nucleus for plant gentic resources work, but also needs to be expanded.

6.6 Strategies for maintenance of agro-genetic resources

According to **Frankel** (1983), there are two strategy options for the conservation of a species:

1. The creation or maintenance of a habitat in which a species can survive and further evolve without being actively influenced in its development. This possibility is rare for components of biodiversity, and will become even rarer in the future (**Brush** 1995).
2. If these habitats do not exist, the species, varieties or breeds must be moved into collections such as those of botanical gardens or gene banks.

Theoretically, the following strategies can be developed from these options (see Table 27):

1. For agricultural crops, *in situ* maintenance is cultivation needing more or less intensive human attention. There are gradual differences from "no management" (for example in the central zone of a national park) to "little management" on to "intensive management" (if conservation can only be accomplished by the simultaneous maintenance of the humanly-influenced situation). *In situ* or *on-farm* conservation relates to the maintenance of genetic resources in agriculture or horticulture as in, for example, traditional house gardens (so-called "Conucos", see **Esquivel** & **Hammer** 1992).
2. *Ex situ* maintenance takes place in gene banks, botanical and zoological gardens and aquariums. There are numerous measures available for the maintenance of plants. Included among these are seed collections, field collections, *in vitro* cultures, pollen conservation, protoplasten culture, and cryo-conservation. Animals are maintained in zoo populations, while sperm, egg cells and embryos can be cryo-conserved.

TABLE 27: Strategies for the maintainence of agrobiodiversity (after Franck et al. 2000)

Maintenance method	**Advantages**	**Disadvantages**
In situ	• Interactions with other species and organisms are possible • Interspecific and infraspecific variations can be combined Can also be used for vegetatively reproducible species or those with recalcitrant seeds (characterization, property rights)	• Large area necessary for maintenance • Only a small number of genotypes can be managed this way. Does not protect against epidemics, diseases, etc., possible losses • Access to the material is difficult
In situ or *on-farm*	• Further evolution through natural evolution and choice of varieties is possible	• No conservation of the status quo, selection • Gene erosion is possible
Ex situ Seed banks	• Seed (accession) is always available • Catalog • Little space necessary (small seeds) • Genetic status quo of the stored seeds can be maintained with appropriate reproduction strategy	• No further evolutionary development dependent on the surrounding environment • Problems with the maintenance of recalcitrant and vegetatively reproducible species • Large amount of space necessary for storage (large seeds) • The original surrounding flora is not conserved as well • Regeneration needs space and is money and labor intensive • Only a limited portion of the variability is collected and maintained

Maintenance method	Advantages	Disadvantages
		• Change of population structure through reproduction of populations that are too small
Tissue culture	• Little space needed • Good for vegetative material and recalcitrant species • Disease minimized	• High technical outlay • Somaclonal variation • Related species are not maintained as well
DNA	• Little space needed • Can be used anywhere • Future method of last resort in isolated cases	• Is not a germplasm conservation method *per se*

Cultivated plants and domesticated animals on one hand, and that portion of agrobiodiversity that lives in the wild must be differentiated with regard to conservation strategies. The wild components can be maintained *in situ*, but this method is only rarely practicable for domesticated animals and plants, since these are usually dependent on human help for their survival. Their permanent maintenance is possible *in situ, on-farm or ex situ* (**Kosak** 1996). *On-farm* maintenance usually only occurs within "traditional" agriculture, which is often marked by diversity of cultivation. In "modern" or "industrial" agriculture, which is characterized by only a few species of genetically homogenous, high-yielding plant varieties and animal breeds, diversity must be maintained *ex situ*.

Brush (1995) suggests introducing systematical *in situ* and *on-farm* maintenance as a supplement to *ex situ* conservation in isolated areas within the centers of domestication, where only small-scale agriculture is practicable. It is not a simple case of preserving the *status quo*, but of making further evolutionary processes possible.

6.6.1 Examples for conservation strategies of certain cultivated plant species

- Wheat: Almost 800,000 wheat (*Triticum*) accessions are maintained worldwide *ex situ* (FAO 1996b). A large part of these accessions are old landraces. Although there are certainly duplicates among the 800,000 accessions, the sheer numbers make a systematical *in situ* or *on-farm* maintenance simply impossible for organizational reasons. Two biological characteristics predetermine *ex situ* maintenance strategies for wheat:
    1. Wheat is a self-pollinator, which means that complicated measures for pollination management or parcel isolation are not necessary (but occasionally outcrossing can occur).
    2. The samples must only be regenerated every 25 years if they are kept in cold storage. This is enough to maintain germination.
- Cassava: Cassava (*Manihot*) is a vegetatively reproduced species. There are 28,000 accessions in worldwide *ex situ* collections. 23% of these are landraces or old varieties and 9% are varieties or breeding stock (FAO 1996b). It is probable that the collections constitute more of a random selection than a complete inventory. Cassava clones must also be re-grown each year. The best conservation strategy is therefore to maintain habitats in which a large diversity of cassava varieties is cultivated. The wild relatives should be also considered as useful plant genetic resources (**Nassar** 2001).

These two examples give us guidelines of how to proceed to find the optimal conservation strategy for each species.

In order to effectively utilize the material maintained *ex situ* in gene banks and other collections, **characterization and evaluation** is necessary. That means that during characterization the passport data of an accession (source, name, taxonomy) are cataloged. In the evaluation, data about resistance, constituents or special features are collected. Tips about data processing are given in the IPGRI descriptor list. Because evaluation of all material is very time-consuming, gene banks traditionally study certain sections of their entire collection more intensively. The concept of the "core collection" was brought up by **Frankel** & **Brown** (1984), see also **Hodgkin** et al. (1995) originally understood as a means for rationalizing genebank accessions. It is important that today those accessions that do not form part of the core collection are not neglected. That might constitute a case of throwing the baby out with the bath water. These "leftovers", or other large collections, gain importance when certain characteristics, such as resistances, are not available in the core collection. The classic example of this was the screening for resistance against the grassy stunt virus of rice at the International Rice Research Institute (IRRI) in the Philippines. Under 30,000 studied accessions (varieties, old landraces, wild rice), only one single wild rice (*Oryza nivara*) had the urgently needed resistance (**Khush** & **Beachell** 1972). Several similar examples (**Chang** 1989) leave no room for doubt of the necessity of maintaining large collections.

The distance from newer varieties to many characteristics of the old landraces and especially of the wild varieties increases in proportion to the development of high-yielding varieties. Gene bank material utilization becomes problematical if it is too far removed from the present-day spectrum of varieties, because less desirable, as well as positive character traits are also transferred to elite material through crossing. In this case, **pre-breeding programs** are essential. A famous example for successful pre-breeding is given by **Harlan** & **Martini** (1938), see also **Suneson** (1956). They discovered that the 5,000 barley accessions then found in the United States gene banks were not very useful for the breeding purposes of that time. Therefore, they selected 28 outstanding or extreme accessions from the barley-growing regions of the world and crossed these with each other. Seed of the F2-generation of all crosses was mixed and cultivated as a vital population with the name of *Composite Cross II* around the world. From this population, a number of excellent varieties were developed (NRC 1993). The fact that gene bank material often has to be made available for present-day breeding through pre-breeding, should in no sense be taken as an argument against the "Noah's Ark principle", as is often the case. This is clearly illustrated through the example of grassy stunt resistance.

During the development of agriculture, old varieties have always been displaced by newer ones, since these are better adapted to demand. Because of the uniformity of agriculture attained in large areas of Europe and North America, the associated biodiversity of plants and animals has decreased more and more. The example of the rice grassy stunt virus shows how quickly a certain trait of a single source or accession can become important and valuable.

The principle of prevention (Noah's Ark principle) tells us to **maintain as much material as possible**. There is presently no scientific method, except the identification of duplicates, which can give us a secure assessment as to which parts of the collections are expendable.

While political discussion (Global Plan of Action of the FAO, Leipzig 1996) as well as scientific discussion (**Brush** 1995) concentrates on demanding increased *in situ* conservation activity, the large size of the collections alone tell us that *in situ* maintenance *cannot* always be the main method of conservation. **Virchow** (1999) comes to the conclusion that for plant genetic resources, "*in situ* conservation programs should only be supported in a limited manner". His reason for this statement is the relatively high cost of *in situ* conservation.

The basis for deciding which method of conservation is appropriate should be the reproduction biology of each species and the reliability of each method of maintenance or institution (including the sustainability of the institution's financing as well as the ease of access for other parties).

If *in situ* conservation is chosen, it should be remembered that the benefits reaped from the maintenance of the genetic resource will not necessarily accrue to the advantage of whoever invests in the conservation. Therefore, goal-oriented incentive systems must be developed for *in situ* maintenance. Goal-oriented conservation strategies as well as monitoring systems must be developed.

Altogether, we must remember that the development of *in situ* or *on-farm* conservation measures for latent biodiversity (i.e. diversity not presently in demand), is not a substitute for diversified agriculture. The conservation or creation of sustainable agricultural systems that actively use as much biodiversity as possible must remain the major goal. The active use of agrobiodiversity also insures multifunctional land use and makes the *in situ* maintenance of the utilized components less difficult. As a result, ecosystem contributions of biodiversity in agricultural systems can help to lead to more environmentally compatible and sustainable agriculture.

6.7 Recording the functions of biodiversity

External inputs in agriculture are often substituted for the achievements of biodiversity. If we agree that agrobiodiversity can best be protected by sustainable utilization, the following research areas assume priority:

- Recording potential and present-day contributions of agrobiodiversity to the productivity, stability and sustainability of agricultural ecosystems.

- The goal-oriented contribution or use of biodiversity as a “farming element” urgently needs to be studied. This includes cataloging the ecological contributions of agrobiodiversity as well as the economic value of agrobiodiversity.

6.8 Recording and characterizing agrobiodiversity

Record taking of *on-farm* agrobiodiversity must either be initiated or accelerated on a worldwide basis. Priority should be given to domesticated plants and animals on a species and variety level as well as to microorganisms, particularly soil inhabitants. Those crops that do not belong the “top 30” should be given special attention.

The systematic study and evaluation of the genetic resources now available through *ex situ* collections is also of basic importance and needs to be supported. Important single questions are:

- Studies on genetic diversity with molecular and morphological markers are often based on less than 100 gene loci (as opposed to approximately 10,000-100,000 genes found on an average in higher organisms). It is important to study the genetic variation in the loci that are responsible for agriculturally important character traits.
- Further development of classical morphological-systematical methods are necessary for the conservation and utilization of diversity within particularly richly-structured cultivated plant species.

6.8.1 Optimizing conservation strategies

The Global Plan of Action, which was ratified at the end of the 4th International Technical Conference of the FAO in Leipzig in 1996 gives preference to *in situ* maintenance over *ex situ* measures. The development of optimal conservation strategies must, however, take a number of factors into account and be developed according to the requirements of each species. Priority should be given to:

- Promoting the study of the suitability and reliability of *in situ* measures for the maintenance of genetic diversity under different ecological conditions.
- Study of the cost and utilization of different conservation steps, including an analysis of the distribution of the costs and benefits of agrobiodiversity, geographically as well as within society. Agrobiodiversity is, at least partially, in the public domain, and this must be taken into consideration.

Three single questions on the subject of “optimizing conservation strategies” should be given priority:

1. The development of efficient transfer mechanisms to finance conservation and a system of benefit sharing for the utilization of agricultural genetic resources.
2. The establishment of practical, cost efficient methods of reproduction.
3. The determination of the necessary population size for both *in situ* and *ex situ* conservation, in order to prevent genetic drift as much as possible.

6.8.2 Analysis of the social, economical and political framework

The agricultural sector is highly economically controlled in most countries. There are also several international regulatory bodies that influence the conservation and utilization of agrobiodiversity. The following should be given priority:

- Studies of social and economic factors that influence the association of relevant players with agrobiodiversity.

- Analyses of the best national and international legal frameworks for the protection and utilization of agrobiodiversity and the resulting long-term consequences.

Important parts of this are:

- The results on agrobiodiversity of the increasing concentration of life-science industries. Can breeding of “minor crops” be guaranteed in the future?
- The question of how far different systems of intellectual property rights protection influence the availability of genetic resources.
- The international regulatory agreements (above all the Convention on Biological Diversity and the International Undertaking (IUPGR) of the FAO. Do they guarantee effective protection of agrobiodiversity? How can they be improved? How can they be coordinated and harmonized?

7 Sustainable utilization of agrobiodiversity as a political priority

There is a need to suitably express the enormous importance of agrobiodiversity for the food security of future generations, for the sustainability and stability of the agricultural ecosystems of the world, and as a source of original material for breeding and biotechnology innovations. Its conservation and sustainable utilization must be formulated as a political priority in all important areas of politics. The active utilization of agrobiodiversity must also be placed in the foreground as the first option for conservation. Agricultural production that is as diverse as possible can help to implement this. Special attention should be paid to the reliable, sustainable financing of utilization and conservation strategies. Delays or interruptions can lead to **irreversible** losses, as is the case when necessary regeneration measures cannot be carried through and accessions lose their vitality, or when ecosystems are destroyed that offer a habitat to rare components of agrobiodiversity. The irreversibility of loss needs to be taken into special consideration because it differentiates the area of “biodiversity” fundamentally from other environmental problems. Early warning systems, such as the Commission on Genetic Resources for Food and Agriculture (CGRFA) would like to introduce for plant genetic resources, gain special importance in light of these considerations (see **Serwinski** & **Faberová** 1999, **Hammer** et al. 1999).

The benefits achieved by diversity and also its endangered status must be made into a central aspect of practical and academic courses of study. In the academic area, there is a special need for high-quality instruction in taxonomy, agricultural ecology and genetics.

7.1 The conservation of agrobiodiversity

The conservation of a large part of worldwide *ex situ* collections is itself endangered. Therefore, priority should be placed on securing and providing financial support for existing collections. The regular regeneration of material is essential and must be made possible.

Collections that have been developed by different non governmental organizations (NGOs) (for example community gene banks in developing countries, or NGO collections in industrial and developing countries) should be included in funding considerations, as well as the gene banks at the research centers of the Consultative Group of International Agricultural Research (CGIAR). These collections should be networked in a global initiative leading to increased efficiency and cooperation. The existing collections must be supplemented according to the prevention principle (Noah’s ark principle).

Priority should also be given to the expansion of species collections in the centers of diversity. A Red List for endangered cultivated plants should be put together as a basis for the creation of suitable conservation measures and for their financing. The maintenance of endangered domesticated animal species and breeds must be included as a further important part of the efforts to conserve agrobiodiversity.

Since *in situ* or *ex situ* conservation is often the only possibility of preventing the total loss of certain agrobiodiversity components, these measures must be supported. Because of the decentralized distribution of these measures, the international political will to effect changes is particularly important. In many cases it is necessary to **avoid disturbing** locally-organized *in situ* or *on-farm* maintenance and utilization measures to maintain agrobiodiversity. In the past, disruption has often occurred through restrictive regulations about the exchange and distribution of seed or through agricultural advisors burdened with one-sided views about "modernization".
In order to bring valuable genes from genetic resources into elite material and to expand its genetic basis, sizeable and publicly funded pre-breeding programs (if possible with ties to gene banks) are necessary, together with basic evaluative work on genetic resources.

In the area of utilization of agrobiodiversity, the financing of secondary evaluations of genetic resources or the characterization of presently utilized agrobiodiversity has priority. Especially the study of resistances and specific characteristic traits should be given closer attention.

The following **concluding remarks** can be made. The large number of *ex situ* conservation possibilities shows us the intensive work done in this area. The relatively secure installation of such a system in the beginning phase, which at first involves only a functional long-term storage system for seeds, leads to unrealistic optimism about the following tasks. This is the main limiting aspect of this method. It is especially effective for the conservation of richly-structured major cultivated plant species.

In situ conservation is well-established in protected conservation areas. Networking between these areas leads to a stronger integration of ecological components. Almost all wild species, including the plant genetic resources among wild plants, can best be protected *in situ*.

On-farm conservation is a relatively new concept and long-term experience with it is not available. This method is especially promising for cultivated cross-pollinators and the large mass of the so-called neglected cultivated plants.

A combined approach can connect the different methods in an appropriate manner. Developments in the gene bank sector have led to the concept of the integrated gene bank (**Hammer** 1996). But there is presently no formally accepted method of conservation of genetic resources in Germany that makes use of both *ex situ* and *in situ* methods.

8 Biotechnology and genetic resources

Biotechnology has significant influence on plant genetic resources. On the one hand, it allows plant genetic resources to be better utilized as primary material for the improvement of cultivated plants, and, on the other side, biotechnology contributes to the more efficient use of the conservation methods themselves (**Conway** 1992, **Callow** et al. 1997). Both directions can be complementary.

8.1 In-vitro methods

In-vitro methods are employed for the conservation of vegetatively-reproduced species (garlic, potatoes, stalk cabbage, and others) as well as several varieties with unorthodox seeds and other samples that are difficult to reproduce. As opposed to conventional vegetative maintenance, the method guarantees freedom from pest infestation and diseases. Virus elimination is also possible. Rare varieties can be maintained in larger numbers and be prepared for re-introduction into *in situ* conservation.

Through somaclonal variation (**Larkin** & **Scowcroft** 1981), genetic changes can occur in the material, a development that is not desirable for true-to-type reproduction. Optimal conditions of cultivation can prevent the occurrence of genetic variation to a large degree, if not to one hundred percent (**De Langhe** 1984).

In vitro collections, especially for potatoes, but also for onions and stalk cabbage exist in Germany. The method is extremely labor and cost intensive and can therefore only be used for special material as a long-term storage possibility. *In vitro* conservation is also widely used by botanical gardens for the reproduction of rare species. For special breeding research projects, anther culture, embryo culture, protoplast culture (**Schieder** 1997) and embryo rescue also come into consideration.

8.2 Cryo-conservation

Cryo-conservation (storage in extreme deep freeze situations) is accomplished with liquid nitrogen at -196° Celsius (**Hammer** & **Hondelmann** 1997). It is suitable for seeds and leads to a dramatic prolongation of germination rates. For *in vitro* maintenance cultures, it is the choice of preference because somaclonal variation can be prevented.

But we still need strenuous research in the area of cryo-conservation (as well as seed storage) in order to establish this method as standard procedure. It can probably be used in the future for the security storage of duplicates. Within the last few years, it has been used for this purpose in the gene bank system of the United States. Because of the insecurity of the reproduction process, original samples must also be stored separately under the usual long-term storage conditions.

In any case, the cost of cryo-conservation is very high, especially for technical equipment. A constant supply of liquid nitrogen also has to be available at all times.

8.3 Molecular methods

Molecular methods can be employed to better characterize genetic resources. Above all, they help to measure genetic variation (**van Treuren** & **van Hintum** 2001. Beyond this, they are used to securely locate duplicates. Because of the large amount of material in gene banks and the high costs of reproduction, a search for undesirable duplicates is an efficient means of removing them from the cost-intensive reproduction and storage process. This is especially important for vegetatively-propagated species such as potatoes, or species (for example, fruit) that must be maintained in expensive field gene banks.

An overview of molecular and other methods for the measurement of genetic variation is given in Table 28. The large number of new methods can be seen at one glance. The morphological method for measuring genetic variation is often underestimated. The trained eye can see a large number of variations after many sample repetitions (the variation has been listed in the table as “low” for some reason). This can be reproduced well in repeated trials (listed in the table as “middle”). Such results can otherwise only be achieved with high-technology methods. Physiological and other characteristic traits, which can be applied to measure genetic variation, are also missing in the table.

TABLE 28: Advantages and disadvantages of several methods of measuring genetic variation (according to *FAO* 1996b)

Method	1	2	3	4	5	6	7
Morphology [a)]	slight	high	small number	medium	phenotypical characteristic	qualitative/ quantitative	low
Pedigree analysis [b)]	medium	-	-	good	degree of parent relationship	-	low
Isoenzyme [c)]	medium	medium	small number	medium	proteins	co-dominant	medium
RFLP (low copy)	medium	low	small number (specific)	good	DNA	co-dominant	high
RFLP (high copy)	high	low	high number (specific)	good	DNA	dominant	high
RAPD [d)]	high to medium	high	high number (random)	slight	DNA	dominant	medium
DNA sequencing [e)]	high	slight	small number(specific)	good	DNA	co-dominant/ dominant	high
Seq tag SSRs [f)]	high	high	middle number (specific)	good	DNA	co-dominant	high
AFLPs [g)]	medium to high	high	high number (random)	medium	DNA	dominant	high

a) Anon.1995a ; **b) Cabanilla** et al.1993; **c) Brown** & **Clegg** 1983; **d) Tingey** & **Del Tufo** 1993; **e) Sasaki** et al. 1994; **f) Saghai-Maroof** et al. 1993, **Zhang** et al. 1995; **g) Keygene** 1991

1= variation found, 2= throughput of samples, 3= examined loci/assay, 4= reproducible on repetition, 5= analyzed character type, 6= inheritance of examined character trait, 7= necessary level of technology

In conclusion biotechnology presents us with a new arsenal of methods suitable for the study of genetic resources and also for certain conservation techniques. These methods are usually cost-intensive and can only be utilized on a limited amount of material. But they are subject to rapid development and will, in the near future, be better suited for the extensive characterization and evaluation of large *ex* situ and *in situ* collections.

8.4 Gene technology

Gene technology increases the possible use of distantly-related trait carriers as donors for the desired characteristics. Gene technology's declared goal is to demote all biodiversity to the status of donors of desired characteristic traits. Plant genetic resources in the customary sense will still play a role since they remain the most important carriers, to both gene technology and also to tried-and-true traditional breeding processes.

9 International treaties and agreements

Above all, mention must be made of the UNCED process (Conference of the United Nations on Environment and Development - Rio de Janeiro 1992), which culminated in the Convention on Biological Diversity. In chapters 14 and 15, Agenda 21 included measures for the conservation and use of genetic resources. The financial mechanism that allows the developing countries to implement ecological conservation measures in the interest of global considerations is the Global Environmental Facility (GEF). It is the central financial instrument for the realization of the convention ratified in Rio. In 1994, the GEF was restructured and endowed with $ 2,02 billion for the years 1994-1997.

The global system of the FAO gives preference to plant genetic resources in its considerations. The International Undertaking on Plant Genetic Resources, which Germany has also joined (although with some reservations about plant genetic resources found in private hands), was ratified in 1983. Since then, a global system with an *ex situ* as well as an *in situ* network and a "Global Information and Early Warning System for Plant Genetic Resources" (WIEWS) has been put into place (see **Serwinski** & **Faberová** 1999).

The Organization for Education, Science and Culture of the United Nations (UNESCO) passed a resolution in 1970 for the program "Man and the Biosphere" (MAB). In it, projects for the protection of biodiversity and genetic material are grouped together in a network of biosphere reservations. The Ramsar Convention, an International Undertaking for the Protection of Nature 1971 (see Table 26), for the protection of wetlands became effective in 1976 in Germany. 29 protected wetlands are registered internationally. And, last but not least on this list, the Global Plan of Action (GPA) should be mentioned. It was ratified in 1996 in Leipzig.

Because of the important consequences they have had for plant genetic resources, the Convention on Biological Diversity, the International Undertaking for the Plant Genetic Resources and the Global Plan of Action for the Conservation and Sustainable Use of Plant Genetic Resources have been subjected to more in-depth study for this book (see also ITPGR 2001).

The basis for international action is global gene erosion. The most important reasons for loss of genetic diversity are summarized in Table 29.

TABLE 29: Reasons for the present loss of genetic diversity in agriculture according to the country reports (FAO 1996b)

Reason	**Number of countries that list these reasons**
Laws/politics	23
Unrest	6
Population growth[1]	46
Disease, weeds, pests	9
Environmental stresses	34
Eradication, land clearance[2]	62
Overgrazing	33
Reduced fallow area[3]	6
Overuse from agricultural systems	18
Displacement of local landraces	82

[1] including expansion of cities
[2] including loss of forest area and fires
[3] clearing by fire

9.1 The Convention on Biological Diversity

The preamble to this document already mentions *ex situ* and *in situ* measures. It states that ecosystems and natural habitats must be preserved as a basic requirement for the conservation of biological diversity (see **Schulze** & **Mooney** 1993). Vital species populations are to be conserved in their natural habitat or re-introduced into it.

Ex situ measures also play an important role in this convention, especially if the facilities are situated in the land of origin of the plant genetic resource. This shows the priority that should logically be accorded to *in situ* as opposed to *ex situ* measures according to the convention.

Articles 8 and 9 deal with conservation measures, article 10 with the sustainable utilization of plant genetic resources, and article 15 refers to the availability of these resources. Since plant genetic resources make up a large part of plant biodiversity, these articles are particularly important for the problems faced by biodiversity.

Article 8

This article deals with *in situ* conservation in 13 clauses.
a) A system of protected areas. Especially valuable for wild plant genetic resources.

b) Guidelines for protected areas. Especially valuable for wild plant genetic resources.

c) Conservation and sustainable use of important resources, within and outside of protected areas. Especially valuable for wild plant genetic resources.

d) Protection of ecosystems and natural habitats. Conservation in natural habitats is important, with support for populations and species. This is significant for genetic diversity.

e) The development of regions that border on protected areas. The goals are sustainable and ecologically-sound developments. *On-farm* maintenance doubtlessly belongs here.

f) The rejuvenation of damaged ecosystems. Regeneration of endangered species including wild plant genetic resources.

g) Minimizing the risks of genetically manipulated organisms. This deals with organisms with potential negative influence on the environment. Human health is to be taken into consideration.

h) The introduction of non-native species. It is often extremely difficult to control such species or to eliminate them. Many wild plant genetic resources belong to the adventitious species.

i) Present usage should be compatible with the conservation of biological diversity. Sustainable utilization is an important requirement.

j) Protection of the experience and rights of communities exercising traditional forms of life. The *on-farm* conservation of plants can be classified here.
k) Laws for the protection of endangered species and populations. This relates to wild plant genetic resources.

l) Control of negative influences on biological diversity. The appropriate actions are to be regulated or legislated.

m) Financial and other support for *in situ* conservation. In particular, developing countries are to be supported.

It becomes evident that only single clauses in the framework are relevant for the *on-farm* conservation of cultivated plant genetic resources, and that *on-farm* conservation is not explicitly mentioned. The importance of wild plant genetic resources is considered to be extraordinarily high.

Article 9

This article deals with *ex situ* conservation in five clauses.

a) Measures for *ex situ* conservation, especially in the lands of origin. It is often difficult to properly designate the countries of origin of cultivated plants.

b) Institutions for *ex situ* conservation are to be created in the lands of origin, if at all possible. For wild plants, this is appropriate, but hard to realize for cultivated plants, because of the reasons already mentioned.

c) Re-introduction of endangered species to their natural habitat. This is advisable for wild plants, but not necessarily effective for the *on-farm* conservation of cultivated plants, because these were not considered in the decision-making process.

d) Access to resources. Here, again, emphasis is on wild material. *Ex situ* measures are explicitly designated as temporary, an attitude that is far removed from present reality, considering the large number of cultivated plant samples stored in gene banks.

e) Financial and other support. Institutions for *ex situ* maintenance should be created for developing countries.
Ex situ measures are implicitly given the role of supporting character to other measures. The special problem of cultivated plants, which are very variable, is not dwelt with. It therefore still needs special attention.

Article 10

The problem of the sustainable use of plant genetic resources in particular, but also of all biological diversity, is of importance here, as later in the Global Plan of Action. Five clauses are included in article 10.

a) Conservation and sustainable use. These issues are to be included in the international decision-making process.

b) A plan of conservation measures compatible with plant utilization. Negative influences on diversity should be prevented this way.

c) Traditional cultural practices are to be protected and supported. The *on-farm* conservation of cultivated plants is included here.

d) Inclusion of local and indigenous population groups. The *on-farm* conservation of cultivated plants is also possible here.

e) Cooperation between government agencies and the private sector. Developing methods for sustainable use.

Sustainable use refers basically only to *in situ* conservation including *on-farm* maintenance. Questions about the sustainable use of *ex situ* material are not asked, since this material is obviously not considered to be sustainable (in other words, suitable for the future).

Access to genetic resources

Article 15 of the Convention on Biological Diversity contains seven clauses.

The most important is the guarantee of sovereign rights (**Svarstad** 1994), although, as already noted several times, this must be viewed with a certain skepticism, for it is difficult to ascertain the countries of origin for a large amount of cultivated plant material. It can also be complicated trying to assign countries of origin to certain especially valuable wild plants.

9.2 International Undertaking on Plant Genetic Resources of the FAO

The International Undertaking on Plant Genetic Resources 1983 begins with the precept that plant genetic resources are the "common heritage of Mankind". Because of this, they should be freely available for utilization and at the same time everyone has a common responsibility to conserve and maintain them. This basic approach evolves from the origin and evolution of the most important cultivated plants. For example, Italian corn can be traced back to a centuries-old process of selection and adaptation that took place in Italy. But corn was originally domesticated in Central America. The ways in which it traveled to Italy are still unclear and it is impossible to estimate the part played by other countries, especially those in northern Africa, southern Europe and western Asia. It is also impossible to precisely designate the countries of origin because of changing modern borders for the area of domestication in Central America. A second area of domestication in western South America must also be included in these considerations. The genealogical relationships between single modern corn varieties are much more complicated because extremely geographically heterogeneous material was used in their development. This example shows us that it is practically impossible to assign countries of origin to corn genetic resources. This is also true for many other plant groups. The geographical heterogeneity of cultivated plants has, for example, been worked out for Italy (**Hammer** et al. 1992).

The International Undertaking was the basis for national and international work with plant genetic resources for a long time. It supported a collective sense of responsibility toward a resource responsible for securing the nutrition of a steadily growing world population. There were some contradictions in the FAO system of plant genetic resources. For example, a concentration of landraces exists in the gene banks of those developed countries in which most plant breeding occurs, although the centers of diversity defined by Vavilov are in the developing countries. Because of this, critical alterations developed that caused worldwide agitation (among others, **Mooney** 1979, **Flitner** 1991, **Vellvé** 1993, **Shiva** 1993, **Heins** 1993). In addition to this, the International Undertaking only accepted the limited access to varieties consistent with plant breeders' rights according to the UPOV convention (**Anon**. 1984).

The International Undertaking is an agreement of intent that is not legally binding. Unfortunately, the FAO did not emphasize the importance of cultivated plants for "food and agriculture" energetically enough during the preparation for the Convention of Biological Diversity to further certain advantages of the International Undertaking through the legally binding Convention on Biological Diversity. Appropriate initiatives are now being taken toward the harmonization of these two important agreements for plant genetic resources. The first results appeared after more than ten years (see ITPGR 2001).

9.3 Global Plan of Action

The Global Plan of Action for the Conservation and Sustainable Utilization of Plant Genetic Resources for Food and Agriculture is based on the fact that world nutrition is not secure and that more than 800 million people suffer from hunger. In the next 30 years, the world population will in all probability increase to 8.5 billion people. A precisely-planned, comprehensive system is necessary to secure their nutrition. This system has to include plant genetic resources and their conservation and utilization in order to form a basis for the adequate production of food (FAO 1996b). Because the Global Plan of Action is the most recent of these agreements, it will be given more in-depth treatment here.

The Report on the State of the World's Plant Genetic Resources for Food and Agriculture (FAO 1996a), which was compiled from the single reports of more than 150 countries, showed a number of gaps and organizational weaknesses occurring during the conservation and utilization of plant genetic resources. These have resulted in a decrease of diversity *in situ* as well as *ex situ.* Interactions between the conservation of plant genetic resources and their utilization by plant breeders or farmers and gardeners are not highly developed. The advantages gained from plant genetic resources are not appreciated enough, at least not with all their implications, and we are far from a fair distribution of financial and other advantages reaped from plant genetic resources.

The Global Plan of Action had developed as a logical consequence of the Report on the State of the World. The 4th International Technical Conference of the FAO on Plant Genetic Resources in Leipzig ratified it formally on the 23rd of June 1996, together with the Leipzig Declaration that confirmed its implementation in the context of national activities.

The Global Plan of Action is considered a framework for activities on the local, national, and international level. Coordination, cooperation and planning should help to concentrate expertise and facilities. It is assumed that the Global Plan of Action will provide an important contribution to the Convention on Biological Diversity.

Important fields of endeavor of the Global Plan of Action are:

- securing the conservation of plant genetic resources for food and agriculture as the basis for world nutrition,
- supporting the utilization of plant genetic resources to aid development and to reduce hunger and poverty,
- supporting fair compensation for advantages gained from the use of plant genetic resources,
- strengthening existing programs, supporting institutional facilities and fostering expertise.

The Global Plan of Action includes 20 activities, which are divided into 4 groups, listed below.

9.3.1 *Ex situ* conservation

As has already been pointed out, the loss of genetic diversity is very high worldwide (see Table 29). Therefore, effective *ex situ* conservation is absolutely necessary.

Despite the fact that now more than 100 gene banks exist, only 30 countries have secure long-term storage. Because of this, many *ex situ* collections are in bad shape, also because of relentless pressure towards rationalization at all costs (**Clark** et al. 1997). According the official wording of the Global Plan of Action, at least one million samples have to be urgently reproduced. Our experience suggests that the number is actually much higher (see Tables 30 and 31). Roughly 50% of all samples in gene banks are also estimated to be duplicates (**Lyman** 1984), which further reduces the actual number of unique accessions. In botanical gardens, a number of varieties with great value for food and agriculture are also being maintained.

TABLE 30: Analysis of the problems of *ex situ* collections worldwide (according to *FAO* 1996a)

			Problems of accessions					
Region	**Number of countries**	**Number of accessions**	**1 %**	**2 %**	**3 %**	**4 %**	**5 %**	**6 %**
Europe	24	1,468,102	50	35	37	20	35	36
Near East	14	271,343	60	30	35	22	35	21
Africa	21	279,659	70	20	42	22	48	2
Asia	16	1,307,543	50	20	32	22	31	22
America	20	1,171,146	55	22	50	45	37	9
Total	**95**	**4,495,793**						

1= bad or nonexistent long-term storage, 2= problems with cross-pollinators, 3= financial problems, 4= technical problems, 5= staff problems, 6= no specific problems

TABLE 31: Need for regeneration of the largest national *ex situ* collections in the world (according to *FAO* 1996a)

Country and institutions	Accessions	Storage capacities	Need for regeneration
China Institute of Crop Germplasm	300,000	long-term storage	not required because gene banks is only 8 years old
USA National Seed Storage Laboratory	268,000	long-term storage, capacity for up to 1,000,000 accessions	19% must be regenerated, difficulties obtaining staff & with cross-pollinators
Russia	177,680	no long-term	therefore need for

Country and institutions	Accessions	Storage capacities	Need for regeneration
VIR		storage	frequent regeneration
Japan NIAR	146,091	long-term storage	4% must be regenerated, no problems
India NBPGR	144,109	new gene bank for 600,000 accessions is being built	63% must be regenerated, no specific problems reported
Korea, Republic Suwon	115,639	long-term storage for 200,000 accessions	50% must be regenerated, problems with cross-pollinators
Germany IPK, Gatersleben	103,000	long-term storage	major problem is need for staff
Canada PGRC	100,000	long-term storage	no specific problems
Brazil CENARGEN	60,000	long-term storage for 100,000 accessions	64% must be regenerated, financial problems, problems with infrastructure and lack of staff
Germany BAZ, Braunschweig	57,000	long-term storage	lack of staff
Italy Bari	55,806	long-term storage	no specific problems
Ethiopia	54,000	long-term storage	8% must be regenerated, financial problems, lack of staff and land
Hungary Institute for Agrobotany	45,833	long-term storage	40% must be regenerated, no specific problems
Poland Plant Breeding and Acclimatization Institute	44,883	long-term storage	3% must be regenerated, no specific problems
Philippines NPGRL	32,446	long-term storage	no specific problems

The following program points are underlined:

- Support of existing *ex situ* collections through inclusion in a rational, effective and flexible system, capable of expansion. All countries without a long-term storage system can keep their collections in international or regional gene banks. The rights of the single countries to their material can be guaranteed through appropriate agreements.
- Those million gene banks accessions that need to be reproduced worldwide should be regenerated. Unique samples and samples from long-term storage have priority over others.
- Material should be collected to close gaps in existing collections. Also, certain regional and neglected plant groups are to be added to the collections, as well as samples from countries that have not yet been categorized.
- Field gene banks, *in vitro* storage and new technologies should be further developed so that plant groups that are difficult to reproduce through seed can be maintained. Botanical gardens can play a more important role, especially for plant groups that are not adequately represented in conventional gene banks.

9.3.2 *In situ* conservation

Natural ecosystems are home to numerous plants that are of great importance for food and agriculture (**Davis** et al. 1994). But even the resources found in the 8,500 national parks on the world are not secure. Many farmers and gardeners are maintaining plant genetic resources by growing traditional material, especially in the developing countries (**Harlan** 1995). These resources have been more or less neglected in the global studies made to date. The Global Plan of Action demands the following measures:

- A comprehensive overview of plant genetic resources for food and agriculture must be made. Country and regional studies are urgently needed in order to do this.
- *On-farm* management should be supported. Ties between farmers and gene banks should be intensified. Landraces from the gene banks should be activated and the farmers' plant selections made available.
- In crisis situations, many adapted landraces are lost. The international community is challenged to develop methods of obtaining seeds of landraces in order to guarantee support for the re-establishment of local agricultural systems after the crisis is past.
- The *in situ* conservation of wild species related to our cultivated plants and other prospectively useful species deserves support. Training of local talent is necessary

9.4 The utilization of plant genetic resources

The utilization of plant genetic resources is a central problem. In the developing countries, the methods of using plants are relatively simple. There is also generally a lack of scientific expertise (see **Rao** & **Hodgkin** 2002). In the countries with highly developed plant breeding, the gap between genetic resources and the elite varieties is often so large that breeders are very hesitant about utilizing material if special support is not offered through breeding research and pre-breeding programs.

The following measures are included in the Global Plan of Action:

- The characterization and evaluation of material should be markedly intensified. Core collections are to be consulted to give a firmer basis to these evaluations.

- The use of genetic resources must be mobilized through long-term programs. At first, this could be limited to 15 crop species of regional as well as international importance.
- Sustainable agriculture should be supported through diversification of crop species and the full utilization of infraspecific diversity. Important measures are: studies of genetic uniformity and its results, studies of measures that pertain to the diversity of crop species, increase in the number of variety mixtures, improvement of the utilization of genetic resources as part of integrated pest management, and support of decentralized plant breeding strategies with farmer participation.
- The development and marketing of neglected cultivated plants and other species can be assisted by recording data about them, by developing of methods of sustainable management as well as marketing and post-harvesting procedures, and by supporting measures for the development and utilization of neglected species.
- Seed production and distribution should be aided by encouraging the participation of all seed producers. This means expanding local seed production and systems of distribution, including valuable material from *ex situ* collections in reproduction as well as distribution, and reviewing certification guidelines.
- New markets for diversified landraces and products that support diversity are to be developed. Particular care should be paid to the creation of suitable niche markets.

9.5 Institutions, capacity-building and training

Cooperation between different geographical areas is essential for the Global Plan of Action. In the regions and sub-regions, there are usually a large number of plant groups and other plant genetic resources that are not limited to one country. Because of this, cooperation on the regional and supra-regional level is as much a necessity as work on the national level.

The following measures are part of the Global Plan of Action:

- The expansion of strong national programs should be supported as an important basis for a functional global plan.
- Support for networks of cooperation in the area of plant genetic resources, including new networks for the Pacific area, the Caribbean, Central Asia and Caucasus, West and Central Africa, East Africa as well as the islands of the Indian Ocean. Networks for single crops must also be improved. The plan stresses the need for strengthened cooperation with international agricultural research centers.
- Inclusive information systems for plant genetic resources are to be expanded on a national level. Global coordination exists through the world information and early warning system of the FAO.
- The early warning system of the FAO must be further developed to point out incipient dangers of gene erosion. This system should be examined and expanded to meet this need. Activities on local and national levels are especially important.
- The training and further qualification of people working with plant genetic resources should be stepped up. It is especially important to include farmers working on a practical level in these training programs. The role women farmers play in the conservation of genetic diversity is often overlooked.
- Public relations must be bettered. The inherent and irreplaceable value of plant genetic resources is not yet anchored in the public mind.

9.6 Harmonizing and coordinating international agreements

Since the Convention on Biological Diversity contradicts the International Undertaking of the FAO in some aspects, but the Undertaking has been ratified as a central, legally binding element, it has become necessary to institute changes in the International Undertaking.

The Commission on Plant Genetic Resources of the FAO (CPGR, now renamed as the Commission on Plant Genetic Resources for Food and Agriculture, CGRFA), has therefore come to a consensus to reformulate the International Undertaking so that it corresponds to the Convention on Biological Diversity. This coordination process began with an extraordinary meeting of the CPGR in November of 1994 in Rome. A first draft was prepared in which farmers' rights and the availability of plant genetic resources were taken into consideration, especially regarding *ex situ* collections, which existed before the Convention on Biological Diversity. After the completion of the coordination process, the International Undertaking of the FAO will be nominated for status as the official protocol of the Convention for Biological Diversity (see ITPGR 2001).

Thus the special status of plant genetic resources for food and agriculture is granted international, and accepted legally binding.

10 A concluding word about the need for action and effective beginning steps

Plant genetic resources belong to that part of biodiversity designated as economically important. Only with the aid of a comprehensive concept, which includes plant genetic resources for food and agriculture as well as the other potentially important plants, can the problem of conservation (which begins with gene erosion) be solved.

Single factors should be evaluated specifically, and a differentiated approach is needed to take into account *ex situ* as well as *in situ* conservation in combination with the different plant groups.

10.1 Future need for plant genetic resources

According to **Frese** (1996), two basic conservation strategies for *ex situ* measures exist:

- The so-called "Noah's Ark principle" is based on the basic worth of all resources endangered through gene erosion. This material is maintained in *ex situ* collections. Through evolutionary processes such as, among others, domestication, cultivated plants have been subject to a number of gene combinations, more so than most other plant groups. These complicated combination of characteristic traits are conserved in separately stored samples. It is cheaper and more practical to fall back on original stored samples, with characterized and evaluated character traits, than to find and combine single genes from an artificial population.

- Another approach that can be termed a population-genetics approach, and is also supported by some gene-technologists. It is based on the assumption that only a relatively minimal amount of plant genetic resources is necessary if populations are compiled in such a manner that all the genes and alleles of a plant species are represented. Unfortunately, the requirements for such a process, even with the use of molecular techniques, do not presently exist. The futurist vision of gene banks evolving to institutions that can efficiently manage a few populations of plant genetic resources with little outlay (**Frese** 1996), can develop into an extremely dangerous concept that limits important future options. This is especially true in our present era of budget cutting that tends to evaluate future scenarios as today's reality.

Despite the scientifically attractive population-genetics approach, we should begin with the principle of Noah's ark, which combines both *ex situ* as well as *in situ* conservation in further strategies.

With the further development of scientific and technical possibilities, the need for various plant genetic resources will increase. Therefore, all effort should be made to cover this future need by utilizing both *in situ* as well as *ex situ* maintenance. The results of unabated gene erosion must by all means be reversed.

10.2 Necessary strategy to meet demand

The Global Plan of Action is considered the big success of the 4th international Technical Conference on Plant Genetic Resources of the FAO (**Borchert** 1996). On the other hand, groups such as non-governmental organizations (NGOs), criticize that the plan is not very practical, and that the suggestions made in it are not suitable for fighting the actual causes of gene erosion.

Future strategy should orient itself toward this plan of action and at the same time attempt to fill the gaps in it. For the interplay of international powers, the

Conventional on Biological Diversity is, of course, centrally important. For cultivated plants, the International Undertaking of the FAO has been given ample consideration.

These basic agreements make it possible to set goals in a suitable manner for this problem.

The **global** structure and quality of plant genetic resources should dictate specific methods of proceeding to deal with conservation problems. Wild growing resources must be differentiated from cultivated plants. Wild plants can be further divided into wild plants and weeds. Weeds are a separate category because they inhabit agro-ecosystems and therefore form a borderline category to cultivated plants.

The basis for a strategy concept is given in Table 32. This concept is based on the methods of conservation (*ex situ, on-farm, in situ*) as well as on the type of diversity, species diversity and diversity of the ecosystem.

It becomes obvious looking at this table that there is one practical possibility for the conservation of the unbelievably large **genetic diversity of the most important cultivated plants**: through gene banks. *On-farm* maintenance can only take care of a part of the variability of the most important, richly-structured cultivated plants. It is unrealistic to assume a substantial expansion of the capacities of gene banks. A better solution is more effective use of the existent space for 6 million samples in gene banks.

TABLE 32: Conservation methods for different categories of diversity rated by their importance for specific groups of diversity (changed, based on *Hammer* 1998a)

Method of conservation	***ex situ* (genebanks)**	***on-farm* (agro-ecosystems)**		***in situ* (other ecosystems)**
Category of diversity		**Developing countries**	**Developed countries**	
Infraspecific diversity	C** R* W**	C*** R*** W***	C** R* W*	C° R*** W*
Diversity of species	C* R* W**	C*** R*** W***	C** R* W**	C° R** W*
Diversity of ecosystems	C° R° W°	C*** R*** W***	C* R** W***	C° R** W*

Explanation: the number of stars indicates the relative importance of the methods for the various diversity groups

C= **C**rop species

R = Wild **R**elatives of Crop Species

W = **W**eeds

° = no importance

* = low importance

** = important

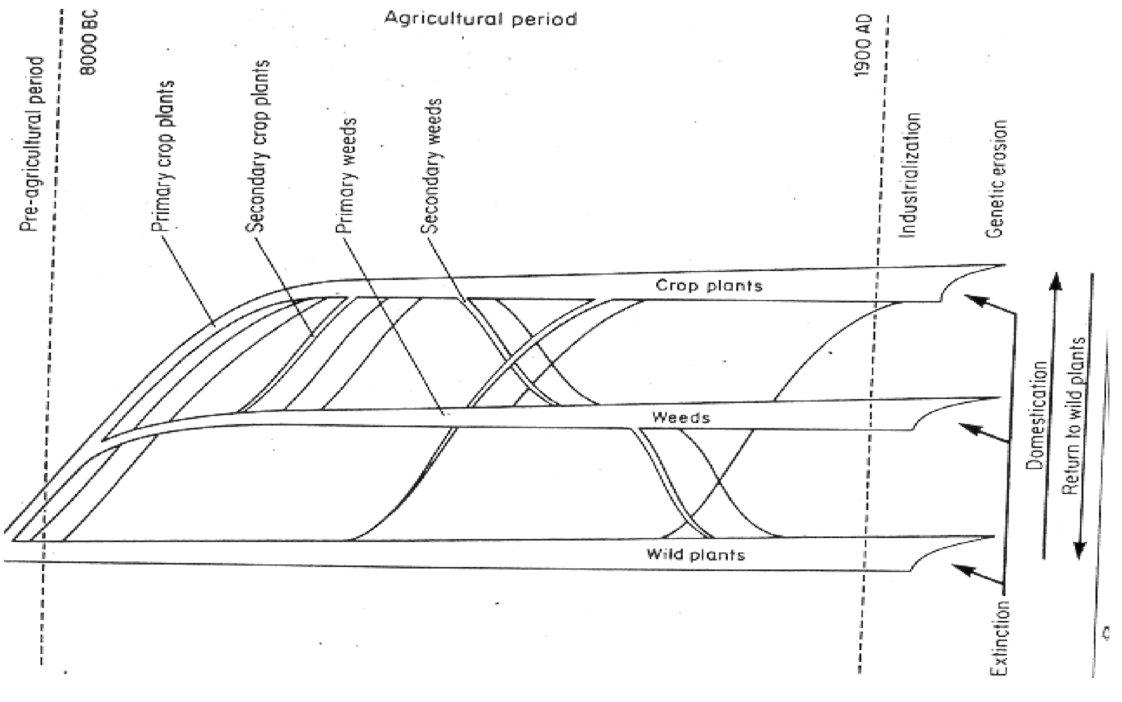
*** = very important

For the diversity of cultivated plant species, i.e. **the diversity of the species themselves**, *on-farm* conservation is the best possibility. Traditional farming plays a central role here. E*x situ* institutions can also contribute, but they will never be in the position to store the entire species diversity of cultivated plants. They will have limit themselves instead to a capacity of some 2,000 species with high variability. For the remaining 5,000 species, suitable niches must be found through *on-farm* maintenance. Effective systems of data collection of the species diversity of cultivated plants are necessary to prevent heavy losses.

The **diversity of ecosystems for cultivated plants** is only important in terms of *on-farm* conservation. But the relatively limited *on-farm* maintenance possibilities make this ideal option impractical. To pass through this bottleneck, the *ex situ* conservation of cultivated plants becomes an absolute momentary necessity.

For the **weeds** among genetic resources, *on-farm* methods are the best conservation methods available, although they are not ideal. For genetic diversity and, in some cases, species diversity as well, *ex situ* methods are necessary to protect richly-varied weed groups and endangered species. This is especially true of weeds of the convergent development type (for example, *Agrostemma githago*), which cannot find enough niches in modern agriculture.

Fig. 9: Plants under human influence and evolution of weeds.
***K. Hammer* et al. (1997).**



In any case, the **related wild species of cultivated plants** can best be protected *in situ.* Material should only to be taken into *ex situ* conservation if it needs certain types of protection. The goal should remain: reproducing these groups for a subsequent reintroduction into natural ecosystems. *Ex situ* measures can heighten security for the genetic diversity of certain wild species. Some of the related wild species are maintained *ex situ* in order to satisfy the need for research and breeding material. Through these *ex situ* measures, wild stands of the plants are protected, since only a small portion of seed or other material is taken from them.

It is obvious that *in situ* conservation is the method of choice for the largest percentage of **wild plant genetic resources**. Not only because it is the most adapted, i.e. the most natural method, but also because *ex situ* institutions would have to work with extremely large grow-outs, which would demand a thousand times more outlay than the present, which is already large enough. Even dramatic developments and modern methods cannot make this possible.

It has become evident that only a balanced relationship between *ex situ* and *in situ* conservation can guarantee security for plant genetic resources. A diversified method of approach, taking into account the evolution of the resources, their systematic specialties and the method of conservation, is necessary. Specific strategies can then be developed.

The framework for progress is formed by international contracts and agreements, which we should consider to be capable of expansion, if we look at the most recent hesitant movements in the international sector as a result of the conference in Rio. But a coordination of these treaties is also definitely needed. The initiatives taken by the various countries as a result of these agreements should be influenced by the present rapid increase in gene erosion.

World strategy is also applicable to Europe. Specific instruments are the European Union Ordinance Nr. 1467/94 and Nr. 2078/92. The European Cooperation Program for Plant Genetic Resources (ECP/GR) also plays an important role. Priority is given to the creation of a common research and conservation strategy for plant genetic resources in Europe.

National programs are the basis for the Global Plan of Action (see Table 33).

TABLE 33: Creation of national programs for PGRFA according to the suggestions of the sub-regional meeting in preparation for the 4th International Technical Conference. Approximately 55 countries have national programs and another 20 countries have a certain amount of coordination (according to FAO 1996b)

National programs for plant genetic resources for food and agriculture (PGRFA)	
Goal	
Contribution to national development, food security, sustainable agriculture and the conservation of biodiversity through the conservation and utilization of PGRFA	
Functions	
Development of national measures and strategies Creation of basic building blocks for regional and international cooperation	Coordination of national activities
Activities	
Cataloging, discovery and collecting Maintenance *in situ* and *ex situ* Characterization and evaluation Utilization Breeding Seed production and distribution Documentation and dissemination of information	Education and development of capacities Research Fundraising Lawmaking Regulation of access and exchange of genetic resources Public relations
Partner	
Ministries and government representatives Universities, research and other educational institutions Non-governmental organizations (NGOs), farmers`groups	The private sector and semi-governmental companies Regional and international organizations and networks

In **Germany**, there is an urgent need for a national program to be worked out and set into practice. This program must not only fulfill administrative and institutional regulations, but must also be based on the aforementioned scientific principles. Basic structures for this already exist (see **Bommer** & **Beese** 1990, **Begemann** & **Hammer** 1993, **Thoroe** et al. 1994, **Oetmann** et al. 1995).

Since the areas of responsibility for plant genetic resources are found in different ministries, a coordinated modus operandi is necessary between the main players, the Ministry of Food, Agriculture and Forestry (BML), the Ministry of Environment and Reactor Safety (BMU), the Ministry for Education, Science, Research and Technology (BMBF) as well as the Ministry for Economic Cooperation and Development (BMZ) for international questions. Political willingness to carry this through must be present in order to bring it into effect. Otherwise, the need for action and necessary measures have already been listed in detail in the German country report for the 4th International Technical Conference of the FAO in Leipzig in 1996 (**Oetmann** et al. 1995). The following important points are called for:

- the examination of relevant laws and regulations,
- the inclusion of German collections in the worldwide network of the FAO,
- the creation and expansion of a German documentation system,
- the development of a collection strategy for the further expansion of existing collections,
- the further development of *in situ* conservation in natural habitats,
- the extensification and diversification of agriculture,
- support for products and processes that conserve resources,
- the creation of improved scientific qualification possibilities,
- the extension of the traditional working areas of botanical gardens and
- the improvement of public relations and media work.

Further measures pertain to agriculture and horticulture, to forestry as well as to Nature and environmental conservation (*in situ* conservation).

11 Synopsis

In **conclusion** we can say that within the framework of international, European and German contracts, agreements and laws, plant genetic resources should be consigned to the appropriate method of conservation (*ex situ, in situ, on-farm)* according to the scientific basis of biodiversity (genetic diversity, species diversity, ecosystem diversity) and the status of evolution (cultivated plants, weeds, related wild plants).

Up until now, the fact has usually been overlooked that Germany is fairly rich when it comes to native genetic resources. This is especially true for ornamentals, medicinal plants and seasonings, woody plants including fruit trees, and fodder plants. Vegetables, plants containing starch and sugar, and pulses, i.e. plants that are particularly important for human nutrition, are much less numerous. The primary domestication and a large part of the further evolution of these group members occurred outside of Central Europe. If we concentrate too much on these important cultivated plants in a worldwide context, we see a distorted picture of the resources situation in Germany.

Single plant families often represent different areas of utilization, for example as fodder plants and at the same time as pulses. Their evaluation as plant genetic resources should therefore also be differentiated. The examples from Germany show that one region can be classified as being poor in genetic resources with regard to one area of utilization, and rich in another.

On-farm conservation is a special form of *in situ* conservation based on the groundwork of traditional farming and gardening methods.

According to first estimates, the plant genetic resources now found growing in fields and gardens account for some 25% of the diversity that was recorded in the first half of the last century. This includes not only a loss of species but also genetic infraspecific loss within richly-structured cultivated plant species. There is a definite north/south axis as to the availability of resources *on-farm*. Relatively few plant genetic resources can be found *on-farm* in modern industrialized countries.

This is the case for Germany. Here, the total cultivation of traditional varieties is very limited. Gene erosion has already reached more than 90%. But the cultivation of traditional material must still be viewed with some differentiation. Good possibilities for grasses and fodder plants exist, and traditional fruit varieties are also present in variety in various culture forms.

Crop plants are generally limited in their diversity, but horticulture conditions offer positive possibilities through the presence of numerous niches in which plants can persist. This is a general observation that also holds true for Germany.

More and more members of the informal sector are joining traditional cultivators in agriculture and horticulture. They are cultivating traditional varieties from different and varying motives that often go beyond purely economic reasons.

Large *ex situ* institutions have evolved, especially in the last 30 years, in order to protect those richly-structured cultivated plants that are highly endangered through gene erosion. They contain an impressive abundance of samples of the most important cultivated plants.

Some 60% of the diversity of related wild species and cultivated forms of the most important crops can be found in *ex situ* collections. The largest part of the material is present in gene bank collections. But this estimate must also be further differentiated. For some crops such as spiked grains and sugar beets, the largest part of the material is in *ex situ* maintenance. For grasses and fodder plants as well as medicinal and seasoning plants, much less material is preserved. The utilization as well as the distribution and the importance of each group of cultivated plants are responsible for these differences.

For *ex situ* maintenance, there is a typical north/south dividing line: large collections in the industrial countries, and relatively small capacities in the developing countries. Crop plants are much better represented in the gene banks than horticultural plants. Strangely enough, there is a correlation between this situation and the reproduction of the plants: most of the crop plants are annuals, and tend toward self-pollination, which makes them easier to reproduce.

Collections of wild plants in gene banks are relatively small. There is great need for wild material and character traits that allow further breeding improvements of highly-domesticated cultivated plant groups. This material is added to gene bank collections primarily to make the material easily available to breeders and researchers. Occasionally, protection of the plants also plays a role. The extensive experience gained over the years by botanical gardens in this area must by all means be taken into consideration.

Ornamentals are often maintained in botanical gardens and arboreta *ex situ*. The activities of NGOs are becoming more important in this field.

German *ex situ* collections contain more than 90% of the available variability of native cultivated plants. Also included in these collections is material that originated in other geographical zones, but in most cases is not available there any more. Re-introduction programs can help to balance this problem. Nonetheless, the material must continue to be maintained *ex situ* to guarantee necessary security as an international undertaking.

Possible conservation methods become evident within the framework of the qualities listed above.

Numerous variations on the theme of *ex situ* conservation let us see an intensive amount of work in this sector. The relatively secure installation of this system in the beginning phase (basically, it only requires a usable long-term seed storage facility) leads to undue optimism about the amount of follow-up work, such as reproduction and research, required to keep the system functional. This quickly shows the limitations of the method. *Ex situ* conservation is particularly required for highly-structured cultivated plants.

In situ conservation is well established in protected areas. Networking between these areas leads to stronger consideration of ecological components. Almost all wild species can best be protected in this manner.

On-farm conservation is a relatively new concept. Long-term experience is not yet available. This method shows promise for cross-pollinating plants and for most of the so-called neglected cultivated plants.

A combination of these methods can bring the different conservation measures closer together. Developments in gene banks have led to the concept of the integrated gene banks. But, in Germany, a coordinated method of conserving genetic resources using both *ex situ* and *in situ* measures has not yet been approved.

A **critical evaluation of conservation measures** must take the different aspects that form the basis of these measures into account.

From the differing perspectives of user and conserver, but also from those of other groups, the basis strategies have both advantages and disadvantages. The advantages of *in situ* conservation, which maintains a large abundance of species and at the same time guarantees further evolutionary adaptation, are undisputed.

The access possibilities for *ex situ* material are viewed as positive. A large amount of material, above all in the infraspecific area, of the important crops can be secured through *ex situ* methods.

On-farm conservation can be seen as a mixed procedure, with economic aspects in the foreground.
With regard to the different conservation strategies, specific advantages and disadvantages exist for each. Concentration on one strategy alone cannot do full justice to the conservation and utilization of plant genetic resources.

The financial evaluation of plant genetic resources is still in the beginning phase. *Ex situ* measures are relatively costly, but useful estimates for *in situ* measures do not exist yet.

Biotechnology, a new area of biology, opens new possibilities for the conservation and utilization of plant genetic resources and at the same time provokes us to make new prognoses of the future importance of these resources.

Biotechnology offers us a new arsenal of methods for the study of genetic resources, but also for certain conservation techniques. These methods are generally very expensive and can only be used on a limited amount of material.

But they are subject to rapid change and will certainly be better suited in the future for the characterization and evaluation of numerous *ex situ* and *in situ* collections.

Gene technology increases the possible use of distantly related trait carriers as donors for the desired characteristics. Gene technology's declared goal is to demote all biodiversity to the status of donors of desired characteristic traits. Plant genetic resources in the customary sense will still play a role since they remain the most important carriers, to both gene technology and also to tried-and-true traditional breeding processes.

Important **international agreements and conventions** exist that are important for the conservation and utilization of plant genetic resources. Included among these are the Convention on Biological Diversity, the International Undertaking of the FAO and the Global Plan of Action of the FAO.

During the process of securing and utilizing plant genetic resources, it has become evident that resources for food and agriculture (PGRFA) need different attention and methods than other resources, for example those for the pharmaceutical industry. A coordinating process for the different international agreements and conventions is absolutely necessary, and has already begun to be put into practice. The Treaty, adopted in November 2001 by consensus of the United Nations Food and Agriculture Organisation's 140-member nations, is the highest international law addressing the conservation of plant genetic resources.

Despite the necessity for improving the details of these international agreements and conventions, they form a significant basis for further work with plant genetic resources.

12 Abstract

The **need for action** regarding plant genetic resources can be deduced from our present as well as our future need for them. Presently, they are widely utilized. It is not feasible that this need will become smaller in the future, even with the help of modern technologies.

Within the framework of international, European and German contracts, agreements and laws, plant genetic resources should be consigned to the appropriate method of conservation (*ex situ, in situ, on-farm)* according to the scientific basis of biodiversity (genetic diversity, species diversity, ecosystem diversity) and the status of evolution (cultivated plants, weeds, related wild plants).

Ex situ measures are absolutely necessary for richly-structured cultivated plant species, and weeds of a convergent type of development. *On-farm* methods must be used to maintain the species diversity of cultivated plants, while wild plants should in most cases be maintained *in situ*.

The best method for the prevention of heavy losses through gene erosion is through a complementary approach to the different measures. The demand for a complementary approach must also be made in Germany, including the different ministries in concentrated action.

Plant genetic resources are always a global problem. The noble principle of the “heritage of Mankind” and the resulting duties should at least be respected and upheld by those countries with the necessary financial capabilities.

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