

Plant genetic resources a perspective

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Introduction

Mankind is facing a new threat, and one primarily of its own making. Whatever the final outcome, global warming is taking place as a result of the release into the atmosphere of a spectrum of gases which increase the 'greenhouse effect'. Principal among these is carbon dioxide (CO₂), concentrations of which have increased dramatically in recent years, mainly as a result of the combustion of fossil fuels and through deforestation. Other so-called 'greenhouse gases' include water vapour, chlorofluorocarbons (CFCs) and methane. Recent concern over damage to the ozone layer has led to increased public awareness of the greenhouse effect. International agreements are aimed at replacing CFCs in aerosols and refrigeration units, for instance, but the task of eliminating CFCs completely is an awesome one. CFCs are potent greenhouse gases, many thousand times more effective than CO₂ in storing heat energy. Methane concentrations have also increased, due to the expansion of rice paddies in South-East Asia, and also to the increase in cattle populations in many parts of the world. Methane is also many times more effective than CO₂ in contributing to the greenhouse effect. Nevertheless, in terms of sheer quantity, CO₂ is by far the most important greenhouse gas, and strategies must be aimed at reducing CO₂ emissions to levels lower than they are at the present, if we are to make any impact on the rate of global warming.

Until the global circulation models (GCMs) used for predicting climatic change are more accurate, the consequences of the greenhouse effect cannot be predicted with confidence (see the chapter by Rowntree, this volume). Consequently, we can only develop various scenarios which attempt to explain what the consequences of global warming might be. There is general agreement that climatic change will occur, and this will develop within a far shorter time-span than ever experienced before. World temperatures will rise, and this warming is predicted to be greatest at higher latitudes. Rainfall patterns are likely to be altered, with some areas becoming wetter and others much drier than present conditions. In

some places, weather patterns may become even more variable than at present.

Loss of biological diversity may be seen as one of the likely consequences of climatic change. The geographical distribution of different ecosystems and their structure are likely to be altered as temperature and rainfall patterns change, and these ecosystems are subjected to different environmental stresses. Species will respond in different ways. Increased CO₂ levels will benefit C₃ plants, but will not be as beneficial to C₄ plants.

Apart from the future of natural ecosystems and the question of their conservation under global warming (which are addressed by Hattemer & Gregorius, this volume), it is important to explore the future of agricultural ecosystems and their associated crops. In this context, the importance of plant genetic resources has not been addressed to date. Scientific concern about the effects of global warming on biological diversity has concentrated on the possible extinction of species, and changes in species composition of natural ecosystems, rather than on the narrowing of genetic variation within species (Peters, 1988). Moreover, it is often easier to convince the public of the needs for conservation in terms of the extinction of plant and animal species, or destruction of ecosystems as in the case of the tropical rainforests for instance, rather than of the importance of maintaining patterns and levels of genetic variation in all species which have evolved over large time scales. In this chapter we shall give a brief introduction to plant genetic resources, and how they are conserved and utilized, before attempting to describe a scenario for their value and more effective use in the future under global warming.

Feeding the world

Our ability to adapt to changing climates will be determined, to a considerable extent, upon our ability to feed ourselves, to provide shelter and clothing, and for many peoples in many developing countries there will be problems in obtaining fuelwood for cooking or heating.

In the short term, widespread famine can be averted only by raising crop yields, particularly in the developed nations, in order to sustain supplies of direct food aid. The Green Revolution was launched to combat the threat of mass starvation, and demonstrated that plant breeding could, given the right circumstances, provide solutions to world food problems. The basis of the Green Revolution was the availability of genetic diversity which the plant breeders could manipulate, such as the dwarfing genes which led indirectly to dramatic yield increases, in wheat and rice, for instance. Unfortunately, the cultivation of these varieties had a social cost as well, and increases in petroleum prices in the mid-1970s led to increased production costs, so that much of the Green Revolution technology was beyond the reach of many peasant farmers in the Third World.

Faced with probable changes in global climatic patterns, can plant breeders meet the challenge and breed varieties needed for the next century? Furthermore, are we able at this stage to identify the sorts of genetic resources which will be required? In later chapters (Ellis *et al.*; Squire; and Erskine and Muehlbauer) various scenarios are presented in this context.

Plant genetic resources

Plant genetic resources is a term used to describe the total genetic diversity of cultivated species and their wild relatives, much of which may be valuable to breeders. Hawkes (1983) has distinguished the following types of material within this definition:

Landraces or primitive forms which are races or populations, often collected from remote areas where the new, highly bred cultivars have not been introduced. They are highly diverse genetically, and have often been grown as mixtures of species, as well as diverse populations of one species. They may often originate from the old Vavilovian centres of diversity, and have not been bred as varieties, but under natural and artificial selection (probably largely of an unconscious nature) have become adapted to the conditions under which they are cultivated. Such materials are closely allied genetically to modern varieties, and are extremely important genetic resources. These materials have received top priority for genetic conservation.

Weed races occurring as part of crop-weed complexes in gene centres. In many instances they incorporate useful genes derived from wild progenitors or related wild species which have moved from the weedy forms into the crops themselves. In these instances nature has helped the breeder by inserting genes (some of them useful) from wild species into suitable 'cultivated' genetic backgrounds.

Related wild species that sometimes occur in the gene centres of cultivated plants, and sometimes far outside them, that can be crossed with the cultigens.

Currently grown commercial varieties (cultivars) from a breeder's own country or exotic ones from other countries.

Obsolete commercial varieties that are now no longer commercially grown but which may still be obtained from seed merchants or individual collections.

Breeding lines or stocks which may be a breeder's own stocks or those obtained from other breeders, not yet developed into commercial varieties but possessing some potential value.

Induced or natural mutations occurring within the breeder's own collections.

Although the term 'genetic resources' is often used in a more restricted sense for landraces, weed races and related wild forms, it is clear that

to meet the challenge of global climate warming, we must also include currently grown commercial varieties. This latter aspect is addressed by Parry and Carter (this volume) in terms of existing varieties which are currently adapted to a particular environment being used in areas where climate can be expected to be modified sufficiently to allow their cultivation in the future but which may not survive under present conditions.

How did these different types of genetic resources originate? The commercial varieties, breeding stocks and mutations are the result generally, of modern plant breeding, and are of recent origin. By their very nature the landraces of crop plants have not been subjected to conscious plant breeding, although they have evolved in different agricultural systems under the influence of man since the origins of agriculture at the beginning of the Neolithic Revolution, some 9,000–10,000 years ago. If we take the case of wheat as an example, this is a crop plant which is associated with the earliest stages of agriculture in the Old World. Archaeological sites in the Fertile Crescent of the Near East provide ample evidence of man's utilization of this cereal, and that evolutionary changes from wild plant to domesticate were extremely rapid. Wheat has become differentiated into a number of wild and cultivated taxa, and even within the tetraploid durum wheats or the hexaploid bread wheats, the range of phenotypic variation is immense. Here, as for most primitive crop races, there is a high degree of polymorphism for many characters, which is often taken to indicate high genetic diversity.

In the last few decades, however, this genetic variation has been under threat due to the introduction of new varieties, and genetic erosion, as it is called, has led inevitably to the loss of genetic resources in many parts of the world. Fortunately this situation has been recognized, and steps have been taken to collect and conserve germplasm in genebanks at various locations. The methodologies for genetic conservation, especially in the light of pending global climatic change, are discussed later in this chapter. With global warming we shall be faced with the dual challenge of ensuring that genetic conservation takes place, as well as the utilization of germplasm to breed new varieties.

The need for plant genetic conservation is highlighted effectively within proposals for a 'World Conservation Strategy' by the International Union for the Conservation of Nature (IUCN, 1980):

Earth is the only place in the universe known to sustain life. Yet human activities are progressively reducing the planet's life-supporting capacity at a time when human numbers and consumption are making increasingly heavy demands on it. The combined destructive impacts of a poor majority struggling to stay alive and an affluent minority consuming most of the world's resources are undermining the very means by which all people can survive and flourish.

The great Russian geneticist and plant breeder, N.I. Vavilov, has often been described as 'the father of plant genetic resources' (Ford-Lloyd & Jackson, 1986). As long ago as 1926 he proposed that crop plant

improvement should draw from wide genetic variation, and to this end he collected cultivated plants and their wild relatives from most parts of the world. These were to provide 'gene pools' from which cultivars could be bred. Vavilov (1926) was able to reveal that genetic variation in cultivated species was concentrated in certain regions of the world, which he termed 'centres of diversity'. These are the principal areas from which breeders have collected raw material for their work. In recent years the radical changes which have taken place in modern agriculture have presented a formidable threat to the diverse resources held in the Vavilovian centres. Pending climatic change now poses yet another threat to the continued survival of these gene resources, and is another potential cause of genetic erosion.

History of plant genetic resources conservation

In Vavilov's time, the idea of active germplasm conservation had generally not been considered. Material could always be re-collected if seed ran out, or was lost. How times have changed!

Fortunately there was a small group of visionary scientists around the world who began to 'ring the alarm bells' concerning the threatened status of crop germoplasm. Among these were Sir Otto Frankel from CSIRO in Australia, Professor Jack Hawkes from the University of Birmingham, UK, and Professor Jack Harlan at the University of Illinois, USA, members of the Food and Agriculture Organization (FAO) Panel of Experts on plant genetic resources. International activities for genetic conservation were co-ordinated initially in the 1960s by FAO, which established a Crop Ecology and Genetic Resources Unit. In addition, FAO hosted two technical conferences in collaboration with the International Biological Programme (IBP). The recommendations of the first conference held in 1967 are worth highlighting:

1. The location and nature of genetic resources in the field should be surveyed (i.e. in centres of diversity).
2. A corresponding survey of material in existing collections should be made.
3. Assembled material should be effectively used and preserved, this being served by adequate classification and evaluation.
4. Strongest emphasis should be placed upon the conservation of plant genetic resources.
5. Efficient documentation should be carried out at all stages of activity.
6. International co-ordination, guidance and administrative backing should be sought at the highest level.

In 1974 the International Board for Plant Genetic Resources (IBPGR) was established under the auspices of the Consultative Group on International Agricultural Research (CGIAR), which funds a network of International Agricultural Research Centres (IARCs). Since IBPGR was created,

a great deal of progress has been made towards the organization of a global network of genetic resources centres, and a large number of germ-plasm collecting missions have been carried out. IBPGR has had a dramatic catalytic effect upon conservation efforts of scientists and agricultural centres throughout the world.

Patterns of crop diversity

Vavilov focused attention on the diversity to be found in crop plants, and to the fact that it was concentrated in 'centres of diversity'. These centres lie between 20° and 45° latitude north and south of the equator, often in mountainous regions. Vavilov assumed that agriculture developed independently in these areas, because of differences in agricultural method, implements and domestic animals. The concepts of 'centres of origin' and 'centres of diversity' made an important contribution to our understanding of agricultural origins and the geographical distribution of genetic diversity in crop plants. While these concepts have been criticised and subsequently modified by various authors, they still provide a focus for understanding the distribution of genetic resources on a worldwide scale.

However, Harlan (1975) has proposed that the patterns of geographical variation can best be examined on a crop-by-crop basis. In terms of planning genetic resources activities, this scheme allows us to focus in on individual crops, their patterns of variation and how climate might affect this diversity. Harlan has recognized a number of distinct situations which best describe the pattern of domestication and variation. There are five categories:

1. Endemic — crops that originated in a limited area and did not spread appreciably. Good examples include the small-grained cereals from West Africa *Brachiaria deflexa* and *Digitaria exilis*.

2. Semi-endemic — crops that originated in a definable centre and with limited dispersal. Examples include two Ethiopian domesticates, *Eragrostis tef* and *Guizotia abyssinica*, both of which are grown on a limited scale in India. Crops in both of these categories are likely to receive little more than local attention in terms of genetic conservation. Nevertheless, evaluation for different climatic conditions might be worthwhile.

3. Monocentric — crops with a definable centre of origin and wide dispersal without secondary centres of diversity. Crops of this class are mostly new plantation or industrial crops, such as rubber and arabica coffee. In terms of conserving genetic diversity of these crops, natural ecosystem preservation is of extreme importance, since it is in these that the genetic resources are found. Wild rubber trees are components of Amazon rainforest. Wild coffee is being protected *in situ* in Ethiopia.

4. Oligocentric — this category includes ancient widespread crops,

with a definable centre of origin, wide dispersal and one or more secondary centres of diversity. The whole Near East complex of barley, emmer wheat, flax, pea, lentil, oats and chickpea fall within this category; all have secondary centres in Ethiopia, and some also have centres in India and/or China. This particular complex of crops is discussed in the chapter by Erskine and Muehlbauer (this volume).

5. Non-centric — these are crops whose patterns of variation suggest domestication over a wide area, and include sorghum and common bean (*Phaseolus vulgaris*). Such crops perhaps already offer possibilities of adaptation to different environments.

In many areas of the world where traditional varieties can still be found in contact with related wild species, hybridization and introgression continually lead to gene flow between species. This dynamic system continues until modern agricultural practices and varieties replace traditional ones, and 10,000 years of natural evolutionary change are brought to a halt. The threat of global warming will also disrupt the balance between the processes which characterize this dynamic system. In order to be able to respond to climatic change, plant breeders will need sources of genetic variation, and wild species will need to continue to adapt to such changes. The importance of plant genetic conservation can easily be appreciated in this context.

Conservation methods

The strategy employed for the conservation of germplasm depends very much on the nature of the material. Conservation strategies may also be affected by the degree to which environments will change when subjected to climatic change due to the greenhouse effect. Conservation by *in situ* methods will be affected as may field genebanks, other methods will not.

In situ conservation is applied mainly to wild species related to crop plants, to forest and pasture species. It is often recommended that such species should be preserved, maintaining the genetic integrity of their natural state, as communities in stable environments. It is evident that unstable environments, or those undergoing rapid change will not be suitable for conservation purposes. The establishment of 'natural' or 'genetic' reserves recognizes long-term objectives of conservation and the need for continued organismal evolution within natural environments. It might be thought that plants conserved in their natural environments subjected to climatic change would simply fill one objective of *in situ* conservation, and evolve naturally. This, of course, cannot happen over the very short time-spans which apply to climatic change as it is predicted.

There are areas in Israel where diversity in wild wheats, barley and oats is great, where they grow amongst rocks and on poor soils and where the rough terrain creates a natural sanctuary. These communities

are protected against heavy grazing pressure from sheep and goats, and it is assumed that they will continue to evolve. In Anatolia, wild orchards of pears, apples, plums and pistachio have been preserved for thousands of years, and could continue to survive if natural reserves were created. The perennial wild relative of maize, *Zea diploperennis* is currently being conserved within a small area of the 142,000 acres of forest making up Mexico's Sierra de Manantlan Biosphere reserve. The preservation *in situ* of this potentially important species requires special measures, differing from those commonly taken to preserve an endemic species. Conservation of the existing system of traditional land use and management is required. How this reserve and these other examples of *in situ* conservation will fare under the threat of changed climatic conditions can only be surmised at the present time, and such uncertainty poses a major question mark over the whole concept of *in situ* techniques.

Various *ex situ* methods provide the more reliable alternatives for conservation under changing climatic conditions, at least when employing one or other kind of genebank as opposed to botanic gardens, arboreta or mass gene reservoirs which will be exposed to the same problems as *in situ* methods. Static conservation, taking the form of storage of seeds or vegetative material in genebanks where the life processes of the germplasm are reduced to a low level, is both the safest and cheapest method.

Storage of seeds

For the majority of crop plants and many of their wild relatives, seeds can be maintained with retention of viability for long periods of time under conditions of decreased moisture content and low temperature. Under conditions of -20°C and 5 per cent moisture content, it can be predicted that seeds of barley will retain adequate viability for over 70 years (Roberts, 1973). Genebanks with large controlled environment rooms running under these conditions can be found in many parts of the world. These hold large numbers of seed samples. However, small collections of germplasm can be stored equally well for very low cost in domestic deep-freezers.

There are crop plants for which seed storage is not appropriate or even possible. Those which are normally vegetatively propagated, or which do not produce viable seeds, or those where the seeds produced are very short-lived and are killed by exposure to low temperature and moisture, have to be conserved by other means. Many species of fruit, and some large-seeded tree species have seeds which are relatively short-lived and last for no more than a few weeks or months. These include such economically important species as cocoa, rubber, tea, most tropical fruits and many timber species. Vegetatively propagated crops such as potato, cassava, yams, sweet potato, sugar cane and temperate fruit trees present special problems for conservation, not because their seeds cannot be stored conventionally but because it is not convenient to propagate them

commercially from seed due to high levels of genetic heterozygosity, and breeders and horticulturalists commonly require uniform clones.

For these reasons, much interest has focused on the application of tissue culture or *in vitro* techniques to plant genetic conservation (De Langhe, 1984; Withers, 1984). It is possible now to store plants *in vitro* for short periods of time, or longer if subculturing is carried out after certain intervals. Such technology also opens up the possibility of ultra-low temperature storage of vegetative material, or cryopreservation at temperatures as low as -196°C . By this means, germplasm may be stored indefinitely, in 'suspended animation'.

Genetic vulnerability

Nowadays nearly all major crops that we grow have narrow genetic bases, and it is this fact which has contributed to their genetic 'vulnerability'. The problem was first highlighted in the USA in 1970 with the southern corn leaf blight epidemic, when the maize crop was devastated by disease. It came about because most of the hybrid varieties in cultivation at that time had a common form of a specific cytoplasmic gene which happened to confer susceptibility to a particular race of fungal pathogen.

More recently the citrus business in Florida has been continuously attacked since 1984 by a bacterial pathogen (*Xanthomonas campestris*) which is particularly virulent on the small handful of varieties which are grown in that state. Undoubtedly the genetic base of the citrus crop is too narrow and is totally susceptible to the citrus canker bacterium (Sun, 1984).

Other examples of genetic vulnerability can be related more closely to climatic conditions, one particularly in the USSR which was triggered by cold weather (Fischbeck, 1981). Lulled by a series of mild winters in the Ukraine, farmers began growing a wheat variety called 'Besostaja', normally grown only further south. Its popularity grew, until 15 million hectares were being planted by 1972. Disaster struck with a severe winter which caused a shortfall of millions of tons of winter wheat.

Of even greater significance as far as climatic change is concerned are examples of genetic vulnerability of crops brought about by changes in climate which cause changes in crop pathogens. Changes in weather can render conditions more favourable to disease outbreaks, particularly those caused by fungi. Different races of fungal pathogens are known to have different temperature optima. Therefore changes in average temperature in a particular season may well change the races of pathogen which are most common as well, resulting possibly in a lack of resistance in the local crop varieties.

Along these lines, when large areas are planted to a few varieties only, weather-related disease epidemics can cause severe economic losses. Farmers in the eastern USA and Canada lost more than \$240 million due

to blue mould (*Peronospora hyoscyami*) on tobacco (Lucas, 1980). Unusually cool and wet weather had favoured the rapid spread of blue mould. In the following year, the disease hit Cuba, destroying 90 per cent of the cigar crop. Similarly in Korea in 1980, a temperature-related epidemic of rice blast (*Pyricularia oryzae*) required the importation of large quantities of rice. This epidemic was almost certainly due to the narrow genetic base of the Korean crop at that time, where three-quarters of the country's rice growing area were planted with high-yielding varieties of very similar genetic origin (Chang, 1984).

Using genetic resources

The Irish potato famine of the mid-1840s is another classic example of fragility of crop productivity due to a narrow genetic base. The fact that no major crop failure brought on by 'simplification' (Plucknett *et al.*, 1987) has occurred quite on the scale of the Irish one is attributed largely to efforts to build up and use germplasm collections.

The collection and conservation of genetic resources has been undertaken throughout many parts of the world since the 1960s and particularly since the formation of the IBPGR, which stimulated germplasm collection worldwide as well as promoting research into efficient methods of long-term conservation. Germplasm collections, both large and small, covering a range of crop plants are now in existence (IBPGR, 1987).

The actual value of this germplasm and the genes which it may hold can remain undiscovered until it is evaluated alongside new cultivars introduced to a particular region. The semi-dwarf wheats of the Green Revolution when first grown in Mexico were overcome by fungal rust disease, while the 'tried and tested' local varieties resisted attack. Hurried crosses had then to be made using genetic resources available locally, and these gave rise to a successful, high-yielding and disease resistant crop (Borlaug, 1968). When attempts have been made in West Africa to cultivate pearl millets previously bred in India, they have suffered so much with mildew disease that they could not compete with the less highly bred traditional varieties of local origin (Arnold, 1970).

Restriction of the use of germplasm of one region to development of crop varieties in that same region is, however, by no means always the case. For instance, the genetic base represented by potato cultivars in Europe and the USA today can be attributed to the introduction into breeding programmes of genes from many South American landraces and wild species. Yet more important genes await their use according to a report of the International Potato Center in Peru, which has listed nearly 40 conserved potato species containing many agronomically important pest and disease resistance and physiological characteristics (Huaman, 1984).

Rice is an example of a crop where large quantities of genetic material have been collected and conserved over recent years. At the International

Rice Research Institute (IRRI) in the Philippines, scientists maintain seed samples from 84,500 individual collections of wild and cultivated rice in their genebank (Chang, personal communication). This is fortunate because human population increase and urban expansion are continually destroying the natural habitats of wild rices which are known to possess genes of considerable economic importance, and local varieties have been lost due to the cultivation of new varieties. Recently, however, IRRI was able to repatriate local landraces of rice to Kampuchea and the Philippines from where they had been lost (Anon., 1989). It has also been reported to us recently that large populations of wild rice were cleared to build a new airport in Indonesia. A 1983 forest fire in Borneo wiped out another major wild rice area, while in Nepal, swamps in the central and eastern Terai region where wild rice species once thrived have been turned into fishponds. It is impossible to predict how future generations may be disadvantaged by the loss of any wild species and their unique genes. We do know, however, that *Oryza nivara*, a wild rice from India, is the only known source of genes for resistance to grassy stunt virus disease. Incorporation of resistance into improved rice varieties has saved Third World farmers hundreds of millions of pounds in the cost of petrochemical-based pesticides no longer needed to control the insect vector of the virus. A male sterility gene used to assist in the production of hybrid rice varieties came originally from their wild relatives. These hybrid varieties yield up to 30 per cent more than ordinary varieties.

In contrast to rice, collections of sugar beet germplasm are much smaller in number, totalling not more than 5,000 accessions. Within Europe several collections exist in genebanks in Greece, West Germany, the Netherlands, Sweden and the UK (at the University of Birmingham and the Kew Genebank). These collections, along with others in the USA, the USSR and Turkey have recently joined together to form what can be regarded as the first world crop network of plant genetic resources (Anon., 1989). Within this network which is co-ordinated through a computer database in Wageningen in the Netherlands, national germplasm collections can collaborate to discover exactly what they have conserved, what still needs to be collected and how best to rationalize collections and promote the use of these resources for plant breeding.

Within the context of this collaborative network, one of the first plant germplasm collecting missions to visit the UK took place in 1987. A team of scientists from the US Department of Agriculture collected seed of wild sea beet from all around the British coastline. Assistance was provided from the University of Birmingham and the Royal Botanic Gardens, Kew, and over 100 samples were taken back for storage and use in the USA, with duplicates being deposited at Kew. The reason for the visit lay in the fact that recent research in Europe and the USA has highlighted the commercial importance of British and European wild beet for sugar beet breeding. A wealth of genes has been discovered, including resistance to the devastating sugar beet virus disease called 'rhizomania'. What is just as significant is that these wild beets can easily be hybridized

with sugar beet in order to transfer genes of interest. Also, Swedish and Dutch geneticists have just demonstrated that after hybridization, it can take only a few generations of backcrossing to produce a new sugar beet with the desired characteristics:

Available germplasm

Co-operation between the IARCs, national institutes and universities has led to the formation of base seed collections scattered throughout the world (IBPGR, 1987), and, as has already been mentioned for sugar beet (Anon., 1989), for some crops the aim is now to link these scattered collections into self-sustaining world crop networks.

Alongside base collections, active collections hold material under storage conditions that are usually less stringent than those applying to base collections, their material being made available for research and breeding. The development of world crop networks is an attempt to link both active and base collections into efficient international collaborative operations. In the absence as yet of routine handling of germplasm in *in vitro* base collections employing cryopreservation, maintenance of active collections of vegetative material in field genebanks must remain important. In the light of future climatic change the condition of the field collections within the global network (Table 1) should be monitored, particularly as some of these field collections are sited in regions under greatest threat of changing climate.

Over 2.5 million crop accessions are held in some form of storage throughout the world. This figure includes over 1.2 million accessions of cereals, 369,000 accessions of food legumes, 215,000 of forage species, 137,000 accessions of vegetables and 74,000 clones of root crops (Plucknett *et al.*, 1987). A substantial amount of this germplasm represents cultivated forms including landraces. It has been estimated that as much as 95 per cent of the world's cultivated wheat, maize and potato germplasm is already represented in collections. This figure falls to only 50 per cent for crops such as *Phaseolus* beans, sweet potato and cucurbits, and is even lower for crops like millets and cassava. If the coverage of wild relatives of crop plants under conservation is considered, then the picture is vastly different. While it is estimated that 60 per cent coverage of wild species of wheat is achieved, and 70 per cent for a crop such as tomato, only 10 per cent or less of wild species have been collected for a large range of crops including rice, sorghum, millets, *Phaseolus* beans, pea, cowpea, lentil, lupin, cassava, yams and sweet potato.

Referring to the figures quoted above, germplasm conservation can still be regarded as inadequate for some crops, and particularly as far as wild species relatives are concerned (see Williams, this volume). Lack of adequate representation also applies to some geographical areas. For instance, arid areas, the Mediterranean region and the tropics and subtropics will be the focus of much future forage germplasm collecting.

Table 1 Global network of field collections (active collections for vegetative material)

Crop	Species covered	Geographical representation		Institute
		Global	African Asian	
Roots and Tubers	Cassava	●	● <i>Central American</i>	CIAT INIA, Mexico IITA
	Sweet potato	●	● <i>Asian and Pacific</i>	AVRDC, Taiwan, China IITA
Fruits	Banana	●	● <i>Southeast Asian</i>	Banana Board, Jamaica PCARRD, Philippines DGRST, Cameroon
		●	● <i>East Asian</i>	Fruit Tree Research Station, Tsukuba, Japan
		●	● <i>Mediterranean Mediterranean and African</i>	INIA, Valencia, Spain IRFA, Corsica, France
		●	● <i>North American</i>	USDA
		●	● <i>Latin American</i>	CENARGEN, Brazil
		●	● <i>South Asian Subfamily Aurantioideae</i>	IIHR, India* University of Malaya, Kuala Lumpur, Malaysia
Industrial Crops	Cocoa	●	●	University of the West Indies, Trinidad and Tobago
		●	●	CATIE, Costa Rica
		●	●	Sugarcane Breeding Institute, Coimbatore, India*
		●	●	USDA, Florida, USA
Perennial Species	<i>Allium</i>	●	● <i>Short-day species</i>	Hebrew University of Jerusalem, Israel*
		●	● <i>Long-day species</i>	Research Institute for Vegetable Growing and Breeding, Olomouc, Czechoslovakia
	<i>Arachis Glycine</i>	●	● <i>Wild perennials Wild perennials</i>	CENARGEN, Brazil CSIRO, Australia

*Under discussion or awaiting formal agreement

This is of particular significance when taking into account climatic change, as it is the arid and semi-arid regions which are under greatest threat, and where drought-tolerant forages may have the most to offer as a genetic resource to combat the effects of global warming. In this context, collaboration between scientists in the Canary Islands and at the University of Birmingham for the collection, conservation and evaluation of an endemic legume species, *Chamaecytisus proliferus* or tree lucerne, in association with scientists in the developing world may provide a model for germplasm evaluation for climatic change.

More specific examples can be given of the urgency for undertaking collection in certain areas. Until recently very little collecting had been carried out in the Arabian Peninsula, a region where agricultural development in the last 15 years has been very rapid, on top of the fact that it is an area which may be affected to a great extent by climate change during the next 15 years. IBPGR has listed the northern Hajar mountains of Oman as important for wheat collecting, while the collection of alfalfa from the southern part of the Arabian Peninsula as a whole is seen as a priority (IBPGR, 1987). Groundwork is currently underway for the future collecting of wild species both in the arid northern mountains and the unique, monsoon-affected Dhofar mountains of the south.

In order to identify gaps accurately (such as those just described) in the world holdings of germplasm of a particular crop, the genetic diversity of existing collections must be ascertained. This can only be done after passport data are analysed, and evaluation of germplasm is carried out. Unfortunately, complete sets of passport data are not always available in genebanks, and pathetically little germplasm evaluation is undertaken. Information from ecogeographical surveying work and taxonomic studies is equally important but often unavailable. This lack of information makes effective planning for future germplasm collection more difficult.

Genetic resources in the future

Not only are we confronted with a high level of uncertainty related to GCMs and the prediction of what form climatic change will take over the next quarter century, it can be seen that we have a high degree of uncertainty about the future needs for germplasm collection.

As far as utilization is concerned, it may well be that some predictions can be made as to the way in which genetic resources can provide a response to effects of climatic change. There are, for instance, within the list of main oil crops grown throughout the world today, ones which are adapted to different climatic regimes, and these have already been classified (Table 2). Perhaps by juggling with these crops and where they are grown, natural oil production can be maintained in the future under changing climatic conditions, without resorting to breeding new crop varieties.

Given that it is not yet possible with any degree of certainty to predict how climatic change will affect crops in any particular area, it is unrealistic to expect plant breeders to consider changing their breeding objectives at the present time. On the other hand, if we are to expect climatic change to occur rapidly over the next 20 or 30 years, it does not give plant breeders much time to respond in conventional ways. The immediate response in terms of crop production may well be to move existing cultivars about, as in a game of chess, to optimize as much as possible the interaction between crop variety and changing or changed environment, and to obtain better data which allow breeders to predict

Table 2 Distribution of some main oil crops on a taxonomic and climatic basis. (© Crown Copyright, 1971, from Godin & Spensley, 1971)

Species	Family	1	2	3	4	5	6	7	8
Soybean	Leguminosae	+				+		+	
Sunflower	Compositae					+	(+)	+	+
Groundnut	Leguminosae		+	+		+	+	+	
Cotton	Malvaceae			+	+	+	+		
Rapeseed	Cruciferae			(+)		+		+	
Olive	Oleaceae				(+)		+		
Sesame	Pedaliaceae			+	(+)	+	+	+	
Maize	Gramineae	(+)		(+)	+	+	+	+	
Safflower	Compositae			+			+		+
Coconut	Palmae	+	+	(+)					
Oil palm	Palmae	+							
Babassu palm	Palmae	+		+					
Linseed	Linaceae			(+)		+		+	
Castor oil plant	Euphorbiaceae			+		(+)		+	
Tung oil tree	Euphorbiaceae					+		+	
Oiticica	Rosaceae				+				
Niger seed	Compositae			+					
Hemp	Cannabaceae							+	
Perilla	Labiatae							+	
Poppy	Papaveraceae							+	+

() Limited cultivation possible; |, irrigation necessary. 1, tropical rain forest; 2, tropical monsoon; 3, tropical savanna; 4, dry tropical, i.e. steppe and desert; 5, humid subtropical; 6, dry subtropical, i.e. Mediterranean; 7, humid temperate; 8, dry temperate.

Source: Godin, V.J. & Spensley, P.C., 1971, Oils and oilseeds, No. 1, Crop and Products Digest, Tropical Products Institute, London

the performance of different crops under different environmental regimes, as has been tried out on a limited scale for the potato (Young & Tai, 1983). If the situation in the future demands that new varieties of crops be produced to fit changed environments, then plant breeders will need to turn to the new biotechnologies in one way or another in order not only to increase the rate at which germplasm can be utilized in the plant breeding process but also so that genes can be transferred frequently from more distant crop relatives.

It is already a widespread possibility to put genes into crop plants by various techniques of genetic manipulation. Where researchers in molecular biology lag behind is in their ability to identify, isolate and clone major genes of interest, and it is in this area that the rapid response which may be required for climatic change may fail. There is little doubt, however, that the future will see further strengthening in the links between genetic resources and biotechnology. Climatic change may provide the impetus for the research that is still required.

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