Genetic Resources and Modern Agriculture

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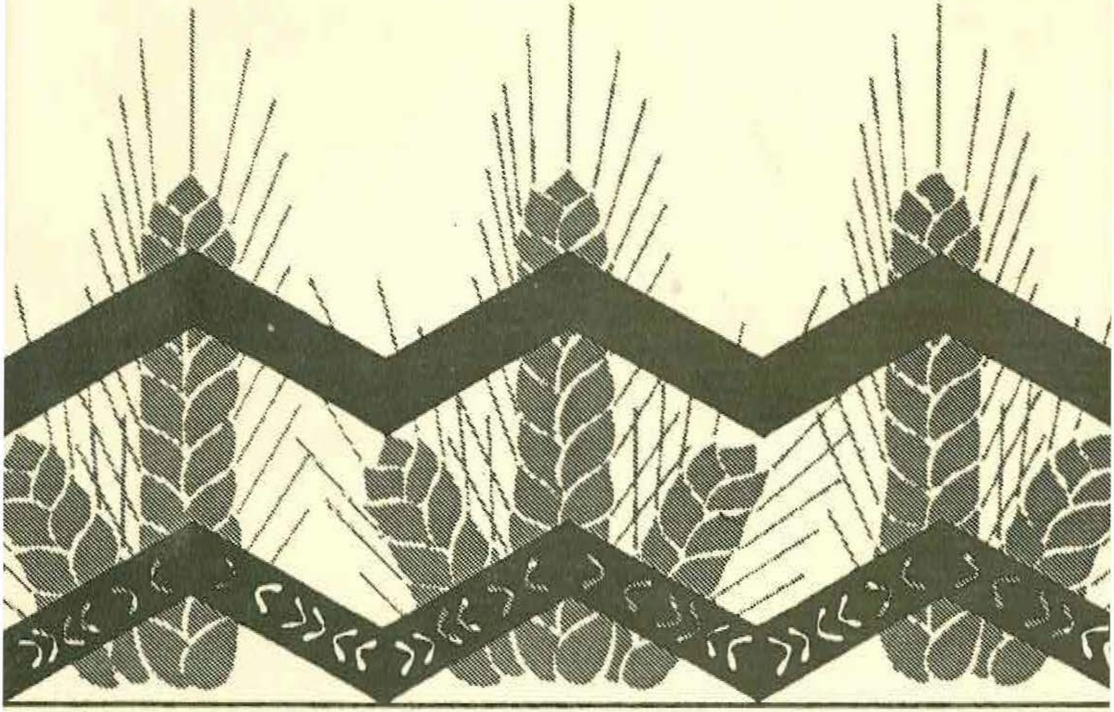

The International Centre of Insect Physiology and Ecology

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SUMMARY

The primary sources of genetic variability that have been stored in genebanks and utilised to stimulate and promote plant breeding in agriculture are mutations accumulated in landraces and introgression of genes from exotics.

Innovative germplasm conservation and handling methodologies for *in situ* and *ex situ* preservation of genetic resources are not available to make possible the optimal maintenance and use of the diversity of wild weeds, arable crops, fruit trees, forest trees, and symbiotic gene pools that can also be applied in developing countries.

For many crops, their genetic resources have proved inadequate for significant crop improvement. However, for crops such as rice, maize, cowpea, soybean, amaranth, root and tuber crops, the tropical and sub-tropical fruits which are mainly grown in economically-emerging countries, the collected and stored genetic resources (although incomplete) have been utilised to breed useful genotypes that have made significant improvements in crop productivity.

Recent progress in biology and analysis of the constraints that limit crop productivity have indicated that in some tropical and sub-tropical areas where cropping is difficult, agriculture systems based on multiple cropping and agroforestry may be convenient for sustainable land use in which crop cultivars can make complete use of environmental resources.

Efficient strategies are needed for the collection, conservation, evaluation and use of genetic resources for breeding crop cultivars to be grown under multiple cropping and agroforestry systems.

Genetic resources represent a universal cause, and awareness for their conservation should be promoted at all levels of human activity, to ensure their availability and use for the genetic improvement of crop cultivars that will face the technical and biological problems posed by current and future agricultural systems.

1 INTRODUCTION

Genetic conservation is one of the targets of present day agricultural research. The need arises from either human pressure on natural ecosystems, which leads to destruction of wild species of plants and animals, or the spread of high input agriculture which promotes the loss of variability in crops (Simmonds, 1979). Estimates indicate that about 5% of the angiosperm flora of the world (20,000 species) is in danger of extinction (Heslop-Harrison, 1974). Forest tree formations are being lost at the rate of 11 million ha per year in the tropical zones of America, Africa and Asia, but only less than 10% of that surface is being reforested (Swaminathan, 1983). Because only one out of six of the tropical species has been given a scientific name, we may not even know what we are losing.

Obviously the pattern is not restricted to forest plants. For example more than 250 wheat land-races grown in Italy at the beginning of this century have completely disappeared (Scarascia Mugnozza and Porceddu, 1972); and in Greece, 95% of all the wheat material in use in 1940 has been lost forever (Bennett, 1970).

The World Conservation Strategy was proclaimed six years ago by the International Union for the Conservation of Nature (IUCN), the United Nations Environmental Programme (UNEP) and the World Wildlife Fund (WWF), with the cooperation of the Food and Agriculture Organisation of the United Nations (FAO), and the United Nations Educational Scientific and Cultural Organisation (UNESCO). It considers genetic diversity a 'buffer against harmful environmental changes and the raw material for much scientific and industrial innovation', the preservation of which is 'both a matter of insurance and investment, and a matter of moral principle'. In spite of its importance, the pool of plant genetic diversity is being rapidly destroyed or depleted; and this is occurring at a time when human populations are demanding more food and consequently more productive crops and better products.

Through plant breeding, mankind can modify the genotypes of cultivated plants; genes responsible for desired characteristics are first identified among the existing genetic resources and then transferred in suitable materials to form new varieties. The enormous importance and economic value of plant genetic resources, which have formed the basis for the enhancement of agricultural production in recent decades, is shown in Table 1, through the changes in average world production of seven important crops. A wealth of examples of successful use of plant genetic resources, both from cultivated and wild species, is contained in the scientific literature (Appendix I). These examples record the improvement in crop quality and productivity, tolerance to environmental stresses, resistance to insects, nematodes and fungal, bacterial and viral diseases, etc. that have been achieved.

Table 1. Changes in average worldwide yield of seven important crops (kg/ha)

Crop	1961–65	1969–71	1974–76	1982
Wheat	1209	1540	1684	2009
Barley	1466	1875	1946	2068
Rice	2038	2331	2471	2871
Maize	2170	2472	2722	3465
Soya	1144	1487	1538	1772
Beans	916	961	1070	1142
Potato	11,939	13,855	13,895	14,421

Source: FAO Production Yearbooks.

Recently there have been new concerns which called for more attention to genetic resources. As a matter of fact, crop cultivation is spreading into areas subjected to environmental hazards and to soils containing toxic compounds. New varieties, bred for specific conditions using cultivated and exotic gene pools, are needed. Furthermore, the increases in grain production, derived mainly from an improvement in the harvest index in cereals, have brought the economical yield of these crops near to the potential yield ceiling. Entirely new gene combinations, such as those contained in wild species, are therefore needed if the crop biological yield is to be improved further. There is a need to reduce the length and cost of the conventional breeding procedures used to constitute new cultivars.

The use of male sterility genes is one way to lower the cost of the hybridisation process. Cytoplasmic male sterility has been identified in rice, allowing the commercial production of hybrids which are deeply modifying rice cultivation in countries such as China and the Philippines. Would it be possible to find or introduce similar genes in other crops? The growing concern about the effects of fertilisers and pesticides on the ecosystem indicates that the plant breeders should select and constitute crop cultivars which are less dependent on high inputs of agrochemicals. This will require a large provision of those genes which enable varieties to make full use of the available natural resources and also to be genetically resistant to both biotic (pests and diseases) and abiotic stresses.

The still widespread demand for excellent and genetically uniform varieties, adapted to high input agriculture and suitable for cultivation under a vast array of geographical conditions, has enhanced the performance of a few cultivars at the expense of variety and crop diversity, initiating the process of erosion of the genetic diversity accumulated over centuries of cultivation. So, for example, in USA 96% of the area devoted to garden peas is planted with only two cultivars, 95% of the groundnut crop area is planted with only nine varieties, soybean gene-pools come from only six varieties (all indigenous to the same Asiatic zone), and almost three-quarters of cultivated potatoes originated from just four varieties. The coffee in Brazilian plantations derives from a limited number of clones.

The genetic uniformity of modern crop varieties makes them more vulnerable to rapidly evolving pests and diseases, and consequently determines an additional need for genetic resources. Classic cases of crop disease outbreaks with severe adverse economic and social consequences have been the potato late blight epidemic in Ireland, the coffee rust epidemic in Ceylon, corn leaf blight in USA, etc. (Table 2). Genetic erosion is also caused by modern farm management and by man-induced alterations to habitats. Farm management methods have brought about the near-elimination of the wild forms of many species that have contributed to the introgression of genes in cultivated material, and to the enrichment of the genetic diversity of crops. Man-induced alterations have destroyed the habitats of

Table 2. Cases of drastic reduction in crop yield due to epidemics of pests and diseases

Year	Crop	Pest or disease	Location
1840	Potato	Late blight	Ireland
1848	Wine grape	Powdery mildew	Europe
1860	Wine grape	*Phylloxera vastatrix*	Europe
1870	Coffee	Rust	Ceylon
1917	Wheat	Stem rust	USA
1942	Rice	Brown spot	Bengal
1946	Oat	Victoria blight	USA
1950	Wheat	Rusts	USA
1970	Corn	Leaf epidemic	USA

many species, reducing their genetic diversity and sometimes bringing plant adaptation to its limit.

Habitat over-exploitation and deforestation also favour the processes of desertification, loss of soil fertility, and flooding. If land degradation and forest clearing continue at the present rate, almost one-third of the arable land in the world and half of the productive tropical forests will be destroyed in the next 20 years, and the biological diversity they contain will be irretrievably lost. During the same period the world population is expected to increase to over 6.6 billion people.

Nobody can deny that the growing but underfed world population is vitally dependent on better crops, and that this is a key element in development and the fight against hunger. Therefore the real and strategic importance of genetic resources, as the ultimate source of food, is enormous, and their possible loss may represent a serious threat to world security in the medium and long term. But nobody should forget that, in his eagerness to increase production, man is robbing nature of a safety mechanism, genetic diversity, which took millions of years to build up. Does man know the genetic vulnerability of the major species? Ways must be found to control the changes taking place and ensure their reversibility. This means that if the world will face problems, which at present we are not even in a position to predict, then we need to maintain, for possible future use, collections of representative samples of both local varieties and endangered wild species.

2 MULTIPLE CROPPING

In relatively recent times agriculture has experienced a rather interesting evolution. Changes started at the beginning of this century in industrialised countries and later spread into some areas of the developing world. The main characteristic of these changes was the use of high return inputs, such as mechanisation, uniform high yielding varieties, use of chemicals to stimulate growth and protect plants, management precision, simplified farm systems, etc. A crop plant is perceived, in the above system, as a machine that converts solar energy into potential organic energy, and all the factors contributing to its efficiency should be at their optimum in order to allow maximum production. The system has been sometimes so effective that it has given self-sufficiency in a number of countries, and even created surpluses that are available for exportation.

Conversely, in a number of instances it has caused severe problems due to environmental pollution and soil over-exploitation. Shortages of inputs difficult to control, such as water, lack or changes in credit policy, lack or shortages of input supply etc., have frequently caused the complete failure of crops, leading to a deep crisis in the farming world. For these reasons the entire concept of advanced agriculture is slowly changing again and moving towards one that requires minimal amounts of exogenous inputs. According to this new concept, varieties must be endowed with genetic characteristics which allow them to make complete use of environmental resources and to resist or tolerate biotic or abiotic stresses, without any detrimental effect on production, while sources of diversity, at both crop and farm levels, would replace uniform varieties and monocultures.

Concepts of multiple cropping, intercropping, polyculture, etc. are no longer synonyms of subsistence agriculture, but pregnant ideas of future agriculture in industrialised as well as in developing countries. Local varieties evolved in subsistence agriculture are a valuable reservoir of adapted gene complexes for an efficient exploitation of natural resources. These gene complexes may in fact contain the proper combination of genes to allow a stable performance in each of the stress conditions that may be faced in difficult environments — such as pests, acid soils, high concentrations of toxic metals in the soil, soil erosion, water shortages, etc. — and in many socio-economic situations characterised by a price increase in agrochemicals, shortages of supplies, changes in credit policies, etc. A number of tropical countries deserve particular attention from this point of view. Their agricultural systems possess a wealth of diversity in terms of not only intra-crop variation but also the cultural practices used to achieve multiple cropping, that is growing two or more crops on the same field in a year, either simultaneously (intercropping), or in sequence (sequential cropping). Yields obtained in these crop systems are relatively stable even in rather severe environmental conditions. In addition, the cultivation of different varieties on the same field prevents outbreaks of pests and diseases, with consequently limited use, or non-use, of chemicals, and low varietal turnover.

Multiple cropping may provide foodstuffs with appropriate balance between calories and proteins, and raw materials for industrial processing; furthermore, it allows better use of climatic factors, such as sunlight and water, and reduced use of synthetic fertilisers, etc. Diversity in cultivation and in crop residues plays, in fact, a significant role in the conservation of soil fertility. Microbial populations and general biological equilibria are kept at their optimum when the organic component in the soil is adequate, ensuring the degradation of root exudate residues, the maintenance of those conditions that allow the natural protection from soil-borne diseases, the prevention of a rapid mineralisation of organic matter, and the promotion of effective and efficient activity by symbiotic organisms. For example, in the Sahelian region farmers plant sorghum and millet in fields that include the perennial *Acacia albida* as intercrop. *Acacia albida* fixes nitrogen, returns organic matter to the topsoil, and modifies soil structure so that rain can be fully absorbed, while its root system extracts water and nutrients from soil strata unexploited by crop root systems. In this condition the grain yield of the intercropped sorghum or millet is exceptionally high. In West Africa the alley intercropping of cowpea and maize with *Leucaena leucocephala*, a leguminous shrub, allows this first species to be pruned and used as mulch to conserve water in the soil in favour of cowpea and maize. Natural nitrogen fertilisation obtained through *Sesbania rostrata* interplantings allows a 30% enhancement of the artificial nitrogen efficiency in sorghum crops.

Although some scientists have indicated that the continuing and even accelerating trend toward specialisation, up to monoculture and larger farms, will lead to the disappearance of small farms and multiple cropping, other scientists have shown the growing importance of multiple cropping even in developed countries. More than 2000 scientific papers have been published on the subject in the last 30 years.

Gomez and Gomez (1983) described a range of systems in Asia in which multiple cropping is important: (1) lowland rice, (2) annual upland crops, (3) perennial upland crops, and (4) hilly land. In lowland rice, three crops per year are possible where water is available; more frequently two crops of rice are followed by a short season "catch crop" such as mung bean or sorghum. Annual upland multi-crops represent more than 60% of the cropped area in Asia and include at least 20 annual food species, such as maize, sorghum, millet, cowpea, groundnut, etc., plus cotton and tobacco. Perennial upland crops are important components of intercropping systems in several parts of Asia and include banana, cacao, pineapple, rubber, papaya, mango, coffee, and coconut. They are intercropped with annual or with other perennial crops to form combinations such as coconut/pineapple, coconut/cacao or coffee, etc. In Africa more than 80% of cowpea, groundnut, maize, millet, sorghum, yam, cassava, cocoyam, banana, and many minor species are grown in intercropping systems. In tropical America multiple cropping systems include maize, beans, cassava, squash, potato, amaranthus and quinoa and, in general, the intercropped area increases on moving from lowlands to highlands.

In multiple cropping, the non-genetic factors that can be manipulated to increase and stabilise production comprise spatial arrangement, planting dates, crop densities, fertilisation time, etc. Breeding approaches need, therefore, to explore and utilise the genetic diversity for characters that affect yield performance in those conditions such as adaptation to target environments, disease and pest resistance, adequate interspecific competitive ability, tolerance to shading, length of growth cycle, etc. (Smith and Francis, 1986). Whenever a large crop germplasm collection has been evaluated, it has always shown a wide range of variation for the mentioned traits. Often, the characters to be improved and the direction in which they should be changed depend on the species included in the system. So, for example, in cereal/pigeon pea (*Cajanus cajan*) intercroppings, the total yield is maximised with early maturing cereals. In rice/maize combinations, tall and long-cycle rice varieties are desirable; in maize/sorghum systems, sorghum varieties with a life cycle of 8–9 months are desirable. Combinations of early sorghum and late millet (*Pennisetum americanum*) varieties give the best production in sorghum/millet intercroppings, and millet accessions with the desired characteristics have been identified by the International Crops Research Institute for the Semi Arid Tropics (ICRISAT) and by the All-India Coordinated Millet Improvement Programme in their germplasm collections.

Photoperiod insensitivity found in rice allowed multiple cropping, permitting the harvesting of two or three sequential crops per year. Determinate types of soybean were more productive than indeterminate types in intercrops in India, but the reverse was true for soybeans intercropped with winter wheat or spring oats (*Avena sativa*). Variability for both plant types was available in soybean genebanks of the International Soybean Program (Urbana, USA), the All-Union Institute for Plant Industry (Leningrad, USSR), and the National Institute of Agricultural Science (Tsukuba, Japan). Intercropping experiments carried out at Mbita Point Field Station in Kenya by ICIPE indicated that sorghum/cowpea and maize/cowpea/sorghum were the best among several combinations for pest control. In all cases multiple cropping was demonstrated to be a system that provides better total yield and more stable production than specialised cultures of the same crops, under a vast array of environmental conditions.

The breeding methodologies for multiple cropping systems are complicated by a number of non-genetic factors that have to be controlled. It seems, however, that the type of characters to be genetically improved in cultivars bred for intercropping (which already have good yield potential and pest and disease resistance when grown in monoculture-intensive systems) are those showing high heritability (plant stature, determinate or indeterminate growth, photoperiod insensitivity, duration of growing cycle, etc.). For such characters, there is ample scope for selection among entries that represent the genetic resources stored in germplasm banks for any given species.

3 AGROFORESTRY

Another form of agriculture based on multi-annual/annual multiple cropping is agroforestry, which can be defined as sustainable land use by interacting associations of field, fruit and horticultural crops, pastures, and woody perennials, all on the same unit of land. Once typical of subsistence agriculture, agroforestry systems can now be used not only for increasing agricultural productivity and sustainability through a multiplicity of outputs, but also to conserve or even improve environmental aspects of an area through restitution or improvement of soils, etc. Large areas abandoned from intensive agriculture are now converted to a sort of agroforestry, combined with recreational uses, in USA and other industrialised countries.

In semi-arid zones, where cropping is difficult, there may be scope for nutrient transfer and improvement of water economy as occurs, for instance, when litter from trees is transported to adjacent strips of land and used for mulching or fertilising agricultural crops.

A number of tree genera, such as *Acacia, Albizia, Alnus, Azadirachta, Balanites, Brosimum, Cassia, Ceratonia, Cordeauxia, Gliricidia, Inga, Leucaena, Parkia, Prosopis, Sesbania* and *Zizyphus*, have been evaluated as important in these systems (Huxley, 1983), and their use is now proposed. Germplasm collections of these trees are still scanty and there is a need to collect and distribute properly authenticated germplasm of such multi-purpose plant genera.

Important characteristics to be considered when establishing priorities for collection, evaluation and use of these plant genetic resources are:

- Adaptation to soil and climate
- Rapid growth rate in the early growth stages
- Good palatability as fodder
- Ability to withstand abiotic and biotic stresses
- Good aerial and soil resource-sharing characteristics
- Capacity to withstand lopping, pruning or browsing
- Capacity for nutrient recycling and/or nitrogen fixing capacity.

Some species do possess these characteristics; for example *A. albida* is a soil-enriching, leguminous tree of African savanna, which loses its leaves in the wet season. Associated crops, like sorghum, millets and groundnuts, can take advantage of the recycled resources from the tree, whilst avoiding the worst effects of competition from the tree for light and water (Felker, 1978).

Alley cropping (zonal agroforestry) of *L. leucocephala* and maize in southern Nigeria is very profitable because of the reduced competition between species and the availability of materials for mulching the zone devoted to maize cropping (Kang et al., 1981). Zonal agroforestry systems should generally be used at the outset of intercropping, when little knowledge is available about the interactions between tree crops and annual crops.

There are 22 FAO/UNDP (United Nations Development Programme) projects and 11 WFP (UN/FAO World Food Programme) assisted projects that involve agroforestry. The list includes a rice/*Sesbania aculeata* system in the Mekong delta of South Vietnam, shade trees (*Gliricidia sepium*) on pepper estates in the Kandy and Matale provinces of Sri Lanka, *Theobroma cacao*/forest trees (i.e. limba, *Terminalia superba*) in Maumbe, Congo Brazzaville, and multi-purpose forest plantations using mainly *Prosopis* spp. in north-west Peru.

Finally, valuable activities for the establishment of genetic resource collections and genebanks of species to be used in agroforestry systems are being coordinated by the International Council for Research in Agroforestry (ICRAF) (Tran Van Nao, 1983).

4 STRATEGIES FOR THE PRESERVATION OF GENETIC RESOURCES

Preservation of genetic resources is an urgent problem for crops having widespread importance (such as wheat, rice and maize) as their variability is becoming increasingly reduced. It is also a problem for crops that have so far only played a role in local agriculture but may represent a key element in modelling new agricultural systems. The categories of materials regarded as important in a reservoir of genetic diversity are listed in Table 3. The wild relatives of some crops may represent a special case.

Priorities for the conservation of the genetic resources of several species are given in Table 4; regional priorities for collecting are indicated in Table 5.

Table 3. Categories of materials regarded as important reservoirs of genetic diversity

Category	Description
Cultivated varieties	Biotypes with high performance in plant production
Obsolete varieties	Local varieties
Primitive varieties or landraces	Local varieties possessing gene complexes for resistance
Wild relatives	Known also as 'exotics'
Species of potential value to man	New oil and rubber producing plants, etc.
Genetic stocks	Mutants, improved germplasm, etc.

Table 4. Priorities for genetic conservation

Group	Ist	2nd	3rd	4th
Cereals	*Triticum* *Sorghum* *Pennisetum*	*Eleusine* *Setaria* *Panicum* *Echinochloa* *Digitaria* *Oryza*	*Hordeum* *Zea* *Avena* *Secale*	*Amaranthus* *Chenopodium* *Eragrostis*
Grain legumes	*Phaseolus*	*Cicer* *Vigna* *Arachis* *Glycine*	*Cajanus* *Pisum* *Vicia*	*Dolichos* *Lens* *Lupinus* *Mucuna* *Psophocarpus*
Roots and tubers	*Manihot* *Ipomoea*	*Solanum*	*Dioscorea*	Aròids Misc. tubers
Starchy fruits	–	*Musa* *Atrocarpus*	–	–
Fibres	–	*Gossypium*	*Corchorus*	*Hibiscus*
Oil seeds	–	*Elgeis melanococca*	*E. guineensis* *Brassica* *Olea* *Carthamus* *Helianthus*	*Guizotia* *Sesasum*
Sugar crops	–	*Beta* *Saccharum*	–	–
Rubber	–	*Hevea*	–	–
Beverages	*Coffea*	*Theobroma*	–	*Camellia*

Source: IPBGR (1986).

Table 5. Regional priorities

Priority	Region
1st	Mediterranean South-west Asia Central Asia South Asia Ethiopia Central America
2nd	South-east Asia East Asia East Africa Brazil Andean zone
3rd	Pacific islands East Africa Southern South America

The techniques for maintaining genetic resources vary with species, geographical distribution, ecology, and breeding system. For instance wheat, a highly inbred species, is conveniently collected as spikes or seeds which are stored in cold rooms; potatoes are often collected as tubers (rarely as seed) and cold, as well as *in vitro* storage, is adequate; sugarcane can be collected only as short-lived buds and the *in vitro* conservation technique is the most appropriate. The coconut, an outbreeding species that cannot be propagated vegetatively and gives seed-lots weighing several kilograms whose viability is rapidly lost during conservation, can be maintained in "evolutionary gardens" or "field collections". A number of wild species may require more natural conditions to continue their evolution, and *in situ* preservation in special reserves would be the most appropriate. Thus the possibilities and approaches for the maintenance of genetic resources differ between species but, in general, there are two main methods: *in situ* and *ex situ* preservation.

4.1 In situ *preservation*

In situ preservation methods are those which seek to maintain self-perpetuating populations in natural ecosystems. They are especially suitable for wild species and perennials. 'Evolutionary garden', 'field collection', 'gene recombination orchard' are all synonyms that indicate a living collection of a crop, that allows for new recombinant forms to appear, and are a modification of the method.

For tropical and perennial species with recalcitrant seeds, *in situ* conservation may become an essential complement to seed and *in vitro* conservation. They guarantee the ecological conditions suitable for regenerating the plants or bringing them to reproductive maturity. They can also back up efforts to reduce the negative effects on allelic diversity elicited by storage conditions and processes.

For the proper establishment and management of *in situ* genebanks a number of factors have to be considered; most of them are concerned with both biotic and abiotic aspects, but social factors may also become relevant. It is therefore essential to stimulate those research programmes that, according to the preservation objectives, might identify the role of (1) initial taxonomical and ecological conditions, (2) number and size of populations, (3) form and management of reserves, (4) access to germplasm, etc.

Priorities for *in situ* conservation indicate that urgent action is needed for groundnut, oil palm, banana, rubber, coffee, cocoa, citrus, mango, *Prunus*, apple, onion and forages (IBPGR, 1985).

Many countries have set up protected areas as wilderness areas or national parks covered by special legislation. The Forest Resources Division of FAO, IUCN, and WWF are among the non-governmental organisations enthusiastically dedicated to *in situ* conservation of plant genetic resources. UNESCO is promoting the establishment of a world network of biosphere reserves to maintain biotic communities of plants and animals within their natural ecosystems.

4.2 Ex situ *genebanks*

The materials to be preserved can be split into two main categories: base collections and active collections. The first category includes materials that require long-term preservation and should be utilised only if the active collections extracted from them are lost. The other category represents the material which is continuously screened by breeders in search of accessions with valuable characteristics. The conserved material can be represented by quiescent organs, such as seeds, or by vegetative parts preserved in cultivation or *in vitro*.

The main types of *ex situ* genebanks can be summarised as follows (Table 6):

Table 6. Different types of *ex situ* genebanks

Description	Duration	Temperature (°C)	Crops
Base seed	Several decades	-20–10	Inbred and outbred annual species with orthodox seeds: cereals, grain legumes, cotton, tobacco, tomato, forages
In vitro base	Very long periods	-196	Tissues of collected genotypes
Active seed	Up to 20 years	0–5	Collections of several species with orthodox seeds
In vitro active	Short	5–10	Tissues of collected genotypes: embryos, shoots, explants
Active field	Plant life cycle	Ambient	Perennial crops (recalcitrant species): rubber, cacao, tea, coffee, etc.

(a) Base genebanks which are long-term base seed collections composed of extremely dry samples stored at –10°C to –20°C for several decades.

(b) *In vitro* base genebanks containing tissues of the collected accessions preserved at the temperature of liquid nitrogen (–196°C) in static conditions for very long periods.

(c) Active seed genebanks which are medium-term seed collections stored in facilities maintained at 0°C–5°C.

(d) *In vitro* active genebanks containing tissues of the collected genotypes maintained under conditions of reduced growth; all material flows through cyclical process of multiplication and monitoring of stability. Organised non-adventitious plant structures (embryos and shoots) meet the required standard for stable *in vitro* genetic conservation.

(e) Active field genebanks which are collections of plants in plantations, orchards, clonal repositories, etc.

The above genetic conservation strategies are based on (1) seed-seedling cycles, without seed storage, and are useful for seed-propagated species and (2) clonal propagation due to sterility or chromosomal number variation (e.g. grape, banana). For certain species such as rubber, cacao, tea and coffee, a combination of seed-seedling cycle and clonal propagation is feasible. The number of accessions which should be put into *in vitro* active collections to represent the variability of the species has been estimated to be 5000 for cassava, 750–1000 for banana, 2000 for sweet potato, and 500 for sugarcane. Between 2500 and 62,500 cultures are estimated as necessary for 100 accessions (IBPGR, 1986).

Cryopreservation of *in vitro* cultures of calli, cell suspensions and protoplasts have been successful for many herbaceous plants (belonging to the genera *Triticum, Glycine, Daucus,* etc.) as well as for forest trees (*Populus americana* and *Acer pseudoplatanus)* and fruit trees (*Phoenix dactylifera)* (Stushnoff and Fer, 1985). Apple shoot tips derived from *in vitro* cultures have shown high survival in liquid nitrogen when previously given 4 weeks of cool temperature. There have been no long-term studies with liquid nitrogen storage, but the most disturbing aspect of this method is the genotypic variability for tolerance to long-term storage and the ability to grow on specific media, to withstand freezing and thawing, and to resume growth after storage.

Ex situ field collections are limited so far to clones of banana, coconut, cacao, sugarcane, sweet potato, potato, cassava and citrus. Present estimates indicate that about 50 base collections will form a reasonably complete network to be complemented by about 60 different active collections. They will cater for about 40 major crops or groups of crops.

In summary, collections of plant materials, in order of priority, are essentially of two categories:

- Base collections (repositories for long-term conservation, for several decades).
- Active collections (to be used for evaluation, breeding purposes, rejuvenation and distribution).

There are various types of base and active collections depending on whether the plant materials are in the form of seed, which can be dried and stored at low temperatures, or in the form of clonal material. Base and active collections are spread worldwide for more than 30 different seed-producing crop plants (Table 7).

Table 7. Seed-producing crop plants for which base and active collections are available

Cereals	Legumes	Vegetables	Root crops	Industrial crops	Forage
Rice	*Phaseolus*	*Allium*	Potato	Beet	Several tropical, Mediterranean, and temperate grasses and forage legumes
Wheat	Pigeon pea	*Amaranthus*	Cassava	Cotton	
Maize	Cowpea	*Capsicum*	Sweet potato	Sugarcane (seed)	
Sorghum and Barley	Groundnut	Crucifers			
Oat	Chickpea	Eggplant			
Rye	Asiatic *Vigna*	*Cucurbita*			
Pearl millet	Soybean	Tomato			
Finger millet	Faba bean	Okra			
Teff	Winged bean				
Panicum	Pea				
Setaria	Lupin				
	Lentil				

Much, however, remains to be done to complete this part of the process of setting up *ex situ* genebanks for the majority of the crop species. An urgent task is to identify the important active collections already in being (at present there are 100 significant germplasm collections around the world).

International cooperation is also essential in order to ensure that the genetic variability of crop plants is adequately sampled and that accessions are maintained and evaluated in appropriate environments. There are, in fact, indications that many of the old collections may not be so valuable as was first thought. Not infrequently the genetic diversity of the crop is poorly represented, and exchange of samples between collections has led to duplications that cannot easily be traced owing to poor records.

One or more base collections are currently held for safety, or will be held by agreement, in the following countries: Argentina, Belgium, Brazil, Canada, China, Colombia, Costa Rica, Ethiopia, German FR, German DR, Greece, India, Israel, Italy, Côte d'Ivoire, Japan, Mexico, Netherlands, Nigeria, Peru, Philippines, Poland, Portugal, Spain, Syria, Thailand, United Kingdom, USA and USSR; and at the Nordic genebank which serves Denmark, Finland, Iceland, Norway and Sweden.

Table 8. Number of samples of 16 important crops preserved in germplasm banks (approximate figures)

Crop	No. of germplasm banks	No. of samples ('000)
Wheat	11	200
Maize	9	70
Millet	6	38
Soybean	6	30
Chickpea	5	24
Lentil	1	6
Cassava	5	10
Tomato	4	7
Rice	15	170
Sorghum	9	80
Cowpea	4	17
Beans	14	73
Groundnut	5	21
Potato	7	41
Cotton	4	8
Pepper	3	2

The status of germplasm collections for wheat, maize, rice, sorghum, barley, millet, cotton, tomatoes, pepper, root and tuber crops, and grain legumes is summarised in Table 8. This table lists the number of seed samples maintained in long-term conservation germplasm banks for each of the listed major crops. The USA and Europe maintain collections of roughly 340,000 and 750,000 seed samples of various crops, respectively. Some 600 botanical gardens throughout the world also share the responsibility for *ex situ* conservation.

Although precise figures cannot be given, the collections of the major, staple, seed-producing crop plants contain well over 20,000 samples. Problems of space and maintenance limit the size of collections of vegetatively propagated crop plants. For crops such as apple, banana, or grape a well-maintained collection of 250–500 accessions would be regarded as satisfactory.

5 PROSPECTS FOR THE FUTURE

More species may be lost over the next 60 years than during the great extinction of the Cretaceous era some 65 million years ago. According to P.H. Raven, Director of the Botanical Garden in St. Louis, Missouri, USA, by the middle of the next century more than 40,000 species of plants will have been exterminated. The earth is already losing forests at the rate of 11 million ha per year and a further 27 million ha are turned into desert or become economically unproductive, according to the Executive Director of UNEP. At these rates, there will not be a single hectare of fertile land on the earth in 200 years time.

In recent years, efforts to deal systematically with these problems have begun at technical, economic and political levels.

In the realm of technology, the development of new methods for genetic resource conservation, such as tissue culture, cryopreservation and storage of DNA strains have opened new possibilities, but they have also led to new and complex problems. Swaminathan (1983), in his presidential address to the XV International Congress of Genetics, expressed the need for an integrated strategy for the conservation of plant genetic resources at several levels:

- Populations
- Individuals
- Tissues and organs
- Cells
- Fragments of DNA.

In each country, such a strategy would provide different levels of conservation according to need and capacity.

Economic resources for *ex situ* and *in situ* conservation are well below adequate levels. The costs of *ex situ* conservation may be reduced by taking advantage of favourable environmental conditions such as natural caves in permafrost zones and/or high-altitude deserts, where cold temperatures and low levels of humidity may allow long-term conservation. These conditions are abundant in some developing countries.

There are more serious problems for wild species that need *in situ* conservation, since most of the areas suitable for this sort of natural reserve occur in developing countries, which cannot afford to bear the burden of this conservation. Since the protection of these areas benefits all mankind, all countries should share the efforts needed. For this reason, the Netherlands Government launched the idea of a World Gene Fund in June 1983. Upon the official proposal of a group of 77 countries, the Second Session of the FAO Commission, in March 1987, created the International Fund for Plant Genetic Resources, but extensive funding is now necessary for its effectiveness and efficiency.

On the political side, the recognition of plant genetic resources as a common patrimony of all mankind has given a major boost to the status of germplasm preservation. However, too many countries have still to decide to participate in these common efforts.

Existing international agreements, such as the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES), governing some 50,000 plant species, are not sufficiently respected and will continue to be disregarded until they are enforced by national legislation. It is of vital importance that legislation plays a role in deterring genetic erosion, protecting indigenous genetic resources, and promoting free access to them. Political and economic support for this purpose can be stimulated by information campaigns, illustrating the importance of genetic diversity and the danger of its depletion.

The erosion and disappearance of genetic resources must be ranked together with problems such as mercury and lead poisoning, fertiliser runoff, industrial water pollution, and massive solid waste production, and the steps taken should become part of the daily life of every human being. Schools and mass media are powerful tools for generating the public awareness that will call for action.

Numerous and unexpected problems have arisen in the search for modern agricultural systems compatible with environmental and economic needs. The situations that future generations will have to face are entirely unforeseeable.

Food and foodstuffs have to be produced in due quantity, and possess both technological and nutritional value; the supply of raw materials may represent one of the key elements for new bio-industries, once petroleum supplies become limited.

Future generations will need the tools and appropriate agrotechnologies to face and solve a number of problems but, more than that, they will need the genetic resources from which new plants, suitable for tomorrow's unforeseeable productions, can be developed. Genetic resources represent a common cause and deserve the highest priority. Scientists, agricultural research managers, programme leaders, policy advisors, political leaders, common citizens, all have great responsibility for promoting the preservation of this precious heritage.

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APPENDIX I

Utilisation of plant genetic resources

Primary reference	Type of utilisation (see col. 4)	Plant	Character	Secondary references	Germplasm supplier institution
(1)	Disease resistance	Pepper (*Capsicum annum*)	Bacterial spot (*Xanthomonas vesicatoria*)	(9) (10) (11)	Southern Regional Plant Introduction Station, Georgia, USA
			Tobacco etch virus	(12)	
			Tobacco mosaic virus (strains PV 135 and PV1)		
		Muskmelon (*Cucumis melo*)	Downy mildew (*Pseudoperonospora cubensis*)	(13)	
			Powdery mildew (*Sphaerotheca fuliginea*) race 2	(14)	
			Gummy stem blight (*Mycosphaerella melonis*)	(15) (16)	
			Watermelon mosaic virus-1	(17)	
		Watermelon (*Citrullus lanatus*)	Gummy stem blight (*M. melonis*)		
			Anthracnose (*Colletotrichum lagenarium*)	(18)	
		Cowpea (*Vigna unguiculata*)	Blackeye cowpea mosaic virus	(19)	
			Cowpea chlorotic mottle virus	(20)	
			Southern bean mosaic virus	(21)	

Contd. on page 27

Primary reference	Type of utilisation (see col. 4)	Plant	Character	Secondary references	Germplasm supplier institution
		Cowpea	Cowpea yellow mosaic virus	(22)	
(2)	Disease resistance	Sorghum (*Sorghum bicolor*)	Downy mildew (*Peronosclerospora sorghi*) Leaf blight (*Helmintosporium turcicum*) Sooty stripe (*Ramulispora sorghi*) Zonate leaf spot (*Gloeocercospora sorghi*) Rough leaf spot (*Ascocyta sorghina*) Grey leaf spot (*Cercospora sorghi*) Oval leaf spot (*Ramulispora sorghicola*) Anthracnose (*Colletotrichum graminicola*) Bacterial leaf streak (*Xanthomonas holcicola*) Smut (*Sphacelotheca* spp.) Mould (*Fusarium* spp.)	(23) (24) (25)	Pakistan Agricultural Research Council (PARC), Islamabad, Pakistan
		Maize (*Zea mays*)	Northern corn leaf blight (*H. turcicum*) Southern corn leaf blight (*Helmintosporium maydis*) Zonate leaf spot (*Gloeocercospora spp.*) Curvularia leaf spot (*Curvularia* spp.) Cercospora leaf spot (*Cercospora* spp.) Charcoal rot (*Macrophomina phaseoli*)		

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Primary reference	Type of utilisation (see col. 4)	Plant	Character	Secondary references	Germplasm supplier institution
(2)	Disease resistance	Maize	Fusarium stalk-rot (*Fusarium moniliforme*)	(26)	
		Pearl millet (*Pennisetum glaucum*)	Leaf blast (*Pyricularia penniseti*) Sonate leaf spot (*Gloeocercospora* spp.) Downy mildew (*Sclerospora graminicola*) Bacterial blight (*X. holcicola*) Rust (*Puccinia penniseti*) Anthracnose (*C. graminicola*) Ergot (*Claviceps fusiformis*) Mould (*Fusarium* spp.) Smut (*Sphacelotheca* spp.)	(27) (28) (29)	
(3)	Disease resistance	Rice (*Oryza sativa*)	Blast		
		Wheat (*Triticum* spp.)	Brown rust		Tohoku Agricultural Experiment Station, Japan
		Adzuki bean (*Phaseolus radiatus*)	Brown stem rot *Phytophthora* stem rot		
		Potato (*Solanum tuberosum*)	Late blight		
		Rice	Bacterial leaf blight Rice stripe virus Grassy stunt virus Barley yellow mosaic virus		National Institute of Agricultural Sciences, Yatabe (NIAS), Aikoku-souto, Japan
		Soyabean (*Glycine max*)	Dwarf mosaic virus Soyabean mosaic virus Cucumber mosaic virus (one strain)		
		Maize	Streak dwarf virus		

Primary reference	Type of utilisation (see col. 4)	Plant	Character	Secondary references	Germplasm supplier institution
(4)	Disease resistance	Chickpea (*Cicer arietinum*)	Wilt (*Fusarium oxysporum* F. *ciceri*)	(30) (31) (32) (33)	
(5)	Disease resistance	Wheat	Resistance genes to following pathogens discovered in one local variety collected in Turkey in 1948. *Puccinia striiformis*; 35 strains of *Tilletia caries* and *T. foetida*; 10 varieties of *T. controversa*. Tolerance to certain species of *Urcocystis*, *Fusarium* and *Typhula*. Resistance to various types of rust introduced from wild species native to the Mediterranean, Near East and Asia Minor.		
		Rye grass (*Lolium multiflorum*)	Some varieties collected in Uruguay were the source of resistance to crown rust in the 1950s.		
		Tomato (*Lycopersicon esculentum*)	The wild species *L. hirsutum* and *L. peruvianum* have been used as donors of fungus-resistant genes.		
(3)	Resistance to insects and nematodes	Rice	Brown plant hopper Green leaf hopper		
		Soyabean	Cyst nematode		Tohoku Agricultural Experimental Station, Japan

Contd. on page 30

Primary reference	Type of utilisation (see col. 4)	Plant	Character	Secondary references	Germplasm supplier institution
(3)	Resistance to insects and nematodes	Sweet potato	Root-knot nematode Coffee-root-lesion nematode		
(5)	Resistance to nematodes	*Bromus biebersteinii*	Resistance to stem nematodes from a primitive alfalfa ecotype collected in Iran in 1940.		
(5)	Resistance to insects	Tomato	Genes coming from wild species *L. peruvianum* Genes coming from wild species *L. hirsutum*		
(3)	Resistance to environmental stresses	Rice	Cold tolerance		Hokkaido Experimental Station, Japan
		Maize	Cold tolerance		Tokachi Agricultural Experiment Station, Japan
(6)	Resistance to environmental stresses	*Phaseolus vulgaris* and *P. coccineus*	Ability to germinate at low temperature		Institute of Plant Breeding and Seed Production, Turin University, Italy
(5)	Adaptation to adverse conditions	Tomato	Genes coming from wild species *L. cheesmanii*		
(7)	Constitution of varieties	Wheat	(a) 10% of resources in pedigree of named cultivars (b) 15% in breeder's lines	(34) (35) (36)	
(5)	Constitution of varieties	*B. biebersteinii*	The optimum vigour and agricultural characteristics of the famous Regar CV are due to a local variety collected in Turkey in 1949		

Contd ...

Primary reference	Type of utilisation (see col. 4)	Plant	Character	Secondary references	Germplasm supplier institution
(5)	Constitution of varieties	*B. biebersteinii*	The commercial alfalfa ecotype AWRPX3 originates from 13 ecotypes collected in 9 different countries		
(3)	Improvement in productivity	Rice	Use of semi-dwarf gene in rice breeding		
		Wheat	Use of semi-dwarf gene in wheat breeding		
		Sweet potato	Enlargement of genetic bases		
		Mint *(Mentha arvensis)* var. 'piperascens'	Use of wild relative *Mentha spicata* var. 'crispa'		
		Guinea grass (*Panicum* sp.)	Use of introduced materials		Kyushu Agricultural Experiment Station, Japan*
(3)	Improvement in quality	Aromatic rice	Use of native aromatic rice		
		Barley (*Hordeum vulgare*)	Use of a high protein and high lysine barley cultivar Hiproly collected in Ethiopia		Shikoku National Agricultural Experiment Station, Japan
	Soyabean		Increase in sulphur-containing amino acids and removal of trypsin inhibitors and enzyme lipoxygenase		
	Potato		Increased starch content		
	Sweet potato		Increased carotene content		

Contd. on page 32

Primary reference	Type of utilisation (see col. 4)	Plant	Character	Secondary references	Germplasm supplier institution
(3)	Improvement in quality	Rape (*Brassica napus*)	Reduction of erucic acid content in rape seed oil		
(8)	Improvement in quality	Durum and bread wheats	Storage proteins (gliadins and glutenins)		Instituto del Germoplasma, C.N.R., Bari, Italy
(5)	Improvement in quality	Tomato	Genes coming from wild species *L. chimielewskii*		
(3)	Improvement in quality	Rice	Cytoplasmic male sterility		
		Rape	Cytoplasmic male sterility		
		Barley	Haploid breeding		
		Potato	Haploid breeding		
		Rice	Wide compatibility genes		

*Germplasm user institution.

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