CURRENT STATUS OF CROP PLANT GERMPLASM

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I. INTRODUCTION

Cultivated plants are part of our human heritage. Without their assured food supply we would not be free to engage in such activities as the arts and learning and/or live at high densities in large metropolitan centers. And yet, this biological treasure is becoming endangered. Never before in human history have the rates of extinction for the ancestral forms of our basic agricultural plants been as high as they are now. To meet increasing demands of our population there is an ominous conflict between agricultural modernization to optimize production, and the preservation of indigenous agriculture along with the genetic diversity found in those areas associated with agricultural origins and development.

Germplasm is the source of the genetic potential of living organisms. Among other things, diversified germplasm allows them to adapt to changing environmental conditions. No single individual of any one species, however, contains all the genetic diversity for that species. This means that the total genetic potential is represented only in populations made up of many individuals. Such genetic potential is referred to as the gene pool. The potential represented in a gene pool is the foundation for our biological renewable crops in agriculture and forestry.

Extinction of a species or a genetic line represents an irreversible loss of a unique resource. This type of genetic and environmental impoverishment is irreversable. Throughout the world, people increasingly consume food, take medicine, and employ industrial materials that owe their production to genetic resources of biological organisms. Given the needs of the future, genetic resources can be reckoned among society's most valuable raw material. Any reduction in the diversity of resources narrows society's scope to respond to new problems and opportunities.[1] To the extent that we cannot be certain what needs may arise in the future, it makes sense to keep our options open. This conservation rationale applies to the earth's endowment of useful plants more than to almost any other category of natural resource.[2] It is difficult to visualize a challenge more profound in its implications yet less appreciated by the general public than plant genetic resources.

II. THE CHALLENGE

Food security will be a more obvious challenge between now and the end of the century.[3] By the year 2000 the human population of more than 6 billion will require an agricultural production 60% greater than that harvested in 1980. Most of this population increase will take place in the developing countries where demand for food and agricultural products will double. The problems of an increasingly precarious food supply and rural poverty is expected to increase the pressure on scarce land for arable farming and meager resources for agricultural inputs.[4-8] According to conservative FAO estimates there would be a horrifying increase in the number of seriously undernourished to some 600 to 650 million.

Since new arable land in the developing nations will become steadily more scarce, higher yields from land already in production will be the only way to support the population increase. Higher yields mean using more fertilizer, plowing and water lifting energy, and improved plant material. Breeding of better crop plants will be the focal point around which all strategies to increase crop yields will develop.[9] It is the positive response of these seeds and other plant material to soil, water, fertilizer, pest, weather, and social institutions that will determine the success of the future agricultural evolution under domestication.[10]

A. Genetic Erosion

The technological bind of improved varieties is that they eliminate the resource upon which they are based. Over the past 10,000 years crop plants have proliferated an innumerable number of locally adapted genotypes. These land races and folk varieties of indigenous and peasant agriculture have been the genetic reservoir for the plant breeder in crop improvement.[11] Suddenly this genetic diversity is being replaced with a relatively small number of varieties bred for high yields and other adaptations necessary for high input agriculture.[12-17] In addition, the scarcity of land is forcing changes in land use and agricultural practices resulting in the habitat disappearance of wild progenitors and weedy forms of our basic food plants. As a result of these two trends, there is urgent need to collect and conserve the diverse genetic materials that remain. In a world where per capita resources are decreasing as the human population grows, the concept of a sustainable future is becoming increasingly more important. Biological diversity is one of the components of any sustainable future that includes humans.[18]

The number of plant species that has historically fed the human population is only about 5000.[19-21] This small number is less than a fraction of 1% of the flora of the world. As the human population has grown in number we have depended increasingly on the shorter list containing the most productive plants. Today only about 150 plant species with about a quarter million local races are important in meeting the caloric needs of humans (Figure 1). The process of plant breeding is a dynamic one of genetic selection in response to changing diseases, parasites, agricultural techniques, and human use. The earliest domesticated crops were probably not much more productive than their wild progenitors, but the act of cultivation was a radical break with the past.[24] This restructuring of the food supply set in motion numerous interlocking forces, many not at the time consciously intended, that have directed the evolution of the crops and the societies that attended them. As the human population increased, the growing of these crops expanded into many different environments and an enormous wealth of genetic variation was created and preserved over the centuries in locally adapted races. Only a small fraction of this variation has been sampled and included in the present leading crop varieties.[25]

For convenience, germplasm resources can be classified into seven distinct categories:

- Varieties or cultivars in current use
- Obsolete cultivars
- Primitive cultivars or land races of indigenous agriculture
- Wild and weedy taxa, near relatives of cultivated crops

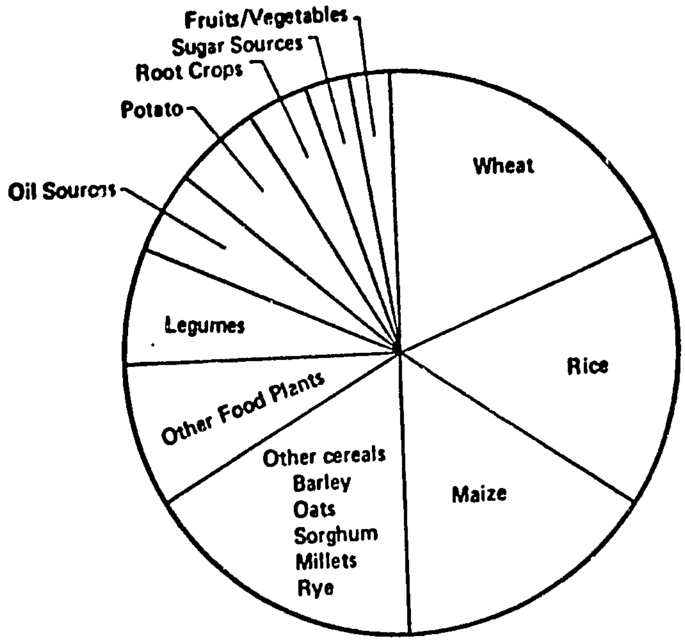

FIGURE 1. Human calorie sources from plants.

- Special genetic stocks, which are the tools of plant breeders
- Induced mutations by X-rays or some other high energy or chemical mutagenic means
- Coadapted genetic stocks, where two forms of a crop, two distinct crops, or a crop and symbiont such as a crop and its unrelated weed or a nodule forming bacteria are grown together

The varieties or cultivars in current use have generally undergone a rather vigorous selection process by plant breeders and are more or less homogenous. These varieties possess a "highly tuned" set of genes but a considerably narrowed gene base over the native land races from which they have come. These advanced varieties are the ones most widely and frequently used as parents in current breeding programs or for introducing a variety into an area of comparable climate.

Obsolete varieties are advanced cultivars from the past that have been displaced by newer releases. Often this older material was one of the parents for the new release. Both special genetic stocks and induced mutational stocks are comparable to obsolete varieties in the amounts of genetic variation they possess.

Primitive varieties or land races are the real treasure house because they are the largest depository of genes for a crop, but also the largest unknown because (1) they are unusually heterogenous and (2) little data exist on their morphological, biochemical, and genetic traits, or their responses to pest or environmental stress. Most companion planting systems of category seven are "special case" land races where two distinct genetic potentials have been coadapted to each other. There are not many of these systems left in the world but genetically they are very valuable because of their potential in the new genetic engineering.

Generally land races perform poorly under inputs of high fertilizer, water, and intensive cultivation and are replaced by the "new seed". On the other hand, there is a fairly wide variation in the ability of land races to survive fluctuating environments, to withstand cold, drought, disease, insect damage, and other such variables. After all, most land races represent accumulated mutational events integrated and balanced in the real world over thousands of years. It is with the genes that they possess that the study of modern plant breeding has been created.[26] Interestingly, we have synthetic fibers replacing cotton and linen, and synthetic rubber replacing natural rubber, but as yet we do not have any synthetic foods replacing our basic crop plants: rice, wheat, corn, barley, rye, oat, sorghum, potato, sweet potato, sugar beet, sugar cane, common bean, soybean, peanut, banana, coconut, and casava that supply ¾ of all human energy worldwide.

This list is primarily a caloric list and does not recognize the important role of low caloric vegetables and fruits in supplying vitamins, minerals, and protein to human nutrition. This list does not include regional foods that locally may supply more than ½ of the calories consumed; and, in addition, both pasture forages and fiber crops are omitted. In the U.S. our five most valuable ($) crops are corn, soybean, wheat, alfalfa, and cotton; and so it becomes obvious that basic caloric food plants are only a part of the genetic resources for crop plants.

Conservation in perpetuity of plant genetic resources can take three forms:[28]

- Entire biomes — the entire preservation of vast tracts with *in situ* conservation of animals and plants. This level of preservation will be extremely important in slowing the species extinct rate but will have little impact on genetic resources of useful plants.[29]
- *In situ* preservation as land races and wild relatives where genetic diversity exist and where wild/weedy forms are present, often hybridizing with the cultivated. These are evolutionary systems that are difficult for plant breeders to simulate and should not be knowingly destroyed. Their preservation probably is not possible but the deacceleration of their disappearance will give us more time to better understand how these systems evolved. Considerable potential for creative institutional arrangements exists for *in situ* preservation, especially in the developing countries.[30]
- *Ex situ* preservation as seed or in vitro cell lines stored in gene banks under appropriate conditions for long-term storage. This is the mode for the preservation of most genetic resources. Such a system draws genes out of circulation and, therefore, to be useful requires documentation and evaluation so that a plant breeder will have enough information to know what to request. Information management will be as important as the physical arrangements of the gene bank. Gene banks slow down crop plant evolution and so the hybridization and breeding process becomes a necessary part in making *ex situ* preservation useful. *Ex situ* preservation has three aspects: exploration, collection, and banking, then evaluation and documentation, and, lastly, breeding for enhancement.[31]

Clearly realizing our dependence on genetic resources creates a sense of humility which, in the arrogance of our accomplishments, we have tried to ignore. In the words of Sir Otto Frankel: "To an unprecedented degree, this decision of vast consequence for the future of our planet is in the hands of perhaps 2 or 3 generations . . . No longer can we claim evolutionary innocence . . . We have acquired evolutionary responsibility."[32] Sir Otto has been very blunt. If we know the value of what we are destroying through negligence and inaction, then we are morally responsible.

B. Genetic Vulnerability

Genetic vulnerability is the risk of high input agriculture with commercial food crop varieties typical of developed nations while genetic erosion, the gradual persistent loss of plant genetic resources, is most typically but not exclusively a phenomenon of land races in developing nations. Genetic vulnerability is the "thin ice" of a narrow genetic base.

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Table 1
ACREAGE AND FARM VALUE OF MAJOR U.S. CROPS AND EXTENT TO WHICH SMALL NUMBERS OF VARIETIES DOMINATE CROP ACREAGE (1969 FIGURES)

Crop	Acreage (millions)	Value (millions of dollars)	Total varieties	Major varieties	Acreage (%)
Bean, dry	1.4	143	25	2	60
Bean, snap	0.3	99	70	3	76
Cotton	11.2	1200	50	3	53
Corn[a]	66.3	5200	197[b]	6	71
Millet	2.0	?		3	100
Peanut	1.4	312	15	9	95
Peas	0.4	80	50	2	96
Potato	1.4	616	82	4	72
Rice	1.8	449	14	4	65
Sorghum	16.8	795	?	?	?
Soybean	42.4	2500	62	6	56
Sugar beet	1.4	367	16	2	42
Sweet potato	0.13	63	48	1	69
Wheat	44.3	1800	269	9	50

[a] Corn includes seeds, forage, and silage.
[b] Released public inbreds only.

Never before have there been such widespread monocultures (dense, uniform stands of billions of plants) covering thousands of acres, all genetically similar. The narrowness of the genetic base is responsible for, on the one hand, the predictably higher yields, but, on the other hand, the greater risk of crop failure as occurred in the wheat stem rust of 1954 or the southern corn blight of 1970 in the U.S. The Irish potato famine in the 1840s is a classic example of genetic vulnerability.[25]

Throughout the world there exists diversity in the many strains of our common plants and their pathogens. Genetic changes, either mutations or new recombinations, are always taking place in a population of the pathogen (bacteria, fungus, insect, nematode, etc.), and if a new genetic combination of an individual suddenly grows successfully on a previously resistant plant host, it will be able to spread across the entire host population if the latter is genetically uniform. With landraces such genetic uniformity seldom extends beyond the fields of a single farmer or the fields of a village.

Following the U.S. corn blight the National Academy of Science Committee on Genetic Vulnerability of Major Crops (1972)[11] looked at the genetic diversity of American crops and found them dangerously narrow. For example, 96% of the garden pea crop (Table 1) was planted to only two pea types, 95% of the peanut crop to only nine varieties, and over half of our two largest harvests, corn and soybeans, were based on less than six basic seed sources.

This Academy report was the first major look at the germplasm resources of this country since the 1936 and 1937 *Yearbooks of Agriculture*.[34,35] The Academy report was limited to the major crops: corn, wheat, sorghum and pearl millet, rice, potato, sugar beet, sweet potato, soybean and other edible legumes, cotton, and the vegetable crops. The report is not as detailed as the more extensive yearbooks. In fact, it might not be possible to achieve today a review as comprehensive as the two volumes produced in a period of exuberance over the use of genetics to enhance agricultural productivity.

The Academy findings of vulnerability in the dominant crops of 1969 are essentially

Table 2
SCIENTIFIC MAN YEARS (SMY) ASSIGNED TO PLANT BREEDING RESEARCH (1969—1970) AND 10 YEARS LATER (1979—1980)

Commodity agronomic	1969—70 Total (SMY)	1979—80 Total (SMY)	Commodity horticultural	1969—70 Total (SMY)	1979—80 Total (SMY)
Corn	65.1	68.0	Potato	20.0	15.6
Grain sorghum	16.4	17.5	Carrot	1.5	2.6
Rice	7.5	10.5	Tomato	20.8	13.1
Wheat	51.2	58.5	Bean-pea	20.1	19.6
Barley	20.0	13.9	Sweet corn	3.3	4.8
Oat	15.2	13.7	Cucurbit	10.5	16.4
Small grains	23.3[a]	11.1[a]	Sweet potato	3.7	3.9
Soybean	35.9	42.4	Crucifer	1.2	2.8
Cotton	45.8	42.0	Onion	1.0	1.4
Tobacco	32.3	16.5	Vegetable crops	35.1[b]	26.6
Alfalfa and other legumes	24.3	42.7			
Grasses and other forages	33.0	35.9			
Total	370.0	372.7	Total	117.4	105.8

[a] Scientific man years assigned to small grains without specifying crop. This value is in addition to the assigned values for wheat, barley, and oat.
[b] Includes lettuce and other crops not itemized separately; in addition, this value would include commitment to the listed vegetables without specifically designating the programs by crop.

From analysis of 1969 CRIS reports by H. J. Hodson, Coop. State Res. Serv., USDA.; analysis of 1979 CRIS report by W. C. Schaefer, USDA-ARS.

true for a decade later. The U.S. is still without the institutional arrangements to monitor genetic vulnerability or mitigate its impact.[36]

The forces that promote uniformity, and, therefore, vulnerability, are market place forces and consumer preferences. The market demands uniformity and efficiency and these are best met with genetically identical varieties. Agricultural inputs, machinery, processing machinery, and visual clues influencing the consumer all promote pressures for plant breeders, plant pathologists, entomologists, and others to go for uniformity and limit most of their work with small and gradual improvements using proven elite germplasm rather than unadapted and unproven exotic varieties.[37]

The fact that most exotic introductions do poorly have convinced many breeders to think of them as worthless. The truth is that seldom are introductions valuable as a superior variety when well-established elite lines already exist for the region, but introduced exotics should be considered valuable as parents and this requires careful screening and evaluation, an effort that has low priority as labor costs increase. Yet the introduction of superior genes is probably one of the most cost effective R and D payoffs in today's market.[38] This high rate of return is one of the reasons genetic engineering is so attractive to the financial community.

Over the past 10 years since the NAS publication on genetic vulnerability the USDA man power engaged in plant breeding has made only marginal changes (Table 2). There are approximately 500 scientific man years in USDA and USDA/State cooperatively breeding programs in the U.S. The exact number of plant breeders for crop plants in the private sector is not known to me but probably is not larger than those in the public sector. The plant breeder is at the research and development end of the use of plant genetic resources and that such a small cadre can maintain a constantly improving list of crop varieties is a tribute to the value of germplasm. For lack of a better scale, the effectiveness of this research and development can be measured by the ratio of researcher over consumer served. Since U.S. agriculture feeds an excess of 500 million (our population plus exports), the effectiveness ratio for public sector plant breeding is $10^6:1$, an efficiency ratio for research and development few institutions or industries could match.

Knowing what is in the world collection has been one of the main stumbling blocks to their use and the second has been the high cost of growing it out every couple of years.[19,40] Lastly, there have not been many rewards for the people who collected, introduced, and maintained genes in crop collections. The payoffs come too late for personal satisfaction or public recognition. Hiproly barley (CI 3947) and (CI 4362) was introduced from Ethiopia and made a part of the USDA world collection of small grains in 1924. It wasn't until 46 years later that the high lysine and total protein were discovered in these accessions. Opaque-2, a mutant maize of an Enfield, Conn., farmer's field (1922) was studied by Jones and Singleton (1938) as a new endosperm gene and maintained in their collection of mutants, but it wasn't valued until the 1960s when it was discovered to possess a gene for high lysine, an essential protein for humans, classically low in maize diets. The impact of a gene depends on it being discovered and on it being valued. Values change and currently very "worthless genes" might hold the key to overcoming a vulnerability in the year 2000.[37]

There is nothing biologically unsound about breeding for high yields, and using a narrow genetic base is a plant breeding expediency, necessary to obtain the most uniform high yielding seed in the shortest period of time. The price of this expediency is constant vigilance and backup of the gene banking system. The 1970 corn blight was quickly turned around by using obsolete cultivars which did not possess the type-T cytoplasm that showed the high susceptibility to the leaf blight fungus caused by *Helminthosporium maydia*. Approximately 80% of the 1970 U.S. corn crop was planted to strains using type-T cytoplasm and approximately 20% of the crop was destroyed. Fortunately for us the effect of the blight was limited to higher food cost and caused no human starvation, but such a crop failure in countries such as Guatemala or Kenya, where people obtain half of their calories from corn, would have been disastrous.[25]

Genetic vulnerability is expected to increase as crops become more genetically uniform. The price for the maintenance of high yields by monoculture farming will be to constantly change the genetic material and breed for resistance against the latest problem that threatens the yields.[41] There is usually a 3- to 5-year lag between the first appearance of the problem and an epidemic. Our first indication of trouble with wheat stem rust which affected the wheat harvest of 1953 and 1954 occurred 10 years earlier in 1942, 43. The corn leaf blight which hit T cytoplasm of maize in 1970 was first identified in 1961. In both cases there was sufficient lead time for breeding programs *if* the early warnings had been interpreted correctly.

C. Genetic Wipeout

The third threat to crop plant germplasm is genetic wipeout. Genetic wipeout is the rapid and wholesale destruction of genetic resources.[16] Social disruptions such as political instability or crop failure and famine can eliminate genetic resources. Quite literally, the genetic heritage of a millenium in a particular valley can disappear in a single bowl of porridge if the seeds are cooked and eaten instead of saved as seed stock. Equally dramatic is the discarding of a genetic collection because a curator retires or the collection is no longer of use to the institution.[2] A classic case of the above is the USDA melon breeding program. The crop was threatened by mildew problems and plant

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explorers assembled a world collection of melons. The resistance was located and bred into the crop and the seed of susceptible melon types discarded. No sooner had the collection been thrown away that attacks of virus threatened the crop and plant explorers went out for a second collection. H. V. Harlan could have thrown out the small grain collection containing Hiproly barley and D. F. Jones could have thrown out his endosperm mutants and we probably wouldn't have high lysine barley and corn today. At the present time there is no institutional arrangements by which the perpetuation of genetic collections can be coordinated. The U.S. has no policy, no clearing house for privately and/or publicly held research, and working collections of genetic stocks

These three processes — genetic erosion, genetic vulnerability, and genetic wipeout — are not mutually exclusive but are, in fact, interlocked by the demands of an increasing human population and rising expectations. Why, if germplasm resources are such an imperative, are plant genetic resources undervalued?

III. THE USE OF GERMPLASM

To better understand why crop plant genetic resources have been undervalued I think we need to look at the context in which they are used. Certainly the most important is plant breeding. Plant breeding is a method of germplasm enhancement of already existing allelic variation, of creative recombination through hybridization of differing genotypes, and intense artificial selection of plant forms that probably would not survive in the wild. Biological diversity is the raw material of the plant breeding process and traditionally this resource has been free — collected in primitive landraces in peasant fields around the world, sent in an envelope on request, stored in a gene bank on the possibility that some person will have need of the plant in the future. The plant explorer who underwent the hardships and dangers never cashed in on the useful gene collected, the plant introduction officer never became a hero for keeping the thousands of envelopes catalogued separately and orderly, and the gene bank personnel were never thanked for maintaining safe storage conditions every hour of every day, year after year. Biological resources are renewable and historically humans could own a tree or horse, but once they had given seed of the tree away or sold the colt of the horse they did not traditionally have claim to the seed or progeny of the colt. Traditional plant genetic resources have been a heritage not subject to the narrow concept of ownership. Because it has been a renewable resource subject to the rapid geometric increase of biological reproduction, there has not been a measured stewardship to preserve the heritage because we could always make more. Suddenly the world is changing and these old assumptions are not holding true. With plant breeders' rights, genetic resources can be owned and without management intervention the genetic heritage of crops will be significantly narrowed.

Plant breeding as a human activity can be viewed as developing historically through three phases, and we are currently on the threshold of a fourth. The earliest domesticated crops were probably not much more productive than their wild progenitors, but the act of cultivation was a radical break with the past. We know that this environmental rearrangement can be traced back to at least five areas (China, Southeast Asia, Near East, Mexico/Guatemala, and South American Andean highlands) and probably more origins of agriculture which took place independently in different parts of the globe.[21,24] This was the first stage of plant breeding or human control over crop plant evolution. All the important world crops (wheat, corn, rice, barley, potato) were developed in this first stage.

The second stage of plant breeding comes with the discovery of the New World and the circumnavigation of the world, with the rapid diffusion of crops, livestock, and farming

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techniques that followed. The U.S. experience with agricultural productivity has been rich because of the worldwide genetic contributions to the nation's plant breeding and improvement process. The earliest settlers brought with them from their homeland the native varieties or landraces and grew them in the new land. Thus, barley from England grew beside barley from Germany in the newly settled colonies. Ship captains often brought back such cargoes as wheat grown in the Punjab of India and purchased in the port of Calcutta, and rice from China or Madagascar for a relative or friend to try on the farm. The Spanish missions in the West introduced arid land crops completely foreign to farmers of the east coast. And later, with the large-scale immigration from central and southern Europe, new and distinct genetic diversity was added to the basic crop plants. The service that these immigrants rendered by bringing seed with them was to establish a broad genetic wealth for plant breeding and improvement, which started on the American homestead and later became a service of the land grant colleges and agricultural field stations.[42] This migration and acclimatization of crops throughout the world often in conjunction with hybridization between dissimilar varieties was the basis of the second stage of plant breeding.

Marquis wheat is a good example of this second phase. Marquis, an outstanding bread wheat, was introduced into the U.S. in 1912 from a cross of Red-Fife (a wheat whose ancestry traces back to Scotland, Germany, and ultimately Poland) and Calcutta (a hard amber wheat from the market in Calcutta but which had probably been grown in the Punjab of India 800 miles away). Marquis wheat is a hybrid of two very dissimilar parents, yet its ancestry is present in about half of all American wheats grown today.

The third stage of plant breeding and improvement began with the rediscovery of Gregor Mendel's classic experiments on the heredity of garden peas, and for the first time the plant breeder had a clear idea of how to proceed with crop improvement. A good case study for this third stage of plant breeding would be the Green Revolution wheats which currently feed over one billion people.[43]

The development of these wheats began in 1943 where the Rockefeller Foundation, in collaboration with the Mexican Ministry of Agriculture, began a research program designed to increase the production of Mexico's basic crops: corn, bean, potato and wheat. A broad-based breeding program was initiated with each of these crops. Because most wheat grown in Mexico was highly susceptible to stem rust, the initial breeding focused on increasing resistance to this fungus disease in existing Mexican varieties. The development of new wheats possessing an accumulation of rust-resistant genes and the development of improved agricultural practices for the Mexican wheat, such as the use of fertilizers, pesticides, better seedbed preparation, and irrigation made a substantial impact on wheat yields. By 1957, Mexico had achieved self-sufficiency in wheat for its population. Over a 10-year period the average wheat yield rose from 740 kg (1628 lb) in 1945/46, to 1440 kg (3168 lb)/ha in 1957/58. (There are 2.2 a[illegible]s in a hectare.) Then the yield response began to level off because plants in the most productive fields would develop weak stems which would not support the heavy seed set when nitrogen fertilizer was applied in quantities of more than 80 kg/ha. To increase the yields further more fertilizer-responsive wheat varieties would have to be bred.

The first intensive breeding program to develop semidwarf spring wheats was started by Norman Borlaug in 1954 when a wheat, Norin 10 × Brevor, was crossed with indigenous Mexican varieties. The dwarf wheat Norin × Brevor came from the U.S. and the dwarfing trait in Norin 10 from Japan. Following World War II an agricultural adviser to the U.S. Army of Occupation in Japan had observed Japanese farmers growing short, stiff-strawed wheat varieties that remained erect under heavy fertilizer application. The dwarfing short-stature gene came from a Japanese wheat which in 1917 was crossed with Glassy Fultz, a selection of the American soft red winter wheat variety

Fultz, at the Central Japanese Agricultural Experiment Station to produce Fultz-Daruma. The variety, in turn, was crossed with the American hard red winter variety Turkey at the Ehime Prefectural Agricultural Experiment Station in 1925 in an effort to produce rust-resistant, short-stemmed, early maturing varieties. Following seven cycles of selection by plant breeders Norin 10 was registered and released in 1935 for Japanese farmers. (The Japanese word "norin" means "agriculture and forestry", and varieties officially released are so named and given a number.) The Norin 10 brought to the U.S. in 1946 was not adapted for direct planting in American field but was introduced into breeding nurseries and released by Orville Vogel from Pullman, Washington as the variety Gaines in 1962. Vogel had supplied the Norin 10 × Brevor cross to Borlaug.

Of the thousands of hybrid seeds containing the dwarfing gene grown in the Mexican program, only three plants were selected as showing promise. The selected progenies of these semidwarf spring wheats possessed the short stature of the Norin 10 and the disease resistance of the Mexican parents along with genes for an increased number of fertile florets per spikelet and an increased number of stalks per plant. These three plants were the narrow bottleneck of vigorous selection from which literally billions of wheat plants have been produced.

The introduction of Norin 10 genes into the Mexican program led to the development of the first short-statured and lodging-resistant spring wheat varieties, which first were grown by Mexican farmers in 1962. Thus, Mexican wheat yields, which had leveled off after 1958 because heavier fertilizer application was not possible, started rising again. With the use of these short-stature varieties yields as high as 8 metric tons/ha became common.

International diffusion of these varieties began almost immediately at the experimental level. India and Pakistan were involved in the program from an early date. The new Mexican wheats were first grown in India in 1962. By 1965 India had an order for 18,000 metric tons of Mexican wheat and Pakistan for 42,000 metric tons. This successful rapid transfer of plant-breeding technology halfway around the world broke the static yield potentials of those regions.

The Mexican varieties proved remarkably well adapted to India and Pakistan because in accelerating the Mexican wheat program two generations of the breeding material were grown each year at different climate and day-length regimes. A valuable side effect of this system was to establish a plant relatively insensitive to day length. The normal winter crop was grown on the northeast coast of Sonora essentially at sea level. The summer crop was grown at high elevations (2600 m, 8530 ft) in central Mexico near Toluca. The Toluca site has heavy rainfall and severe epidemics of both stem and stripe rust. Selection for broad disease resistance and the use of widely adapted varieties that were not bred to pure line standards meant that these semidwarf Mexican wheats — Penjamo 62, Lerma Rojo 64, Ciano 67, INIA 66, and Sonora 64 — possessed a reservoir of genetic diversity that could be incorporated into the breeding programs of new host countries. The adaptation and use of these wheats that is now occurring in less developed nations is a continuing process of crossing them with indigenous varieties and selection for growth fitting local conditions. Good examples are Kayansona and PV-18, both wheat releases of Punjab Agricultural University (Ludhiana) in the wheat belt of India. These two varieties were selected out of seed which Borlaug had sent from the Mexican program in 1963. The wheat variety PV-18 was developed from a cross of Penjamo (from Borlaug) and Gabo 55. The variety Kalyansona is a sister strain of PV-18 and resembles the latter in almost all the plant characteristics except that the grains are amber (the preferred color in Punjab bread wheats). Both varieties possess high-tillering capacity and a wide adaptability to the various climatic conditions of north India.

The specific use of the dwarfing gene from Norin 10 has affected the food supply of one quarter of the people of the world (one billion plus) and for over 100 million it has been the margin of survival. This gene from a Japanese landrace has literally transformed the world wheat crop, yet its value was unrecognized for a long period of time. As early as 1874 the U.S. agricultural attache to Japan described in his reports the Daruma type of short straw wheat, but seed was not collected until 1946 and not released in a U.S. variety until 1962. This 92-year lag period is not going to characterize the fourth phase of plant breeding: genetic engineering. The use of radical phenotypic changes will be more widespread and the incorporation of genes that affect plant responses to stress and productivity will be more immediate.[37]

Plant breeding by genetic engineering promises to have an impact equal to the magnitude of computers in the way we go about managing and structuring the world around us. Suddenly plant breeders have new parasexual systems to transfer genes which have none of the old constraints of being genetically related. This new ability to introduce genes within species and between distantly related species at will, and manipulate them in ways not thought possible until the recent advances in cell biology, are redefining the potential of plant breeding. The dramatic potential to put legume roots and their nodule symbionts onto the shoots of cereals capture newsprint attention but equally dramatic will be the transfer of some of the growth responses of weeds into the crop plant. Many of these weeds are already coadapted at many gene sites to coexist with the crop plant and the addition of this new germplasm will create an explosive evolution for the plant breeder. Some of the most immediately useful genes for genetic engineering will come from companion genetic stocks which have classically been grown together, either two forms of a crop (early and late peas or barley) or two distinct crops (maize and beans, barley and oat), and a third category of a crop and a symbiont (nodule forming bacteria and peas).

Traditional plant breeding is, in fact, genetic engineering, but this term is now being limited to biotechnologies such as in vitro cell culture; recombinant DNA techniques, where genetic material is introduced directly in cell cultures (gene splicing) completely side-stepping the usual sexual process of meiosis, pollen, fertilized ovule, and the seed; or where cell cytoplasm is altered as in protoplast fusion. And, of course, all of these changes depend on cloning technologies where hundreds of identical plants are grown from units as small as a single cell.

Some of the early successes of genetic engineering include the development of bacteria which produce human interferon, human growth hormone, and human insulin on a commercial scale. Now the application of the molecular biology techniques are starting to be reported from plant research laboratories.[44] Already these techniques have been used to screen large numbers of potatoes for potato spindle tuber viroid which is a serious disease of potatoes; the orchid industry has been revolutionized by tissue culture propagation and similar techniques are paying off for apples, pears, and oil palms. Because these advances are produced using unnatural means, they are potentially protected by the laws of ownership when, in fact, genetic engineering doesn't really create new genes but uses already preexisting genes.[45] The current developments in plant breeders' rights might be the turning point in placing a value on genetic resources.

IV. THE U.S. EXPERIENCE WITH PLANT GENETIC RESOURCES

A. Development of Federal Role in Plant Genetic Resources

Traditionally the plant breeder and plant introduction officer have placed the greatest value on genetic resources. Historically their role has been to seek out new material. Plant introduction was one of the earliest activities of the federal government in agriculture.[46]

During the colonial period there were repeated attempts by the Colonies to encourage the introduction and cultivation of various kinds of plants, such as the introduction of fruit tree stock by Governor Winthrop in Massachusetts Bay Colony or the personal introductions of Thomas Jefferson to his estate. After the U.S. had been established, sporadic attempts were made to establish and encourage the introduction of new crops. For example, in 1802 Congress authorized the sale of 2500 acres of public land in southern Ohio to promote the "culture of the vine" (wine grape). In 1817 an allotment of public land in Mississippi territory was authorized for the cultivation of vine and olive and in 1838 land in Florida was set aside for the encouragement of tropical crops. Following the example of Benjamin Franklin who served in England from 1764 to 1775 as agent of the colony of Pennsylvania, American naval and consular officers adopted the practice of sending home seed and cuttings of foreign plants with the idea of introducing new varieties. This was left to the initiative of individual officers until 1819. In that year the Secretary of the Treasury addressed a circular letter to American consuls, requesting them to send to collectors of ports useful plants and seeds for distribution. Foreign plants and trees had already been placed on the duty-free list in the Tariff Act of 1816 and foreign garden seed was exempted from duty in 1842.

In 1836 the U.S. Patent Office under the independent initiative of the Commissioner undertook to distribute seed and plants of foreign origins to farmers throughout the country using for the purpose the postage franks of certain congressmen. The idea caught on and became immensely popular. The franked envelopes of seed distributed almost at random were sometimes the only contact a citizen might have with his congressman. In 1839 Congress appropriated $1000 for seed distribution and in the next to last year of the program, 1922, it was the third largest line item in the USDA budget — salaries being $501,000, cereal investigations being $379,705, and seed purchase and distribution $360,000 out of a USDA total expenditure of $3,327,770.[46] Much of this seed was of garden vegetables and much of it was purchased in Europe. The seed was often of poor quality and exhibited considerable variation. Certain American suppliers of seed such as the Shaker Communities enjoyed a commercial reputation of supplying reliable seed which was both adapted to American conditions and grew true to type. Notwithstanding the faults of the free congressional seed considerable genetic diversity was introduced into American agriculture from 1839 to 1924.

For over 20 years after the initial 1839 appropriation the principal agricultural activity of the national government was the purchase and distribution of cuttings and seeds and the collection of statistics. In 1862 the Division of Agriculture in the Patent Office became the Department of Agriculture under a commissioner. In 1889 the Department was elevated to executive status under a Secretary in the President's Cabinet.

In 1898 Congress first authorized the Secretary of Agriculture to purchase samples of seeds in the open market to test them through the Division of Botany and at his discretion to publish the results and names of the seedsmen in cases where the seeds were found to be below standard. A similar provision has appeared in all later appropriation acts. In addition to seed testing the Secretary was directed to obtain from foreign sources rare and valuable seeds, bulbs, trees, shrubs, vines and cuttings, and plants for experiments in cooperation with state agricultural experiment stations with a view to introduce promising varieties into the country.

Under the reorganization act of 1901 which created the Bureau of Plant Industry, the Office of Foreign Plant Introduction took over much of the search for new crops of the Department of Agriculture. For many years the very prolific writer David Fairchild was the chief in charge of Plant Introduction.[47] The only award for germplasm exploration is named after the "dean" of the plant explorers of this office, Frank Meyer, who from 1905 to 1918 traveled from Turkestan to China exploring for new plants (Figure 2) often on foot. All of this plant exploration work right up to the present represents the second

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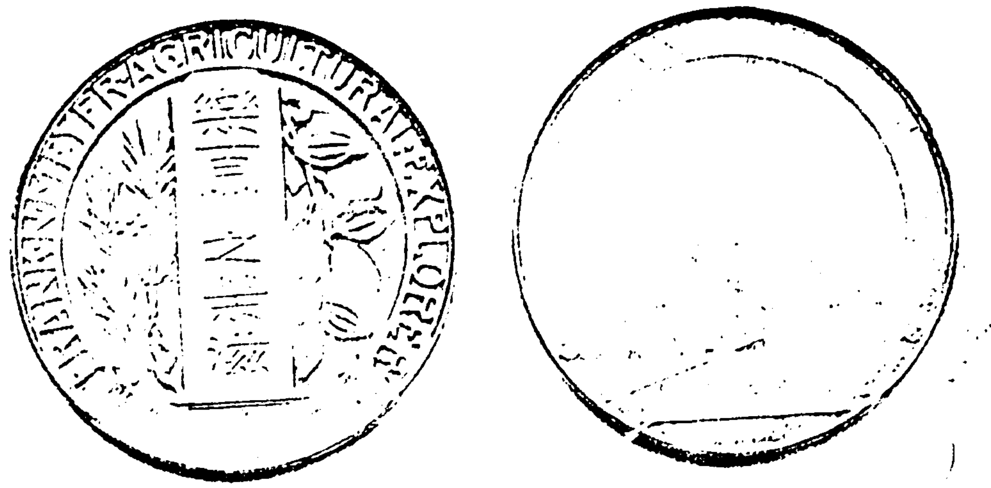

FIGURE 2. The Meyer medal.

phase of plant breeding, the search for useful genes. Basically very few of our major crops are native and so our wheat, citrus, apples, and peanuts represent successful introductions.[48]

This middle period of plant introduction is well documented. Up to 1912 reports as to the seeds and plants imported by the Office of Foreign Seed and Plant Introduction were issued as Bulletins. With the discontinuation of the Bulletin series in 1913 the Inventory of Seeds and Plants was issued as an independent publication cumulating in the quarterly. In addition, at the height of David Fairchild's office there was a mimeographed "Plant Immigrants" for immediate distribution. Currently all introductions are still systematically catalogued with PI (Plant Introduction) numbers and basic passport data (collector, source of seed, scientific name of plant, etc.) when entering the U.S.[49]

The high budget lines for plant introduction began to decrease in the 1920s and the plant breeding establishment became the guardian and trustee of the nation's genetic resources with the formation of the small grains collection and other group specific breeder collections. The emphasis had shifted from the introduction of new crops and varieties to the improvement in the varieties and cultivation practices of the crops which were the most successful. The 1936 and 1937 Yearbooks of Agriculture mark a watershed in the use of plant genetics to improve agriculture. This was the last major coordinated attempt to catalog the genetic diversity used in the nation. The impact of genetics and the third phase of plant breeding has been the improvement of crops and not the search for new crops. When the agricultural production exceeded demand in the 1950s the emphasis shifted further to crop marketing and data collection, and genetic resources experienced their lowest value since the settlement of the colonies.[50] The corn blight of 1970 and the high cost of energy inputs have currently reversed the trend to undervalue genetic resources.[33] In addition, the search for new industrial crops such as lubricating oils from plant sources to replace sperm oil (really a liquid wax) has characterized recent federal plant exploration and introduction activities.[51]

The state of California has considered the issue of biological genetic resources of such importance to the state economy that the California Gene Resource Conservation Program has been established (1980). The multibillion dollar California agriculture is based almost entirely on introduced plants and animals, while forestry and fishing depend on wild trees and fish naturally occurring in the state. The state is currently taking steps to insure they maintain sufficient diversity to promote the well-being of their economy and residents, independent of the USDA national effort.[52,53]

Other groups, often locally based, have been concerned about the genetic erosion of old landraces and open pollinated varieties. One such organization, the Frank Porter Graham 400-acre demonstration farm and training center in Wadesboro, N.C. operated by the Rural Advancement Fund of the National Sharecroppers Fund, has been involved with the preservation and promotion of local landrace germplasm suited for the small, diversified farming, family farm.[54] Another such organization is Southwest Traditional Crop Conservancy Garden and Seed Bank in Tucson, Ariz., whose purpose is to aid native Americans in the southwest and northern Mexico with solving their seed storage problems and recovering seed varieties that were once grown in their communities. The group maintains a conservancy garden to increase seed and as a demonstration site to educate the general public on the value of the southwest's crop heritage, to train tribal personnel to set up similar local gene banks, and, lastly, to document the genetic uniqueness and adaptions to local conditions of the crops.[55]

Also springing up around the nation has been a number of seed saver groups. Some are crop specific such as the large bean collection and others are local groups which gather in the spring before planting to exchange well-adapted open-pollinated varieties or maybe old cultivars of historical interest. In general, all of these are grass roots organizations and have no connection to programs or policies at the national level.

The one group of collections that are generally privately maintained but do have some connections to programs on the national level are the genetic stock collections. The Genetic Society of America has maintained a Committee on Maintenance of Genetic Stocks which updates lists of major stock centers and newsletters relating to genetics. These lists include both animal and plants, and I have listed in Table 3 only the crop plant genetic stock collections in the U.S. In general, these are research orientated working collections of mutants and special chromosome stocks available to everyone.

The lack of a clear national policy on genetic stocks and genetic diversity (both plants and animals) was the basis of a National Academy of Science (NAS) Committee study (1978), *Conservation of Germplasm Resources: An Imperative.*[2] The incorporation of the report findings and recommendations into any kind of national policy is still wanting. The problem is clearly recognized by the technical user community but the public appreciation of genetic resources simply isn't there. The value of genetic resources appears to be limited only to a segment of the biological research community.

B. The Current Federal Germplasm Network

Some of the earliest plant collection trips undertaken by the Office of Seed and Plant Introduction were for specific plant traits: cold-hardiness and drought resistance, Niels Hansen in Russia, Turkestan, and Siberia; durum-type wheats, Mark Carleton in Russia; and commercial rice varieties, Seaton Knapp in Japan. The first recorded plant introduction (PI #1) is a Russian cabbage by N. Hansen 1898.[49] Many of these introductions went directly to experiment stations to be incorporated in ongoing projects. For example, Hansen's fruit collections — apples, crabapples, pears, and small fruit — are still being maintained at the Experimental Station at Brookings, S.D. These working collections have either been problem or crop specific. The working collections of plant breeders — the barley collection of H. V. Harlan in the 1920s and 30s, is a good example — became, literally, world gene collections. Because these collections were being repeatedly grown out for evaluation, seed was replenished; but by the mid-1950s at the time of building the national long-term seed storage facility less than half of the 225,000 recorded introductions were still viable, and most of these were in the small grain collection. Up to the mid-50s the Introduction Service had not been involved in either seed increase and renewal or long-term maintenance.[56]

The concern over the loss of genetic stocks goes back to the 1932 Genetics Congress at

Table 3
IMPORTANT COLLECTIONS WITH CURATORS OF WORKING GENETIC STOCK AND MUTATION COLLECTIONS

	Curator	Holdings	Remarks
Corn	Maize Genetics Cooperative Stock Center Department of Agronomy University of Illinois Urbana, Ill. 61801	51,000 Genotypes, linkage testor, translocation stocks	SEA/AR funding. Maize Genetics Cooperative Newsletter (1932). NSF funded
Wheat	Dr. E. R. Sears Curtis Hall University of Missouri Columbia, Mo.	600 Genetic stocks	SEA/AR funding. Wheat Newsletter (1955)
Tomato	Dr. C. M. Rick Dept. of Vegetable Crops University of California/Davis Davis, Calif. 95616	2,000 Genetic and chromosome stocks and related app.	Tomato Genetics Coop. Report (1951), NSF funding
Barley	Dr. T. Tsuchiya Department of Agronomy Colorado State University Ft. Collins, Colo. 80521	3,000 Genetic stocks	Barley Genetics Newsletter (1971), 50% SEA/AR funding, 50% European funding
Cotton	Dr. Paul Fryxell Curator of Regional Collection of Gossypium Texas A&M University College Station, Tex. 77843	300 Genetic stocks	SEA/AR funding
Peas	Dr. G. A. Marx Dept. of Seed Vegetable Sciences New York Agr. Experimental Station Geneva, N.Y. 14456	5,000 Mutants and genetic stocks	Pisum Newsletter (1969)
Oats	Dr. D. H. Smith, Jr. Small Grain Collection USDA/SEA/AR Beltsville, Md.	200 Genetic stocks, 6,000 wild app. collection, 8,000 common oats	Oats Newsletter
Soybeans	Dr. R. L. Bernard Dept. of Agronomy University of Illinois Urbana, Ill. 61801	8500 P.I. working collection, wild and perennial species	Soybean Genetics Newsletter (1974)

Cornell University and the realization that without coordinated maintenance, genes (mutants) could be lost through neglect. The *Maize Genetics Cooperative Newsletter* was also started by these same movers. The genetics community (*Drosophila* fruitflies and maize) expressed the desirability of a pure culture depository (mutant stock) in the late 30s. In January 1940 the National Research Council (NRC) Division of Biology and Agriculture sponsored a Conference on the Maintenance of Pure Genetic Strains. In 1944 the Division of Biology and Agriculture recommended that the USDA establish a national facility for the preservation of plant germplasm.[57] In 1946 the NRC Committee on Plant and Animal Stocks sponsored a conference attended by representatives of various Federal Government agencies, by state laboratories, and FAO representatives. At the same time the Department of Agriculture was reorganized by the 1946 Research and Marketing Act (RMA) (Public Law 733) in which the RMA charged the Secretary of Agriculture "to stimulate research to encourage the discovery, introduction and breeding of new and useful agricultural crops, plants and animals . . . research relating to any other laws and principles that may contribute to the establishment and maintenance of a permanent and effective agricultural industry . . ."[58]

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The present regional cooperative program for the New Crops started with the passage of the RMA of 1946. Reorganization developed the following goals:

1. The introduction of new plants that may be used directly in furnishing products for chemical or manufacturing industries
2. The introduction of plants possessing special characteristics including disease and insect resistance, cold or drought tolerance, and other qualities that can be utilized in breeding programs to improve crop plants for agricultural or industrial use
3. The evaluation, cataloguing, and preservation of introduced plants so that strains of potential value in future breeding programs or for future industrial development will be continuously available
4. The evaluation, cataloguing, and preservation of native plant materials or plants presently available in the U.S. that have not been adequately tested for industrial or agricultural use

The location and staffing of regional introduction stations was also established. In 1947 the North Central (Ames, Iowa) and Southern (Experiment, Ga.) Regional Stations were established. In 1952 the Western (Pullman, Wash.) and 1953 the Northeastern (Geneva, N.Y.) Regional Stations were established.[1] These four stations, each with specific cooperative missions, were in addition to the already existing Federal Plant Introduction Stations of Glenn Dale, Md. (1919), Coconut Grove (Miami), Fla. (1898), and two stations closed in the 1970s, Chico, Calif. (1904) and Savanna, Ga. (1919) (Figure 3). These centers were the repositories of living collection, either seed or vegetative cultures, in field crops or orchards with present or potential economic value. Because these stations were used primarily for evaluation, more material was grown and discarded than maintained.[58]

In 1949 the National Coordinating Committee for New Crops also established a subcommittee to determine the feasibility of a national seed repository. Their report on February 27, 1950 presented a strong case for a national facility at Fort Collins. In 1956 Congress appropriated funds for a National Seed Storage Laboratory (NSSL) at Colorado State University, Fort Collins, Colo. Construction of the three-floor facility was begun in 1957 and the laboratory was operational in 1958 (see Appendix A). The facility was held static by straight line funding from 1958 to 1974 and generally not recognized as a valuable instrument in agricultural research until the 1970s.[17] The critical role of gene banking has been one of the least appreciated concepts in the agricultural research community and genetic diversity is still generally undervalued. Current proposals call for a reversal of the historical trend and expansion of the now overcrowded NSSL facility.[59]

The movement to restructure priorities and establish a national germplasm policy has been a slow and tortuous development over the past decade. The need for such a policy was clearly stated by H. Harlan in 1936: "In the hinderlands of Asia there were probably barley fields when man was young. The progenies of these fields with all their surviving variations constitute the world's priceless reservoir of germ plasm. It has waited through long centuries. Unfortunately from the breeder's standpoint, it is now being imperiled. When new barleys replace those grown by the farmers of Ethiopia or Tibet, the world will have lost something irreplaceable."[35] They are as irreplaceable now as they were when the barley section of the *1936 Yearbook of Agriculture* was written. The same refrain can be read in the 1956 Brookhaven Symposia on *Genetics in Plant Breeding*[60] and the 1959 American Association for the Advancement of Science (AAAS) Symposium on *Germ Plasm Resources*,[61] especially in the papers of J. Harlan and H. Wallace.

The early 60s saw the development of genetic erosion as an international issue and in 1968 the Society for Economic Botany in cooperation with the International Biological

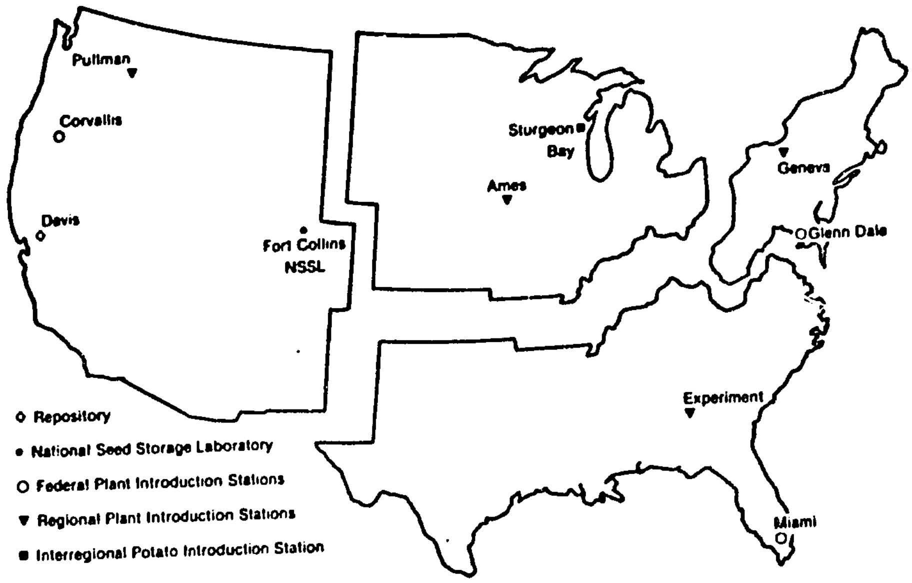

FIGURE 3. Principal stations or laboratories of the U.S. National Plant Germplasm System.

Program (USIBP/UM) held a symposium on Centers of Plant Diversity and the Conservation of Crop Germ Plasm.[62]

In 1971 the Federal/State Cooperative New Crops Program published a major progress report[58] on the accomplishments and historical development of the plant introduction function in the USDA which was starting to take the shape of a national program for the conservation of crop plant germplasm. This was followed by the report of an *ad hoc* subcommittee of the Agricultural Research Policy Advisory Committee in 1973.[63] This report called for a national policy on germplasm assembly, maintenance, and effective utilization. The same focus was the subject of the American Agronomy Society meetings in 1975 and in 1976 the AAAS Symposium: Plant Germplasm Resources — American Independence Past and Future. In the early 70s the word germplasm was being used more frequently and common usage had gone from "germ plasm" to "germplasm." The decade of planning and changing priorities ended with the report prepared by the National Plant Genetic Resources Board (NPGRB) entitled *Plant Genetic Resources: Conservation and Use* (1979).[64] This report, sometimes referred to as the red book because of its cover graphics in red ink, was the blueprint for major restructuring and budget expansion proposed in the subsection "The National Plant Germplasm System: Current Status (1980), Strengths and Weaknesses, Long-Range Plan (1983 to 1997)" of *The National Plant Germplasm System*. The major components of the current state of crop plant germplasm found in the above report is the basis of the following paragraphs.

Prior to 1972, the Plant Introduction Office (PIO) and the four Regional Plant Introduction Stations (RPIS), the four Federal Plant Introduction Stations (now only Glenn Dale and Miami are in service), and the NSSL were administered through the USDA-ARS New Crops Research Branch and the other major collections through the specific branch dealing with the commodity. Since 1972 the system has been subject to the regionalizated administrative structure of the USDA-SEA-AR with the primary coordinating position being the Assistant to the Deputy Administrator for Germplasm within USDA-SEA-AR.

The reorganized National Plant Germplasm System (NPGS) of the USDA mandated its mission "to acquire, maintain, evaluate and make readily accessible to crop breeders and other plant scientists as wide a range of genetic diversity as possible in the form of seed and clonal germplasm of our crops and potential new crops, in order to provide genetic diversity to increase crop productivity and reduce genetic vulnerability in future food and agricultural development, not only in the United States but for the entire world." To accomplish these expanded aims a clonal repository has been established at Corvallis, Ore. (1981) and a fruit and nut repository is under development at Davis, Calif. and other locations (see Table 4 and Figure 3).

The major working components of the current system are

1. The Plant Introduction Office (PIO) whose program is administrated through the Germplasm Resources Laboratory (GRL) within the Plant Genetics and Germplasm Institute (PGGI) (two other laboratories, Economic Botany and Taxonomic Botany, are also in the PGGI) at the Beltsville Agriculture Research Center (BARC), Beltsville, Md.
2. The working collections located either at one of the four regional plant introduction stations, a clonal repository, or with curators (who handle such crops as wheat, oat, barley, rice, soybean, and tobacco as well as genetic stock collections). These are maintained to meet the day-to-day research needs of the user community, only a portion of a given accession leaves the system, and the accession is never exhausted since it is increased as necessary.
3. The base collections located at the NSSL which are not to be drawn upon to meet users needs but are on long-term deposit (see Appendix A for policy statement of the NSSL)
4. The user community, a broad cadre of scientists, crop evolutionists, geneticists, academics, and public and private sector plant breeders
5. The necessary information management system, primarily the Germplasm Resources Information Program (GRIP), to tie the diverse units together as a cohesive whole (see Figure 4)

In total, the NPGS now maintains about 500,000 accessions of germplasm in the form of seed and vegetatively propagated stocks. These accessions are primarily cultivars and unimproved germplasm from foreign sources. New accessions are being added at the rate of 7,000 to 15,000 entries per year.

The NPGS also includes a number of advisory components. The National Plant Genetic Resource Board (NPGRB) is a policy group which advises the Secretary of Agriculture on matters relating to germplasm. The National Plant Germplasm Committee (NPGC) took the place of the New Crops Committee, after the 1972 reorganization, and it provides advice and coordination to the NPGS primarily through AR and State Agricultural Experiment Station (SAES) administrations. It also provides technical advice to the NSSL. The AR Plant Germplasm Coordinating Committee (PGCC) advises the Administrator on operational matters, especially AR funded plant exploration. A regional technical committee, with an SAES director as its administrative advisor, provides advice to each RPIS. Crop Advisory Committees (CACs) are now in existence for ten commodities (wheat, oats, sorghum, potato, tomato, alfalfa, phaseolus bean, pea, soybean, and maize) and the recommendation for the formation of 12 additional CACs for specific crops (barley, citrus, cotton, grasses, other legumes, nut, oilseed, peanut, rice, sweet potato, sugar crops, and other vegetables, [excluding tomato and potato]) has been proposed. These CACs provide technical advice to respective curators.

As could be well imagined from such a complex of participants, a lack of coordination,

Table 4
NATIONAL PLANT GERMPLASM SYSTEM: PRINCIPAL STATIONS OR LABORATORIES RESPONSIBLE FOR INTRODUCTION, MAINTENANCE, AND DISTRIBUTION OF PLANT

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NATIONAL PLANT GERMPLASM SYSTEM: PRINCIPAL STATIONS OR LABORATORIES RESPONSIBLE FOR INTRODUCTION, MAINTENANCE, AND DISTRIBUTION OF PLANT GERMPLASM

Station or laboratory, name and address	Examples of responsibilities for major collections	Total accession held 1980	Samples distributed 1980	Remarks
Germplasm Resources Laboratory (GRL) H. E. Waterworth, Chief Germplasm Resources Laboratory Building 001, Room 324 BARC-West Beltsville, Md. 20705				Administrative unit including Plant Introduction Office, U.S.D.A. Small Grains Collection, U.S.D.A. Rice Collection, SEA Plant Introduction Station (at Glenn Dale, Md.), and related research
Plant Introduction Office (PIO) George A. White Plant Introduction Officer Building 001, Room 322 Beltsville, Md. 20705	None			National focal point for introduction, documentation, initial distribution, and foreign exchange of plant germplasm
SEA Plant Introduction Station H. E. Waterworth U.S. Plant Introduction Station P. O. Box 88 Glenn Dale, Md. 20769	Pome and stone fruits and woody ornamentals	6,200	2,565	Distributes certified pest-free introductions consisting of prohibited and postentry quarantine categories of fruits, woody ornamentals, and certain vegetables
SEA Plant Introduction Station Paul K. Soderholm Subtropical Horticultural Research Station 13601 Old Cutler Road Miami, Fla. 33158	Tropical and subtropical species including coffee, mangoes, and cacao	5,000	2,984	Research on mango, avacado, and other tropical fruits

Table 4 (continued)
NATIONAL PLANT GERMPLASM SYSTEM: PRINCIPAL STATIONS OR LABORATORIES RESPONSIBLE FOR INTRODUCTION, MAINTENANCE, AND DISTRIBUTION OF PLANT GERMPLASM

Station or laboratory, name and address	Examples of responsibilities for major collections	Total accession held 1980	Samples distributed 1980	Remarks
Northeastern Regional Plant Introduction Station (NE-9) Desmond D. Dolan N.Y. State Agric. Expt. Sta. Regional Plant Intro. Station Geneva, N.Y. 14456	Perennial clover, onion, pea, broccoli, timothy	20,000	7,749	Operating through Regional Research Project, NE-9, 12 states, SEA, FS, and SCS participating
Southern Regional Plant Introduction Station (S-9) G. R. Lovell Regional Plant Intro. Sta. Experiment, Ga. 30212	Cantaloupe, cowpea, millet, peanut, sorghum, pepper	40,000	18,757	Operating through Regional Research Project, S-9, 14 states, SEA, and SCS participating
North Central Regional Plant Introduction Station (NC-7) Willis H. Skrdla Regional Plant Intro. Sta. Iowa State University Ames, Iowa 50011	Alfalfa, corn, sweet clover, beets, tomato, cucumber	22,000	20,815	Operating through Regional Research Project, NC-7, 13 states, SEA, and SCS participating
Western Regional Plant Introduction Station (W-6) S. M. Dietz Regional Plant Intro. Sta. Room 59, Johnson Hall Washington State University Pullman, Wash. 99163	Bean, cabbage, fescue, wheat grasses, lentils, lettuce, safflower, chickpeas	28,000	17,714	Operating through Regional Research Project W-6, 13 states SEA, SCS, FS, and BLM participating
Interregional Potato Introduction Laboratory (IR-1) Robert E. Hanneman, Jr.	*Solanum tuberosum* and *Solanum* spp.	4,000	4,389	Operating through Interregional Project 1, SAES, and SEA in four regions participating

Interregional Potato Introduction Station Sturgeon Bay, Wis. 54235		
Northwest Clonal Repository Otto L. Jahn Northwest Plant Germplasm Repository 33447 Peoria Road Oregon State University Corvallis, Ore. 97330	Pears, filberts, small fruits, hops, and mints	
Fruit and Nut Germplasm Repository D. E. Parfitt University of California Davis, Calif. 95616	Grapes, stonefruits, nuts	Not yet operational
Planned locations		State agricultural experiment station locations
Davis, Calif.	Stone fruits, grapes, walnuts, almonds, pistachio nuts	
Geneva, N.Y.	Apples and grapes	
Riverside, Calif.	Citrus, figs, and certain other subtropical fruits	
Poamoho and Kona, Hawaii	Macadamia nuts and subtropical fruits	
Carbondale, Ill.	Black walnuts, chestnuts, and hickories	
Corvallis, Ore.	Strawberries, caneberries, blueberries	Science and Education Administration-Agricultural Research locations
Byron, Ga.	Stone fruits and apples	
Orlando, Fla.	Citrus	
Miami, Fla.	Avocados, mangoes, and other subtropical fruits	
Mayaguez, Puerto Rico	Coffee, cocoa, bananas, pineapples, and mangoes	
Indio, Calif.	Dates	
Brownwood, Tex.	Pecans	

Table 4 (continued)
NATIONAL PLANT GERMPLASM SYSTEM: PRINCIPAL STATIONS OR LABORATORIES RESPONSIBLE FOR INTRODUCTION, MAINTENANCE, AND DISTRIBUTION OF PLANT GERMPLASM

Station or laboratory, name and address	Examples of responsibilities for major collections	Total accession held 1980	Samples distributed 1980	Remarks
National Seed Storage Laboratory (NSSL) Louis N. Bass National Seed Storage Lab. Colorado State University Fort Collins, Colo. 80521	Gene bank collections of seed crops and their wild relatives		1,732	Long-term storage
U.S.D.A. Small Grains Collection D. H. Smith, Jr. USDA Small Grains Collection Building 046, BARC-West Beltsville, Md. 20705	Collections of wheat, oats, barley, and rye	82,295	99,000	
U.S.D.A. Rice Collection A. J. Oakes Building 001, Room 338 BARC-West Beltsville, Md. 20705	Rice	15,000	765	

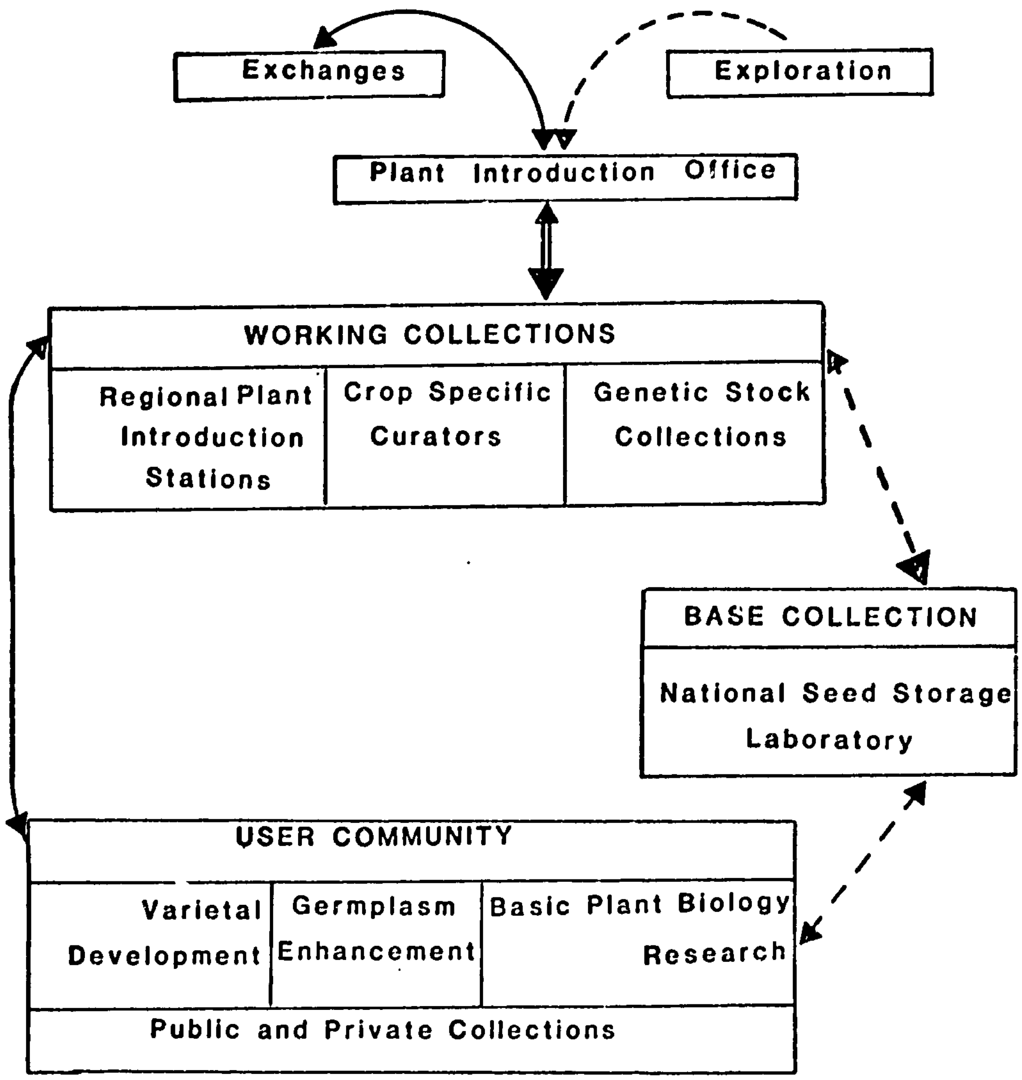

FIGURE 4. The major working components of the current U.S. Plant Germplasm System.

communication, and feedback from users are some of the current weaknesses in the system. Another is the current inability to truly assess genetic vulnerability. The U.S. collections of Chinese soybeans, wild relatives of crop plants and tropical crops, are currently in need of strengthening. In general, the system is slow to respond to user needs and there is no overview of priorities or strategy in coordinating acquisitions. Too few collection trips are being coordinated to areas undergoing rapid genetic erosion and the USDA lacks the trained corps of plant collectors to match those of earlier days. The absence of any use of the academic plant taxonomists and botanical garden resources of the nation is an example of the "in house" attitude of the USDA regarding plant exploration.

Certainly, the requirements for more space at the NSSL merits immediate funding. Without more value being placed on genetic resources and clearer lines of authority (currently there are too many lines and levels of authority), the issue of germplasm maintenance and preservation within the nation will muddle along.

Not withstanding the faults, any system that can distribute over 100,000 annual

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requests for breeding and experimental materials (1980), and provide safe long-term storage of over half a million entries is both supporting agricultural research and insuring the long-term needs of our $100 billion agricultural enterprise. Agriculture is the nations largest employer with 23 million working at agricultural related jobs and currently that agriculture has its future in an undervalued gene bank. The consensus for the maintenance of germplasm has been slow.

In addition to the cooperative national program involving Federal, State and the private sector; the NPGS is a major component of the international plant germplasm network and as such coordinates its efforts with the International Board of Plant Genetic Resources (IBPGR) a center of the Consultative Group on International Agricultural Research (CGIAR) with its supporting Secretariat located in FAO, Rome, Italy. The NPGS could not accomplish its mission without strong international links. Approximately ¾ of all plant introductions are provided by a world wide exchange program coming from either CGIAR research centers such as the International Rice Research Institute (IRRI), or the Centro Internacional para Mejoramento de Maiz y Trigo (CIMMYT) or from Plant Introduction Offices or Germplasm Collections of other nations, for example the All Union Vavilov Institute of Plant Industry (U.S.S.R.) or the National Bureau of Plant Genetic Resources New Delhi (India). At the present time plant genetic resource newletters which coordinate germplasm exchange and preservation are published by several governments (Canada,[65] India,[66] and the U.S.[67]) and the IBPGR.[68] Recently the first issue of a news journal for the plant genetic resources community called *Diversity* has appeared, which promises to be a good communication link in the U.S. for the user community.[69]

Priorities are changing rapidly and plant genetic resou. :es are becoming more widely recognized as central to the maintenance of a productive American agriculture. The immediate future will tell if the National Plant Genetic Resources Board will bridge the gap from plan introduction and the search for new genes to its newly established duties

- To inform themselves of domestic and international activities to minimize genetic vulnerability of crops
- To formulate recommended actions and policies on collection, maintenance, and utilization of plant genetic resources
- To recommend actions to coordinate the plant genetic resources plans of several domestic and international organizations
- To recommend policies to strengthen plant quarantine and pest monitoring activities
- To advise on new and innovative approaches to genetic enhancement and plant improvement

V. THE INTERNATIONAL COORDINATION OF PLANT GENETIC RESOURCES CONSERVATION

A. Development of a Consensus to Support an International Network

The evolution under domestication of our cultivated plants has taken place around the world starting from a specific region where the plant was once part of the native vegetation. Often major gene diversity and significant changes in productivity of a crop have taken place far from where the crop originated.[21,70] The major food plants of the world are not owned by any one people and are quite literally a part of our human heritage from the past. Some cultures have influenced the development of specific crops more than others but no one culture owns the invention of agriculture; this was a human discovery in several separate regions of the world, each contributing a distinct set of unique plants to the world collection. Therefore, the conservation of genetic resources is

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a world problem because no one nation possesses all the genetic diversity. The consensus to arrive at this conclusion has been slow to development and implementation is just now taking place.

The development of a worldwide consciousness of the value of genetic resources has been forming over the past 25 years. The international effort parallels the same transition from plant introduction to base working collections and gene banking that the USDA has experienced.

The first major world gene bank was the result of the extensive search for crop plant gene diversity (see Figure 5 for a map of the Vavilov Centers of Genetic Diversity[26]) by the Russian, Vavilov, in the 1920s.[11,21] Many of these collections are still available from the N. I. Vavilov All-Union Institute of Plant Industry, Leningrad. Much of the drive behind this world collection was Vavilov, himself, and the Institute was not viewed as a world resource in the dark days of the late 1930s.

In general, the search for new germplasm has been either a national effort (for example, the USDA Plant Introduction Office) or the function of a specific breeding and crop improvement program (for example, the Rockefeller Maize Improvement Program in Mexico and the extensive collections of indigenous landraces of maize from 1942 through the 1950s), whose main function has not been gene conservation. This secondary aspect of gene banking has also been true of the FAO, which, since its inception of work with crop improvement in 1947/48, saw as its main thrust the function of acting as a clearing house for information on germplasm, cooperation in plant exploration, and the removal of artificial barriers to the interchange of plant stocks. The development to the present state has been slow and the early history has been recorded elsewhere.[17,71-73,79]

In 1959 the *Plant Introduction Newsletter* No. 6 published a world list of germplasm banks and their custodians. This marked a move from seed exchange and plant introduction (such as world catalogues of genetic stocks for rice and wheat) to the maintenance and management of crop diversity. In 1961 the FAO held the first Technical Meeting on Plant Exploration and Introduction.[72] The second meeting in 1967 was jointly planned by the International Biological Program (IBP) and helped finalize the shift from information and introduction functions to action for the exploration and maintenance of crop genetic resources.[73] In 1970/71 the *Plant Introduction Newsletter* No. 24 (December 1970) became the *Plant Genetic Resources Newsletter* No. 25 (January 1971), recognizing the larger role of FAO in plant exploration and plant collecting, as well as the evaluation and utilization of the genetic resources of cultivated plants and their near wild relatives.

Faced with the urgency of genetic erosion created by the greatly accelerated rate of displacement of local cultivars by more productive methods, the IBP Handbook No. 11 *Genetic Resources in Plants — Their Exploration and Conservation* was a turning point in developing the scientific background and methodology for defining goals and strategies.[73] The term genetic resources was given meaning in this report by Frankel and Bennett and their value to society fully established. The broad scientific issues had been clarified but what were lacking were the institutional arrangements and international will for implementation of well-defined practical programs.

The FAO Expert Panel recommended by the first Technical Meeting (1961) met for the first time in 1968 and, subsequently, to 1974 elaborated the major recommendations of the 1967 conference:

- Exploration and survey of critical regions for genetic resources
- Collection of genetic diversity and location of already existing collections
- Evaluation of collections to promote the most efficient utilization of genetic resources

Each of the world's basic food plants originated in a relatively confined geographic region. The regions overlap for a number of crops, but nine major and three minor centers in the Old and New World have been identified as being the areas which account for the origin and diversity of the vast majority of cultivated plants in our world. Known as Vavilov centers, after a Russian plant breeder and geneticist, these valuable reservoirs of crop plant germplasm are now disappearing.

OLD WORLD CENTERS

1. ETHIOPIA
Banana (endemic)
Barley
Castor bean
Coffee
Flax
Khat
Okra
Onion
Sesame
Sorghum
Wheat

2. MEDITERRANEAN
Asparagus
Beets
Cabbage
Carob
Chicory
Hops
Lettuce
Oats
Olive
Parsnip
Rhubarb
Wheat

3. ASIA MINOR
Alfalfa
Almond (wild)
Apricot (secondary)
Barley
Beets (secondary)
Cabbage
Cherry
Date palm
Carrots
Fig
Flax
Grapes
Lentils
Oats
Onions (secondary)
Opium poppy
Pea
Pear
Pistachio
Pomegranate
Rye
Wheat

4. CENTRAL ASIATIC (Afghanistan—Turkestan)
Almond
Apple (wild)
Apricot
Broad bean
Cantaloupe
Carrots
Chick pea
Cotton (*G. herbaceum*)
Flax
Grapes (*V. vinifera*)
Hemp
Lentils
Mustard
Onion
Pea
Pear (wild)
Sesame
Spinach
Turnips
Wheat

5. INDO-BURMA
Amaranths
Betel nut
Betel pepper
Chick pea
Cotton (*G. arboreum*)
Cowpea
Cucumber
Eggplant
Hemp
Jute
Lemon
Mango
Millets
Orange
Pepper (black)
Rice
Sugar cane (wild)
Taro
Yam

6. SIAM, MALAYA, JAVA
Banana
Betel palm
Breadfruit
Coconut
Ginger
Grapefruit
Sugar cane (wild)
Tung
Yam

7. CHINA
Adzuki bean
Apricot
Buckwheat
Chinese cabbage
Cowpea (secondary)
Kaoliang (sorghum)
Millets
Oats (secondary)
Orange (secondary)
Paper mulberry
Peach
Radish
Rhubarb
Soybean
Sugar cane (endemic)
Tea

NEW WORLD CENTERS

8. MEXICO-GUATEMALA
Amaranths
Bean (*P. vulgaris*)
Bean (*P. multiflorus*)
Bean (*P. lunatus*)
Bean (*P. acutifolius*)
Corn
Cacao
Cashew
Cotton (*G. hirsutum*)
Guava
Papaya
Pepper (red)
Sapodilla
Sisal
Squash
Sweet potato
Tobacco (*N. rustica*)
Tomato

9. PERU-ECUADOR-BOLIVIA
Bean (*P. vulgaris*)
Bean (*P. lunatus*)
Cacao
Corn (secondary)
Cotton
Edible roots (oca, ullucu, arracacha, añu)
Guava
Papaya
Pepper (red)
Potato (many species)
Quinine
Quinoa
Squash (*C. maxima*)
Tobacco (*N. tabacum*)
Tomato

Minor Centers

10. SOUTHERN CHILE
Potato
Strawberry (Chilean)

11. BRAZIL-PARAGUAY
Brazil nut
Cacao (secondary)
Cashew
Cassava
Maté
Para rubber
Peanut
Pineapple

12. UNITED STATES
Sunflower
Blueberry
Cranberry
Jerusalem artichoke

FIGURE 5. The Vavilov Centers of Genetic Diversity for the worlds basic food plants. (Reprinted by permission of *The Bulletin of the Atomic Scientists*, a magazine of science and public affairs. Copyright © 1977 by the Educational Foundation for Nuclear Science, Chicago, Ill., 60637.)

- Conservation of genetic resources in long-term base collections
- Documentation and international coordination

The Panel named priority targets for exploration and urged that the proposed survey of threatened resources be undertaken. This survey, which was far from complete, was

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published in 1973[74] before the Third International Technical Conference on Crop Genetic Resources was convened.[75]

Certain regions, notably Western Europe, were able to organize themselves to implement regional planning for genetic resources. During the late 60s and early 70s the work of the European Association for Research on Plant Breeding (EUCARPIA) intensified and gene banks were established at Bari, Italy, and Braunschweig, West Germany.[76,77] But this was a region of developed nations and many of the regions of high priority for the collection and preservation of genetic resources were in less developed regions with few institutions strong enough to undertake the task. Some of the International Agricultural Research Centers (IARCs) (Table 5), such as the International Rice Research Institute (IRRI), did take on the responsibility for the collection, evaluation, and banking of rice germplasm,[78] but by the early 70s it had become evident that on a world-wide scale the genetic resources program languished for the want of a strongly focused program of action.[79,80]

The late 60s and early 70s was a decade of increasing environmental awareness and concern by the general public, especially of the developed nations. The International Biological Program (IBP) had considered agriculturally productive habitats in the global ecological context and Sir Otto Frankel chaired the IBP germplasm committee. The Rockefeller Foundation, concerned over the potential of a diminished genetic base resulting from the widespread adoption of the Green Revolution wheat and rice varieties,[14,81-91] initiated crop-specific committees to assess the genetic erosion of wheat, maize, rice, millets, and sorghum. Some of these committees later evolved into the crop advisory committees of the IBPGR. The seriousness of genetic vulnerability was reinforced in the minds of policy makers by the Southern Leaf Blight on the American corn crop of 1970 with type "T" cytoplasm.

Considerable publicity attended the United Nations Conference on the Human Environment held in Stockholm in 1972. The Stockholm meeting passed seven (Nos. 39 to 45) resolutions which helped focus world attention on the urgency of action to preserve genetic resources. The climate for further initiative was set by recommendations of the Technical Advisory Committee (TAC) to the Consultative Group on International Agricultural Research (CGIAR), the umbrella organization of the IARCs. In 1972 the TAC convened an *ad hoc* working party of scientists, the "Beltsville Conference", which proposed an action plan endorsed with modification by TAC and by CGIAR. This plan resulted in the creation of the current International Board for Plant Genetic Resources in 1974 as an autonomous, international, scientific organization under the aegis of the CGIAR and its secretariat provided by the FAO of the U.N.[94] The basic function of IBPGR, as defined by the CRIAR, is to promote an international network of genetic resources centers to further the collection, conservation, documentation, evaluation, and use of plant germplasm and thereby contribute to raising the standard of living and welfare of people throughout the world.[79]

The late 1960s had seen the Crop Ecology and Genetic Resources Unit of the FAO set up the first regional genetic resource unit at Izmir, Turkey; an independent postgraduate training course had begun on conservation and utilization of plant genetic resources at the University of Birmingham, U.K., under Professor J. Hawkes and Dr. J. T. Williams as tutor (later to become the head of the IBPGR), and the compiling of inventories of major gene bank collections then in existence. The *Plant Genetic Resources Newsletter* of the unit continued to serve as a communication link. Many organizational questions arose and had to be resolved as IBPGR began to function and influence the previous rather small Crop Ecology and Genetic Resources programs. Today the *Plant Genetic Resources Newsletter* is published quarterly under the joint auspices of the Crop Genetic Resources Center (the restyled unit which is coterminus with the IBPGR Secretariat and FAO).

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Table 5
INTERNATIONAL AGRICULTURAL RESEARCH CENTERS AND PROGRAMS SPONSORED BY THE CONSULTATIVE GROUP ON INTERNATIONAL AGRICULTURAL RESEARCH (CGIAR)

International institute	Year founded	Location	Research area	Region of the world served
International Rice Research Institute (IRRI)	1960	Phillipines	Rice, multiple cropping	Rain-fed and irrigated subtropics; tropics
International Maize and Wheat Improvement Center (CIMMYT)	1967	Mexico	Wheat, barley, maize	Rain-fed and irrigated temperate; tropics
International Center of Tropical Agriculture (IITA)	1968	Nigeria	Maize, rice, root and tuber crops, cowpeas, soybeans, lima beans, farming systems	Rain-fed and irrigated lowland tropics
International Center of Tropical Agriculture (CIAT)	1969	Colombia	Beans, corn, rice, cassava, beef and forages, pigs	Rain-fed and irrigated tropics (sea level to 1000 m)
International Potato Center (CIP)	1972	Peru	Potatoes	Rain-fed and irrigated temperate to tropic
International Crops Research Institute for the Semiarid Tropics (ICRISAT)	1972	India	Sorghum, millets, peanuts, chickpeas, pigeon peas	Semiarid tropics
International Laboratory for Research on Animal Diseases (ILRAD)	1974	Kenya	Blood diseases of cattle	Mainly semiarid tropics
International Livestock Centre for Africa (ILCA)	1974	Ethiopia	Cattle production	Humid to dry tropics
International Center for Agricultural Research in Dry Areas (ICARDA)	1976	Lebanon, Syria	Wheat, barley, broad beans, lentils, oilseeds, cotton, sheep production	Mediterranean
International Food Policy Research Institute	1975	U.S.		
Programs				
West African Rice Development Association (WARDA)	1971	Liberia		
	[illegible]	FAO headquarters,		

International Center for Agricultural Research in Dry Areas (ICARDA)	1976	Lebanon, Syria	Wheat, barley, broad beans, lentils, oilseeds, cotton, sheep production	Mediterranean
International Food Policy Research Institute	1975	U.S.		

Programs

West African Rice Development Association (WARDA)	1971	Liberia
International Board for Plant Genetic Genetic Resources (IBPGR)	1973	FAO headquarters, Rome, Italy
International Service for National Agricultural Research	1979	Netherlands

International Agricultural Research Centers outside the sponsorship of CGAIR
- Asian Vegetable Research and Development Center — Taiwan
- International Fertilizer Development Center
- International Center for Insect Physiology and Ecology — Kenya
- Centro Agorómico Tropical de Investigación y Enseñanza (CATIE) — Costa Rica

Note: As of mid 1981, CGIAR had 33 donor members. These included the international assistance agencies of 20 countries (including 4 developing nations), 4 foundations, 3 international organizations, and 6 regional organizations. Total contributions for core (basic) activities in 1981 were nearly $140 million. Additional new donors are expected to join in 1982.

The issue of genetic resources is a dramatic model of the importance of consensus, infra structure (UNEP, IBP, CGIAR), and international will from the nonscientific public policy sector. The scientific recognition of the problem and the methodologies were in place by 1968 but the institutional arrangements and support were not fully functional until later. Without the surge of environmental awareness and the role of key individuals in the 70s the international issue of genetic resources might still be floundering.

B. The Current International Board for Plant Genetic Resources (IBPGR)

There is every reason to be optimistic about the current programs and priorities of the International Board of Plant Genetic Resources (IBPGR) with its Executive Secretariat provided in part by the Food and Agriculture Organization (FAO) of the United Nations. In the span of less than a decade the IBPGR, which operates on the principle of the free international exchange of genetic materials and information, has had a catalytic effect upon the building of national and regional institutional capabilities, stimulating collection on iority crops and in priority regions, and the conservation of genetic resources. The broad goal of the IBPGR has been to establish a working network to safeguard the genetic variation of useful cultivated plants and to ensure more timely availability to breeders all over the world.[95-101]

When the Board first identified its priorities for action on crops in 1975/76 they were based on the major food crops (see Figure 1) of greatest significance to human nutrition. The priorities were established using a series of criteria which included:

- The risk that landrace material would be lost due to development changes and introduced elite germplasm from elsewhere to local regional agriculture
- The economic and social importance of the crops and their potential to plant breeding worldwide
- The breath and quality of existing collections held either by national programs or one of the IARCs

In 1981 the revised priorities[102] (Table 6, Figure 6) established the current working matrix for the board. In addition to basic food and fiber crops (including rubber) the new priorities under study include tree species, especially of arid and semiarid zones,[103] of importance for fuel wood (round wood) and/or environmental stabilization and forage plants. The possibility also exists for the addition of medicinal plants on a regional basis.[104,105]

For five major world crops the Board cosponsors crop advisory committees in cooperation with the appropriate IARC. They are the Rice Committee, cosponsored by IRRI; the Maize Committee, cosponsored by CIMMYT; the Sorghum and Millet Committee, cosponsored by ICRISAT; the *Phaseolus* Bean Committee, cosponsored by CIAT; and the Wheat Committee, cosponsored by CIMMYT, with participation of ICARDA. The Board has not convened an advisory committee on potatoes because CIP was already exhibiting leadership and responsibility in this area. The remaining crops of high priority are covered by crop-specific *ad hoc* international working groups which have established regions to be collected and crop descriptors.[79,104]

These panels are task limited and phase themselves out of existence. By 1981 the Board had published internationally agreed lists of descriptors for 17 crops or crop groups: potatoes — 1977, wheat and *Aegilops* — 1978, coconut — 1977, bananas and plantains — 1978, winged beans — 1979, tropical fruits (mango, durian, rambutan, jackfruit, and *Lansium*, all of Southeast Asia) — 1979 revised 1980, sorghum — 1980, coffee — 1980, *Colocasia* — 1980, yams — 1980, cotton — 1980, mungbean — 1980, apricot — 1980, beets — 1980, maize — 1980, rice — 1980, cruciferous crops — 1981; and had initiated

Table 6
PRIORITIES AMONG CROPS

- Cereals
  - 1st Priority level
    - Wheat
      - Although much collecting has been carried out, material still remains to be collected in the Mediterranean, Southwest Asia, and the Himalayas
  - 2nd Priority level
    - Sorghum
      - In view of the sizeable collections assembled at ICRISAT from tropical Africa, priority 2 seems appropriate; however, wild races of sorghum continue to have priority 1 throughout Africa and cultivated sorghums from West Africa, China, and parts of Southeast Asia remain priority 1
    - Pearl millet *(Pennisetum)*
      - In view of the work carried out in 1976 - 80, priority 2 seems appropriate; nonetheless, pearl millet is a priority 1 in Chad, North Africa, and parts of India and Pakistan
    - Finger millet *(Eleusine)*
      - Priority 1 in Africa and Asia
    - Foxtail millet *(Setaria italica)*
      - Priority 1 in China
    - Fonio millet (*Digitaria* sp.)
    - Rice
      - Because of the outstanding work of IRRI, especially in Asia, priority 2 seems appropriate for rice in general, but collections of rice in tribal areas in India, Indochina, China, and the Pacific have priority 1
    - Barley
      - Priority 1 in China, Southwest Asia, and North Africa
  - 3rd Level priority
    - Maize
      - Priority 1 in the Himalayas, China, and Northeast Brazil, Venezuela, and the Guyanas
    - Grain amaranth
      - Priority 2 in the Andean zone
    - Oats
    - Quinoa
      - Priority 1 in the Andean zone
    - Rye
    - Proso millet or common millet *(Panicum miliaceum)*
    - Barnyard millet *(Echnichloa crusgalli)*
  - 4th Level priority
    - Teff (*Eragrostis* spp.)
      - High local priority
    - Kodo millet *(Paspalum scrobicalatum)*
      - High local priority
    - Little millet *(Panicum miliare)*
      - High local priority
- Food legumes
  - 1st Level priority
    - *Phaseolus* beans
      - A broader range of genetic diversity is required for breeding programs; in addition, agricultural land-use patterns are changing rapidly in Central and South America, which may lead to the disappearance of many traditional cultivars of *Phaseolus*
  - 2nd Level priority
    - Groundnut
      - Priority 1 in South Asia, Southeast Asia, and Central America
    - Soy bean
      - Priority 1 in China, Indonesia, and parts of Southeast Asia
    - Cowpea *(Vigna unguiculata)*
      - Priority 1 in South Asia and West Africa
    - Yardlong bean *(Vigna unguiculata spp. sesquipedalis)*
      - Priority 1 in Southeast Asia

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Table 6 (continued)
PRIORITIES AMONG CROPS

- Winged bean *(Psophocarpus tetragonolobus)*
  - Priority in Pacific, South, and Southeast Asia
- Chickpea
  - Priority 1 in Southwest Asia
- Greengram *(Vigna radiata)*
  - Priority 1 in South and Southeast Asia
- Blackgram *(Vigna mungo)*
  - Priority 1 in South and Southeast Asia
- Moth bean *(Vigna aconitifolia)*
- Rice bean *(Vigna umbellata)*

3rd Level priority
- Pigeon pea *(Cajanus)*
- Pea *(Pisum)*
- Broad bean *(Vica faba)*
  - Priority 1 in Mediterranean
- Lentil
  - Priority 1 in Southwest Asia
- Bombara groundnut *(Voandzeia)*
  - Priority 2 in West Africa
- *Vigna angularis*
- *Vigna trilobata*

4th Level priority
- Lupin
  - Priority 1 in Andean zone
- Velvet bean (*Mucuna* spp.)
- *Dolichos* and *Lablab* species
- Jack bean and sword bean (*Canavalia* spp.)
- Kersting's groundnut *(Kerstingiella geocarpa)*
- Cluster bean *(Cyamopsis tetragonoloba)*
- African yam bean *(Sphenostylis stenocarpa)*

Root and tuber crops

1st Level priority
- Cassava
- Sweet potato

2nd Level priority
- Potato
  - Potatoes have a priority 2 because a large amount of material has already been collected and is conserved by CIP

3rd Level priority
- Yam
  - Priority 1 in Pacific

4th Level priority
- Taro and aroids
  - Priority 1 in Pacific
- Minor South American tuber crops
  - Priority 1 in Andean zone
- Minor African tuber crops

Oil seeds

2nd Level priority
- Oil palm *(Elaeis melanococca)*
  - In restricted areas of South America
- Coconut
  - Priority 1 in Southeast Asia and Pacific
- Oilseed brassicas
  - Priority 1 in South Asia and China

3rd Level priority
- Oil palm *(E. guineensis)*
- Safflower

Table 6 (continued)
PRIORITIES AMONG CROPS

- Sunflower
- Olive
- 4th Level priority
  - Niger seed *(Guizotia abyssinica)*
  - Sesame

Starchy fruits
- 2nd Level priority
  - Starchy banana and plantain
    - Priority 1 in Pacific, Southeast Asia, and West Africa
- 3rd Level priority
  - Breadfruit and jackfruit
    - High priority in South and Southeast Asia and priority 1 in Pacific

Tropical and subtropical fruits and nut trees
- 2nd Level priority
  - Desert banana
    - Priority 1 in Southeast Asia
  - Citrus
    - Priority 1 in South and Southeast Asia
  - Mango
    - Priority 1 in Southeast Asia
- 3rd Level priority
  - Avocado
    - Priority 1 in Central America and 2 in Andean zone
  - Cashew
    - Priority 2 in South Asia
  - Date
    - Priority 2 in Southwest Asia
  - Fig
    - Priority 2 in Southwest Asia
  - Papaya
    - Priority 2 in Central America and Andean zone
  - Pineapple
- 4th Level priority
  - Peach palm
    - Priority 1 in parts of Latin America
- Priority level under study
  - Other tropical fruits and tree nuts
    - *Lansium*, durian, and rambutan are priority 1 in Southeast Asia; *Annona* and *Passiflora* sp. are priority 1 in Andean zone

Temperate fruits and nut trees
- 2nd Level priority
  - Apple
    - Priority 1 in Southwest Asia
  - Pear and quince
    - Priority 1 in Southwest Asia
  - Peach and nectarine
- 3rd Level priority
  - Apricot
    - Priority 2 in Southwest Asia
  - Cherry
    - Priority 2 in Southwest Asia
  - Plum
  - Strawberry
  - Grape
    - This includes wine, table, and raisin; high priority is accorded to collection in China, the Himalayas, Central Asia, Southwest Asia, and the Mediterranean
- 4th Level priority
  - Almond

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Table 6 (continued)
PRIORITIES AMONG CROPS

- Priority 2 in Southwest Asia
- Walnut
  - Priority 2 in Southwest Asia
- Priority level under study
  - Other temperate fruit and tree nuts
    - Pomegranate is priority 2 in Southwest Asia

Vegetables
- 1st Level priority
  - Tomato (*Lycopersicon esculentum* and related species)
- 2nd Level priority
  - Amaranth (*Amaranthus* spp.)
    - Priority 1 in West Africa, South, and Southeast Asia
  - Brassicas (*Brassica campestris, B. juncea, B. oleracea*)
    - Priority 1 in China, South and Southwest Asia, and Mediterranean
  - Cucurbits (*Cucurbita* spp.)
    - Priority 1 in Latin America
  - Eggplant (*Solanum melongena* and related species)
    - Priority 1 in South and Southeast Asia and West Africa
  - Okra (*Abelmoschus esculentus* and related species)
    - Priority 1 in the Pacific
  - Onion (*Allium* spp.)
    - Priority 1 in Southwest Asia
  - Pepper (chilli) (*Capsium* spp.)
    - Priority 1 in Latin America, South, and Southeast Asia
  - Radish (*Raphanus sativus* and related species)
    - Priority 1 in Southwest Asia
- 3rd Level priority
  - Bitter gourd (*Momordica charantia* and related species)
    - Priority 1 in Southeast Asia
  - Ethiopian mustard (*Brassica carinata*)
  - Sokoyokoto (*Celosia argentea*)
  - Swede, rapekale (*Brassica rapus*)
  - Globe artichoke (*Cynara scolymus*)
    - High priority in Mediterranean
- 4th Level priority
  - Bottle gourd (*Lagenaria* spp.)
    - Priority 2 in Latin America
  - Carrot (*Daucus carota*)
  - Chaya (*Cnidoscolas chayamansa*)
  - Chayote (*Sechium edule*)
    - Priority 1 in Central America
  - Cucumber, gherkin (*Cucumis sativus*)
  - Fluted pumpkin (*Telfairia*)
  - Indian or Ceylon spinach (*Basella alba*)
  - Jute mallow (*Corchorus olitorius*)
  - Kangkong (*Ipomoea aquatica*)
    - Priority 1 in Southeast Asia
  - Lettuce (*Lactuca sativa*)
  - Muskmelon, Cantaloupe (*Cucumis melo*)
    - Priority 1 in Southwest Asia
  - Watermelon (*Citrullus lanatus*)
  - Spinach (*Spinacia oleracea*)
    - Priority 1 in Southwest Asia

Beverages
- 1st Level priority
  - Coffee
    - New germplasm is needed of *Coffea arabica* because of coffee berry disease and coffee rust; clearing in West Africa may similarly lessen the availability of genetic diversity of *C. canephora* in that region

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Table 6 (continued)
PRIORITIES AMONG CROPS

- 2nd Level priority
  - Cocoa
    - The development of the Amazon region is reducing genetically diverse cocoa material which will be most useful in breeding for disease resistance and higher yields; cocoa is an important shareholders' crop for a major share of their export earnings; in general, the priority is 2 but for Criollo varieties it is 1 because of the potential of this material
- 3rd Level priority
  - Tea

Sugar crops
- 2nd Level priority
  - Sugar beet and related species
    - Beet, in general, has priority 2, but priority 1 is assigned to the genetic resources of *Beta* which are being lost rapidly in parts of Turkey and the Mediterranean
  - Sugar cane
    - Priority 1 in Pacific, South, and Southeast Asia

Miscellaneous crops
- 2nd Level priority
  - Trees for fuel wood and environmental stablization, particularly in arid and semiarid zones
- Priority level under study[a]
  - Forage crops
  - Medicinal and drug plants

Note: Crops used here imply the complex of cultivated forms, and the wild and weedy near relatives.

[a] Both fiber and rubber are not included here but have been prioritized by the IBPGR.

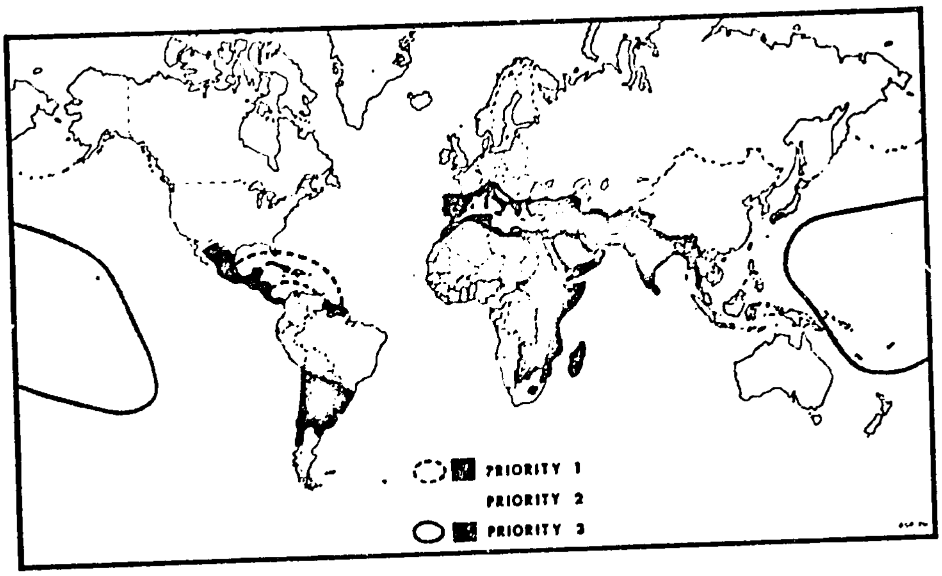

FIGURE 6. Regional plant collection priorities of the International Board for Plant Genetic Resources.

action on 27 others. These additional crops where discriptor lists are being developed include: tomato, sweet potato, soybean, sesame, safflower, quinoa, pigeon pea, *Phaseolus* bean, peach palm, olive, okra, pearl millet, peanut, lupin, grape, eggplant, cucurbit, cocoa, cassava, chili pepper, barley *Amaranthus*, almond, and *Allium*. Use of

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Table 7
IBPGR NETWORK OF BASE CENTERS FOR SEED CROPS[a]

Cereals

Rice	*Oryza sativa*	IRRI, Los Baños, Philippines
	indica	IRRI, Los Baños, Philippines
	javanica	NIAS, Tsukuba, Japan
	japonica	
	Mediterranean forms, temperate South American forms, and intermediate types from the U.S. (plus duplicates from other centers)	NSSL, Fort Collins
	Wild species	IRRI, Los Baños, Philippines
	African forms	IITA, Ibadan, Nigeria
Wheat	Cultivated species	VIR, Leningrad, U.S.S.R.
		CNR, Germplasm Institute, Bari, Italy
		NSSL, Fort Collins (each institute's collection duplicated at one of the others)
	Wild species of *Triticum* and *Aegilops*	Plant Germplasm Institute, University of Kyoto, Japan (duplicated in one of the above institutions and NIAS, Japan)
Maize	New World material	NSSL, Fort Collins
	Asiatic material	NIAS, Tsukuba, Japan
		TISTR, Bangkok, Thailand
	European material	VIR, Leningrad, U.S.S.R.
		Braga, Portugal (for Mediterranean material)
Sorghum	Cultivated and wild	NSSL, Fort Collins
		ICRISAT, Hyderabad, India
Millets	Cultivated and wild *Pennisetum* spp.	NSSL, Fort Collins
		PGR, Ottawa, Canada
		ICRISAT, Hyderabad, India
	Eleusine spp.	ICRISAT, Hyderabad, India
		PGRC, Addis Ababa, Ethiopia
	Minor Indian millets	ICAR, New Delhi, India
	Eragrostis spp.	PGRC, Addis Ababa, Ethiopia
	Panicum miliaceum	ICRISAT, Hyderabad, India
	Setaria italica	ICRISAT, Hyderabad, India
Barley	Cultivated and wild (global collection)	PGR, Ottawa, Canada
	European material	Nordic Genebank, Lund, Sweden
	African material	PGRC, Addis Ababa, Ethiopia
	Asian material	NIAS, Tsukuba, Japan
Oats	Cultivated and wild	PGR, Ottawa, Canada
		Nordic Genebank, Lund, Sweden

Industrial Crops

Sugar beet and other beets		Genebank, FAL, Braunschweig-Völkenrode, FRG

Legumes

Phaseolus	New world material (all species but emphasis on *P. vulgaris*, *P. coccineus*, *P. lunatus*, and *P. acutifolius*)	CIAT, Cali, Colombia (duplicated in NSSL, Fort Collins
	European material	Genebank, FAL, Braunschweig-Völkenrode, FRG
	Wild species	University of Gembloux, Belgium
Pigeon pea		ICRISAT, Hyderabad, India
Groundnut		ICRISAT, Hyderabad, India
		INTA, Pergamino, Argentina

Table 7 (continued)
IBPGR NETWORK OF BASE CENTERS FOR SEED CROPS*

Chickpea		ICRISAT, Hyderabad, India
Cowpea		IITA, Ibadan, Nigeria
Pea		Nordic Genebank, Lund, Sweden
Winged bean		IPB, Los Baños, Philippines
		TISTR, Bangkok, Thailand
	Root Crops	
Potato	Wild and cultivated species	CIP, Lima, Peru
	Vegetables	
Amaranthus	Global collection	NSSL, Fort Collins
	Southeast Asian collection	IPB, Los Baños, Philippines
Allium	Global collection	NVRS, Wellesbourne, U.K.
	Asian collection	NIAS, Tsukuba, Japan
Capsicum	Global collection	CATIE, Turrialba, Costa Rica
	Global collection	IVT, Wageningen, Netherlands
	Southeast Asian collection	IPB, Los Baños, Philippines
Eggplant	Global collection	IVT, Wageningen, Netherlands
	New World collection	NSSL, Fort Collins
	Southeast Asian collection	IPB, Los Baños, Philippines
Tomato	Global collection	CATIE, Turrialba, Costa Rica
		NSSL, Fort Collins
	Asian collection	IPB, Los Baños, Philippines
Crucifers	*Brassica oleracea*	NVRS, Wellesbourne, U.K.
		IVT, Wageningen, Netherlands
	Vegetable and fodder types: *B. campestris, B. juncea, B. napus*	NVRS, Wellesbourne, U.K.
	Vegetable and fodder types: *B. napus*	Genebank, FAL, Braunschweig-Völkenrode, FRG
	Oilseed and green manure crucifers: *B. campestris, B. juncea, B. napus, Sinapis alba, B. carinata*	PRG, Ottawa, Canada
		Genebank, FAL, Braunschweig-Völkenrode, FRG
		PGRC, Addis Ababa, Ethiopia
		Genebank, FAL, Braunschweig-Völkenrode, FRG
	Raphanus species	NVRS, Wellesbourne, U.K.
	Wild relatives	Universidad Politecnica, Madrid, Spain Tohoku University, Sendai, Japan
	East Asian collection	NIAS, Tsukuba, Japan
Other vegetables	Southeast Asian species	IPB, Los Baños, Philippines

Note: The following abbreviations are used: CATIE — Centro Agronomico Tropical de Investigación y Enseñanza, CIAT - Centro Internacional de Agricultura Tropical, CIP — Centro Internacional de la Papa, CNR — National Research Council, ICRISAT - International Crops Research Institute for the Semiarid Tropics, IITA — International Institute of Tropical Agriculture, INTA — Instituto National de Technología Agropecuaria, IPB — Institute of Plant Breeding, IRRI — International Rice Research Institute, IVT — Institute for Horticultural Plant Breeding, NIAS — National Institute of Agricultural Sciences, NSSL — National Seed Storage Laboratories, NVRS — National Vegetable Research Station, PGR - Plant Gene Resources of Canada, PGRC — Plant Genetic Resources Center, TISTR — Thailand Institute of Scientific and Technological Research, VIR - - N.I. Vavilov Institute of Plant Industry.

* As of the end of 1987, the IBPGR states that this network will be in effect and complete for seed crops by 1986.

these agreed-on descriptors will greatly facilitate the international exchange of gene bank readout by machine storage of standardized evaluation data.

Successful implementation of priorities resulting in collection and conservation in an

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IBPGR network gene banking center (Table 7) leads to the ultimate downgrading of the crop status, and so three to four new crops are added annually to the Board's concern as programs in others are downscaled or phased out (Table 8). Over the next decade or so the Board, by completing its function, will, in part, eliminate its role to stimulate the collecting and conservation of plant genetic resources.[104] But genes held in gene banks are worthless unless valued by plant breeders, and to accomplish this there must be evaluation of all existing collections.

The evaluation of germplasm will probably lead to a new function for the IBPGR, and that is the maintenance of the continued free flow of characterized and evaluated germplasm to breeders and the worldwide assessment of genetic vulnerability by monitoring the currently most frequently used elite germplasm on a crop-by-crop basis. This last point is speculation on my part, but the current crop advisory committee already in place is qualified for such a change in function for the IBPGR.

In the early years priority regions for collecting were identified for maize, wheat, sorghum and millets, *Phaseolus* beans, and rice because of the urgency imposed by genetic erosion on these major food crops. Additional world crops have been added (Table 9), but, of necessity, the IBPGR has paid, and intends to continue to pay, less attention to crops with low priority (i.e., ratings of 3 or 4). Yet some crops are important in a regional context, as, for example, the tropical fruits of Southeast Asia[105] and the distinctly different fruits of Central America,[106] and the Board will, on an *ad hoc* basis, stimulate or coordinate and, where necessary, help support collecting of these crops. Another example of a special set of crops are the unique high elevation Andean pseudo-cereals: quinos — *Chenopodium quinoa*, canihua — *C. pallidicaule*, and coimi — *Amaranthus caudatus*; and the minor tubers: oca — *Oxalis tuberosa*, ulloco — *Ullucus tuberosa*, and ysano — *Trapaelluim tuberosum*, which are being replaced by more productive crops just as the Andean potato displaced peas and turnips in the diet of Europeans two centuries ago.

There is considerable scope for the wider use of these regional crops and neither the tropical fruits nor tropical vegetables have had a systematic worldwide evaluation.[107-116] The IBPGR has the potential in this case to stimulate and encourage agricultural diversification and the accelerated crop evolution which occurs when crops are introduced into new but suitable habitats. Many of these crops have recalcitrant seeds which do not survive the drying and low temperature storage of orthodox seeds or are vegetatively propagated clones, and these present problems requiring research in basic biology for solutions.[117-120]

The widespread and rapid movement of plant material, especially vegetative material, poses the threat of disease introduction along with the crop. Very promising new technologies using tissue culture might be a means around the genetic conservation problems of clonally propagated crops, many of which are tropical, and the problems of international quarantine regulations. Specific types of tissue cultures, such as meristem culture, could be transported as certified disease-free stock in sterile test tubes. The IBPGR has been encouraging research with genetic storage of vegetatively propagated crops through living collections in plantations, dry pollen at low temperatures, cell and tissue cultures, and the establishment of expected longevity curves for seeds in long-term storage.[117-120] These technologies will both further gene conservation and speed plant material through quarantine for plant introduction.

As the technology of gene storage, information management, and crop evaluation become more complex, the necessity of special training has become more apparent. The International Postgraduate Training Course on Conservation and Utilization of Plant Genetic Resources, Master of Science course at the University of Birmingham, U.K., has trained over 150 students since 1969. This unique training resource has been supported

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Table 8

THE IBPGR PLANS FOR ACTION ON CROPS (1981—86)

- Continuation of collecting of global priority crops initiated in the past quinquennium
  - Completion of the major part of the work
    - Maize
    - Rice (mostly through IRRI)
    - Rice (mostly through CIO)
    - Sorghum
    - Pearl millet
    - Cowpea
    - Winged bean
  - Continuation of collecting
    - Wheat
    - Minor millets (especially *Eleusine, Setaria, Digitaria*)
    - Barley
    - *Phaseolus* beans
    - Groundnut
    - Banana
    - Cotton
    - Coconut
    - Beet
- Initiation of new programs 1981–86 for global priority crops
  - Planning already well advanced
    - Vegetables (tomato, crucifers — especially *Brassica* spp., *Allium, Cucurbita, Amaranthus, Capsicum,* eggplant, okra)
    - Coffee, cocoa
    - Sweet potato, cassava
    - Forages (in the first instance emphasis will be on the arid and semiarid zones but tropical forms will also receive attention)
    - Trees for fuel wood and environmental stabilization, especially in arid and semiarid zones
    - Grape
  - Planning in 1981 and implementation thereafter
    - Sugarcane
    - Barley (although collecting has been supported, a global plan has not been fully developed)
    - Citrus
    - Asiatic *Vigna* sp.
  - Planning in 1982 and implementation thereafter
    - Soybean
    - Chickpea
    - Cotton (although collecting has been supported, a global plan has not been fully developed)
    - Temperate fruits (especially apple, pear, peach, apricot, cherry, plum)
    - Tropical fruits and nuts (especially avocado, mango, cashew, fig, date, papaya, pineapple)
  - Planning in 1983 and implementation thereafter
    - Rubber
    - Oil palm
    - Medicinal plants
- Continuation of collecting of regional priority crops initiated in the past quinquennium (other than those listed in first section)
  - Southeast Asia
    - Durian, rambutan, mango
    - Vegetables and legumes: *Ipomoea aquatica* and other leafy vegetables, *Momordica, Vigna unguiculata*
    - Tuberous: Dioscoreaceae, Araceae, and Zingiberaceae
  - South Asia
    - Legumes, medicinal plants, spices
  - Southwest Asia
    - Barley, chickpea, lentil, faba beans, fruits
  - Mediterranean
    - Faba beans, lentil, fruits
  - East Africa
    - Minor millets, coffee

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Table 8 (continued)
THE IBPGR PLANS FOR ACTION ON CROPS (1981—86)

West Africa
African rice, cowpea, and other legumes and root and tuber crops
Latin America
Tropical and subtropical forages, quinoa, lupin, Andean tuber crops
Initiation of new programs 1981—86 for regional priority crops
As the Board's regional activities expand, work will be initiated within the region's crops with high regional priority but with lower global priority

Table 9
TABLE SYNOPSIS OF THE REGIONAL CROP PRIORITIES

Region	Crop priority within each region
Mediterranean	1 — Wheat, barley, and sugar beet
	2 — Chickpea
	3 — Maize, oats, rye, *Pisum* sp., *Vicia faba*, brassicas, olive, and safflower
Southwest Asia	1 — Wheat, barley, and coffee
	2 — Chickpea and sugar beet
	3 — Oats, rye, *Pisum* sp., *Vicia faba*, brassicas, olive, and safflower
South Asia	1 — Sorghum, millets, and rice
	2 — Chickpea, groundnut, *Vigna* spp., cassava, bananas, cotton, and sugar cane
	3 — Maize, pigeon pea, *Vicia faba*, yam, jute, brassicas, and safflower
Ethiopia	1 — Wheat, sorghum, millets, and coffee
	2 — Chickpea, cowpea, soybean, bananas, and cotton
	3 — Barley, maize, *Pisum* sp., *Vicia faba*, and sunflower
Meso-America	1 — *Phaseolus*
	2 — Groundnut, cassava, potato, sweet potato, cotton, South American oil palm, and cocoa
	3 — Maize, yam, and sunflower
Western Africa	1 — Sorghum, millets, and rice *(O. glaberrima)*
	2 — Cowpea, groundnut, cassava, and cotton
	3 — Maize, yam, and African oil palm
Andean Zone	1 — *Phaseolus*
	2 — Groundnut, potato, and cotton
	3 — Maize
Central Asia	1 — Wheat
	2 — Rice, chickpea, *Vigna* sp., cotton, sugar beet, and sugar cane
	3 — Barley, maize, oats, rye, *Pisum* sp., *Vicia faba*, safflower, and sunflower
Southeast Asia	1 — Rice *(O. indica* and *O. javanica)*
	2 — Soybean, *Vigna* spp., cassava, sweet potato, bananas, cotton, and sugar cane
	3 — Maize, pigeon pea, and yam
Brazil	2 — Groundnut, *Vigna* sp., cassava, sweet potato, cotton, South American oil palm, rubber, and cocoa
	3 — Maize and yam
Pacific Islands	2 — Sweet potato, sugar cane, and bananas
	3 — Yam
Far East	1 — Wheat, sorghum, and millets
	2 — Rice, groundnut, soybean, *Vigna* sp., cassava, bananas, cotton, and sugar cane
	3 — Barley, maize, yam, and brassicas
Eastern Africa	1 — Sorghum, millets, and *Phaseolus*
	2 — Rice, cowpea, groundnut, soybean (*Glycine* sp.), cassava, bananas, and cotton
	3 — Maize, pigeon pea, and yam
Southern South America	1 — *Phaseolus*
	2 — Groundnut, cassava, potato, sweet potato, and cotton
	3 — Maize

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by IBPGR since 1976 to enable more students from developing countries to attend. Already many of these graduates are the lead officers for plant genetic resources in their country. Because of the need for uniform crop handling procedures, descriptor use, and policies to facilitate the international flow of information, this university course and short regional training courses have been catalytic in utilizing the good will and goals of a cadre of plant scientists at the national level.[121]

Currently there is widespread support for the building of gene conservation institutions, but the present system operates on good will which is subject to sociopolitical uncertainty. The system works well now because it does not make excessive budgetary demands, but costs are going to increase over time. In 1975 there were only eight institutions in the world with refrigerated storage suitable for maintaining seeds at – 18° C necessary for long-term storage as against 0° C suitable for medium-term storage of working collections. Now that the number has tripled, will nations discover they are too expensive to maintain and wish to cut back on their commitments? In perpetuity storage is a long commitment to expect from voluntary working agreements.

In these gene banks a tremendous amount of genetic variation is being stored which is not of any known immediate use on the premise that it *might be needed*. Two questions arise: (1) Will it be maintained until it *is needed* and once needed can it be *mobilized* (i.e., found in the collection fast enough because evaluation has been sufficiently accurate and/or detailed to find it in the vast library of genes)? and (2) Will it be *freely available* to all parties from the evaluation team and/or gene bank? As expenses increase the stability of gene banks in the world, networks are potentially threatened if their usefulness is not obvious on a daily basis to the supporting political arena. The plant breeding process is dependent on utilization of new genes and gene combinations and *so breeders are going to have to establish the efficacy of gene banks and hold to the principle of free and open gene exchange,* whatever the government agreements.

Most of the elements in the current world network -- the gene banks, the uniform common language of descriptors, the free exchange of germplasm -- are on a voluntary basis. Will this good will to share our genetic heritage continue or will, as resources become scarce, the heritage be laid claim to by private groups? Clearly, the future of plant breeding and, therefore, agriculture and world food supply rest on the plant genetic resources of our most productive crop plants. The responsibility goes two ways; both the nations which possess genetic diversity and the breeders that enhance the genetic architecture have an obligation to insure that these resources are used to improve the human condition for all people.

The imperative for genetic conservation develops from three processes in our current world: (1) an increasing human population which leads to further alteration of natural ecosystems and the expansion of food producing agriculture, (2) the widespread adoption of elite crop plant germplasm and agricultural technology which promotes genetic uniformity, sometimes worldwide, and (3) the centers of genetic variability are moving from natural systems and primitive agriculture to gene banks and breeders working collections with the liabilities that a concentration of resource (power) implies. How well the current system is meeting the challenge was the topic of the 1981 FAO/UNEP/IBPGR International Conference on Crop Genetic Resources attended by approximately 60 nations meeting to assess the past 10 years since the last meeting[75] and the actions necessary for the next 10. Their recommendations found in Appendix B represent the international agreement on the issues of genetic erosion, genetic vulnerability and genetic wipeout, and the current perception of cooperative programs necessary to implement the imperative.[122] The real question of the system will be how well and quickly it will deploy resources in the face of genetic vulnerability to prevent the collapse of agriculture, and only then will it be appreciated politically for anticipating the future.

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One last point, there is no equivalent to the IBPGR for forestry, animal genetic resources, or microorganisms. These units were mentioned in the Stockholm Resolutions. If action is not taken, these biological resources are likely to become diminished and limit future genetic improvement for tree crops, domestic animals, and microbes. This was noted most recently at a U.S. Strategy Conference on Biological Diversity[123] which recognized the IBPGR as a model organizational structure. In recent years, the IBPGR has developed both international and regional infrastructures and is, therefore, already in place to be expanded to other biological material if donors and "international will" can see their way to using it.

ACKNOWLEDGMENTS

I owe a debt of gratitude to many of my colleagues for their gracious flow of information and personal insights on the issues of genetic resources. This is especially true for Sir Otto Frankel (Australia), Dr. Trevor Williams (IBPGR), Professor Jack Harlan (U.S.), and Professor J. G. Hawkes (U.K.); the last let me read the editor's manuscript of his soon-to-be published book by Harvard University Press on crop plant evolution and genetic resources. In addition I wish to acknowledge the assistance of Drs. Russell Stevens, Thomas Whitaker, Walter Hodge, Roland Loiselle, Howard Hyland, George White, William Tallent, and John Creech for answering my many questions. The curators of genetic stock collections, Drs. E. R. Sears, G. A. Marx, T. Hymowitz, C. M. Rick, and T. Tsuchiya, have also been very responsive to my request. While these and many others have helped me form my ideas and understandings of the institutions that have developed around plant genetic resources, the interpretations and speculation expressed in the paper are my responsibility alone.

APPENDIX A — NATIONAL SEED STORAGE LABORATORY POLICY STATMENT

General

1. The Laboratory is a federal facility and all seed accepted for long-term storage becomes the property of the U.S. Government and remains so until released by the Laboratory.
2. Only seeds are accepted for storage in accordance with the following policy guidelines.
3. The principal mission of the Laboratory is long-term preservation of valuable plant germplasm as viable seed. The Laboratory conducts research in support of its principal mission. Long-range studies focus on biochemical-physiological and genetic changes in seed during storage and effects of seed moisture content, storage environment, and storage containers on seed longevity. Laboratory procedures for accurate monitoring of seed viability during storage are established on a crop-by-crop basis.
4. The Laboratory issues periodic inventories of the stocks held in long-term storage to inform research workers of materials available.
5. All foreign proposals for storage will be reviewed for approval by the AR Plant Germplasm Coordinating Committee. In making its decisions, the Committee will be guided by recommendations of appropriate crop advisory committees. Acceptance for storage may require an exchange of letters between AR and the requesting agency or institution. Collections accepted for long-term storage (i.e., base collections) will be accessioned and incorporated as an integral part of the Laboratory and,

hence, the U.S. National Germplasm System. Collections for temporary or emergency storage may be accepted but under terms specified in the exchange of letters between AR and the requestor.

Accessioning

6. In keeping with policy here set forth, the Laboratory Director accepts valuable seed stocks from U.S. Federal and State institutions, commercial seed interests, private individuals, and, as specified in item 5 above, from foreign institutions. Information as to source of individual accessions is essential. Genetic composition and complexity of improved stocks should be documented as thoroughly as possible.
7. Only clean seed of reasonably high germination is acceptable for storage. Seed of low viability will be held on a tentative basis until the donor is able to provide replacement seed of acceptable viability.
8. After seed is accepted officially, the Laboratory, unless exempted by specific agreement, is responsible for future increases necessitated by viability decline or stock depletion.
9. The Laboratory assumes no responsibility for replenishment when stocks received are subminimal in quantity or viability. However, for obsolete varieties or rescued collections not meeting the preceding acceptable standards, the Director of the Laboratory, in consultation with appropriate crop specialists, may make arrangements for their increase.
10. The acceptance of seed of commercial varieties by the Laboratory shall not be considered in any way Federal endorsement as to the value of the variety.

Distributing

11. Any bona fide research worker of the U.S., its territories, and possessions may receive, without charge, seed from the collections stored at the Laboratory, but may be requested to return a portion of the increased seed for any item which requires immediate increase. Foreign research workers also may receive seed under the same conditions, provided the U.S. Government and that of the country concerned will permit reciprocal exchange of plant germplasm. No seed will be distributed if it is commercially available or can be located in working stocks of cooperating agencies. The Principal Plant Introduction Officer will provide alternate sources of supply.
12. The Laboratory is not responsible for errors which may occur in original documentation including the cultivar name supplied by the donor.

APPENDIX B — RECOMMENDATIONS — 4TH TECHNICAL CONFERENCE ON CROP GENETIC RESOURCES, ROME, APRIL 6 TO 10, 1981, FAO-UNEP-IBPGR CONFERENCE

Concerning Collecting

1. That the IBPGR should request the F.A.O., UNDP, and CGIAR (cosponsors of the IBPGR) and other agencies to always make collection of endangered local species and landraces an activity within crop improvement projects
2. That more collecting missions for wild relatives of cultivars should be carried out
3. That collecting within mixed plantings and multicropping systems should be done in a way that allows the preservation of combinations of interest

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4. That as different sampling techniques must be used for different crops and different environments, a range of realistic collecting techniques should be developed to meet the needs of collectors

Concerning Forage Crops

5. That an action program to explore, collect, conserve, characterize, evaluate, and use forage plant genetic resources should be initiated jointly by the IBPGR, F.A.O., and UNEP

Concerning Special Crops

6. That genetic resources programs should be encouraged to take responsibility for species of particular significance such as traditional and medicinal plants; and programs with regional responsibilities should endeavor to become centers of excellence for them

Concerning Forestry

7. That emphasis should continue to be placed on forest genetic resources, particularly species used in arid and semiarid zones for fuel and other tree species of wide social and economic importance or potential
8. That countries and agencies responsible for reserves should consider whether or not additional areas are needed for special needs such as the conservation of wild relatives of cultivars, related weeds, and the maintenance of genetic diversity within species
9. That guidelines should be set out for planners and managers of protected areas to advise them on measures that should be taken to conserve genetic resources and at the same time leave them available for use
10. That UNEP and the International Union for the Conservation of Nature (IUCN) should encourage *in situ* conservation in areas that can be used for educational, recreational, and other purposes
11. That as a first step towards the establishment of a data bank for crop genetic resources maintained in protected areas, a comprehensive inventory of the wild relatives of crops should be compiled and other information essential for *in situ* conservation of plant genetic resources should be assembled
12. That an ad hoc committee consisting of representatives of F.A.O., UNEP, IBPGR, Unesco/MAB, and IUCN should be formed to advise on all aspects of the conservation of genetic resources in protected areas and to assist in the coordination of this work with the conservation of forest and range land genetic resources

Concerning Conservation and Regeneration

13. That additional cold stores should be provided to strengthen the international network of these facilities
14. That, as the study of regeneration has been neglected, the IBPGR should support investigations to determine basic principles so that standard methods can be developed particularly for tropical crops and cross-pollinated species
15. That centers holding large working collections should make the improvement of services offered to bona fide users a major goal
16. That the IBPGR should initiate a survey of seed dormancy in the wild relatives of cultivated plants and the techniques used to overcome it

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Concerning In Vitro Conservation

17. That in order to expedite the use of in vitro techniques for conservation, research should be intensified on the following: the improvement of specific techniques for crops for which in vitro propagation has been developed to such a degree that it is now realistic to attempt to apply the techniques, or develop them more extensively, to material in gene banks; basic studies of crops with which little, if any, success has been achieved so far with in vitro culture and propagation techniques; cryo-preservation of all types of plant material with the aim of establishing first principles
18. That a small working group should be appointed to collate and disseminate information on in vitro conservation and to advise on training programs

Concerning Evaluation and Utilization

19. That work on the characterization and evaluation of germplasm in gene banks should be expedited and findings transmitted to the potential users of the germplasm as quickly as possible
20. That the IBPGR should stimulate work designed to transfer valuable characters of wild species into breeding lines of cultivated plants in order to promote the utilization by breeders of useful characters

Concerning Documentation

21. That international descriptor lists should be used as a basis for standardization and data bases should be open-ended
22. That passport data should always be sent to the recipients of subsamples, for each of which the key identifier should be the collector's name and number and the number given by the institute holding the sample; for a breeding line the key identifier should be the breeder's number and institute; for cultivars, the varietal name and name of the institute that bred it
23. That more emphasis should be placed on the improvement of information exchange between genetic resources centers and to the feedback of information from users of plant genetic resources

Concerning Quarantine

24. That all germplasm exchange should take place through national quarantine services
25. That setting up national or regional testing laboratories should be considered by governments to expedite the passage of germplasm through quarantine
26. That the establishment of third-country post-entry quarantine facilities should be encourage particularly for clonal crops and other specific crops and their relatives
27. That the investigation of pathogens and pests carried by germplasm, including those of wild species and wild relatives of cultivars, should be encouraged in national research institutes
28. That research initiatives should be taken in the use of in vitro techniques for "cleaning up" germplasm to meet quarantine requirements, especially as regards viruses

Concerning Training

29. That support for the training courses at Birmingham University on the conservation and utilization of plant genetic resources should continue
30. That the IBPGR should increase the support for practical training which should be obtained when feasible at a gene bank
31. That regional training should be arranged in order to widen participation and reduce costs
32. That the IBPGR should consider giving support for specialist short courses on computer usage in data management to include the use of standard software packages
33. That consideration should be given by F.A.O. to the organization of training courses dealing with problems of plant quarantine

Concerning Publications

34. That the IBPGR should continue to issue manuals concerned with the practicalities of genetic resources conservation and should consider producing them in several languages to enhance their usefulness
35. That a book covering the topics discussed during the Conference should be published
36. That bodies dealing with plant genetic resources should take steps to promote public awareness of the need to conserve and utilize them for the benefit of mankind

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