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THE DEMAND FOR CROP GENETIC RESOURCES: INTERNATIONAL USE OF THE U.S. NATIONAL PLANT GERMPLASM SYSTEM

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ABSTRACT

In contrast to a perception that *ex situ* collections of germplasm are rarely used, this empirical case study reveals large quantities of germplasm samples distributed by the U.S. National Germplasm System to many types of scientific institutions located in numerous countries around the world. Distributions favor developing countries in several ways including the numbers of samples shipped, utilization rates in crop breeding programs, and the secondary benefits brought about through sharing this germplasm with other scientists. Expected future demand is also greater among scientists in developing countries. These findings underscore the importance to global science and technology of retaining such resources in the public domain.

KEYWORDS: developing countries, crop genetic resources, plant breeding, germplasm collection

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THE DEMAND FOR CROP GENETIC RESOURCES: INTERNATIONAL USE OF THE U.S. NATIONAL PLANT GERMPLASM SYSTEM

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1. THE GLOBAL ROLE OF GERMPLASM COLLECTIONS

Regardless of where they live, the world's farmers face rising expectations concerning either the quantity or the quality of the food they produce. The expected growth in world population will increase food demand, with much of the increase coming in areas already without fully adequate food supplies. In many parts of the world, farmers continue to cope with difficult production conditions and have few alternative sources of income to purchase food when their crops fail. In richer countries, producing sufficient quantities of food is hardly an issue, though as their incomes rise, consumers demand enhanced environmental amenities, such as decreased use of toxic agricultural chemicals or unique product attributes. In the meantime, physical constraints such as land quality or water availability limit the expansion of agricultural land in both developed and developing countries. Plant breeding can help meet these challenges, by adding traits that enhance quality, improve tolerance to climatic conditions, or provide disease resistance that is based on combinations of genes rather than purchased chemical inputs.

Crop improvement through plant breeding critically depends on crop genetic resources. All crop output, whether it is the harvest of traditional varieties selected by farmers or modern varieties bred by professional plant breeders, is in some way descended from an array of wild and improved genetic resources from around the world. Advances in yield potential, resistance

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to pests, quality, or other desirable traits in modern varieties have resulted from the crossing by professional breeders of diverse parental material. Both farmers who consume their crop output and professional plant breeders depend on crop genetic resources; in turn, farmers' selection efforts and the achievements of modern plant breeders have generated other genetic resources.

Plant breeding issues are not resolved once and for all--they persist because the problems of crop production change. Pests, pathogens and climates evolve and change, so that breeders continually need new genetic resources from outside the stocks they work with on a routine basis (Duvick 1986). The US Department of Agriculture estimated that new varieties are resistant to biological stresses for an average of five years, while it generally takes 8-11 years to breed new varieties (USDA 1990). Resource constraints and discontinuities in research programs mean that the time to release a new variety can be even longer in the developing world. In disease hotspots such as those for the rusts of wheat in the Asian subcontinent or northern Mexico, virulent new strains may overcome genetic resistance based on single genes in only 2-3 years unless more complex mechanisms of resistance are found (Dubin and Torres 1981; Nagarajan and Joshi 1985).

Uncertainty about the resources that will actually be needed for improving future agricultural production motivates genetic resource managers, particularly those in the public sector, to collect and accumulate a broad range of germplasm in *ex situ* collections. Funds are limited for genetic resource management, however. Duvick (1995: p. 36) stated, "For thirty years and more, germplasm banks have been in operation… Without exception, and differing only in degree, the collections have been imperiled from the day of their assembly." The economic justification for investing in collections of crop genetic resources has remained a subject of controversy. The perception remains that germplasm collections are underutilized and are of questionable economic value (Wright 1997; Simpson and Sedjo 1998).

To address this perception, we offer a summary of how one national genebank is used internationally, based on quantitative data and a study of germplasm requestors. Data reveal large numbers of germplasm samples distributed by the U.S. National Plant Germplasm System to many types of institutions locate* in numerous countries around the world. Moreover, rates of utilization are likely underestimated given the long-term nature of scientific research. Germplasm distributions favor developing countries in several ways. These findings raise questions about previous assumptions concerning the demand for such resources, and may have relevance for ongoing negotiations of international agreements, such as the International Undertaking on Plant Genetic Resources for Food and Agriculture.

2. THE U.S. NATIONAL GERMPLASM COLLECTION

The U.S. National Plant Germplasm System (U. S. NPGS) provides an interesting point of departure for the study of germplasm collections because of its size, the sheer volume of material it distributes, and the documentation maintained by curators. Many national collections, especially those found in the developing world, do not possess the resources to digitize information regarding their activities. Investments would need to be made to enable them to track requests and distributions of their materials, but when funding is severely curtailed as it is for many collections, documentation systems are not a priority. In terms of size, U. S. NPGS holdings exceed 450,000 accessions[5] of comprised of 10,000 species of the 85 most commonly

[5] According to the National Research Council (1993, p. 407), an accession is a distinct, uniquely identified sample of seeds, plants, or other germplasm materials that is maintained as an integral part of a germplasm collection. Many seed samples may be distributed for the same accession, to different requestors.

grown crops, making it the largest national genebank in the world. U. S. NPGS's materials are not held in one location; rather the system consists of a number of publicly funded collections located across the country as well as centralized facilities for coordination, quarantine, and long-term seed storage. Collections include seed and genetic stocks, as well as repositories of clonal germplasm and plant introduction stations.

The U. S. NPGS has a clear mandate to serve the needs of national scientists, and for the ten major crops we study here (barley, bean, cotton, maize, potato, rice, sorghum, soybean, squash, wheat), about three-quarters of the 621,238 samples shipped over the past decade were destined for U.S. requestors. Nevertheless, the collection is of global importance, as indicated by the amount of germplasm it distributes internationally. For these ten crops only, during the past decade the U. S. NPGS distributed 162,673 germplasm samples to scientists in 242 countries outside the U.S. All available germplasm from the U. S. NPGS is provided to anyone free of charge, upon request, though special permission is required to fill germplasm requests from countries with which the U.S. does not maintain diplomatic relations.

A comparison with the volume of distributions from other genebanks is illustrative of the international role of U.S. NPGS. All economically important crops have gene bank collections, and there are hundreds of such collections worldwide, with roughly 6 million accessions for all crops (FAO 1998). The Consultative Group on International Agricultural Research (CGIAR) research centers hold substantial proportions of the accessions included in these collections. One of these centers, the International Center for Maize and Wheat Improvement, distributed 20,540 samples of maize and 39,770 samples of wheat to from 1987 to 1998, compared with larger numbers (30,493 for maize and 154,962 for wheat) by the U.S. NPGS over a similar time period (1990 to 1999). National collections in other richer countries provide another contrast. Two germplasm systems, the Nordic collection (representing the Scandinavian countries) and the Netherlands collection, have provided data that enables a comparison with U. S. NPGS. Over the same 1990-1999 period, the total of germplasm samples for all crops distributed to other countries by the Nordic collection was only 15,477, and for the Netherlands, 25,310.[6] These numbers represent but a fraction of total U.S. NPGS distributions to other countries during the same period, including only the 10 crops we have considered. Based on data reported by Shands and Stoner (1997), we estimate that the 10 crops account for slightly more than half the total distributions of all plant germplasm by U. S. NPGS over the past decade.

The next section describes data sources used. Findings are reported in terms of three questions motivating the study, followed by estimates of actual use rates. Conclusions and implications are discussed in the final section.

3. DATA SOURCES

Data reported here are drawn from two sources. The first is data on germplasm distributed by U. S. NPGS. The U.S. National Plant Germplasm Resources Laboratory, which coordinates documentation for the system through Germplasm Resources Information Network (GRIN) and coordinates the plant exploration program, provided quantitative information about samples distributed from 1990 to 1999 for the 10 crops that we selected for study. The second source of information was original data that we collected directly from requestors of U. S. NPGS germplasm. In order to implement this study, the U.S. National Germplasm Resources

[6] Data reported to the Global Forum for Agricultural Research (GFAR).

Laboratory also supplied the names of all individuals who requested germplasm from 1995 to 1999 for the 10 crops in question.

Because examining users of the entire U. S. NPGS collection of 85 crops was not possible with the resources available to us, we focused on 10 crops. Five crops were selected based on their importance in world production: wheat, rice, soybeans (as a leading oil seed), maize (as the leading coarse grain) and barley (USDA, FAS 2001). Cotton and sorghum are also leading crops in the US, in terms of production volume, hence their inclusion. Potato, beans and squash were also included, not only because of their economic importance, but because they are indigenous to the Americas (as are maize and upland cotton).

To understand the nature of the demand for crop genetic resources conserved in gene banks, we need first to answer the fundamental questions of: 1) *who* uses the genebanks; 2) *what* kind of germplasm is used; and 3) *why* users want germplasm (for what purpose and in search of which plant characteristics) (Wright 1977). We developed a study questionnaire around these questions.

Each requestor was sent a letter explaining the study and a form that asked for information about the recipient's experiences with U. S. NPGS. The format by which responding users submitted information was intentionally brief, to ease response time and improve the response rate. The questionnaire was sent to international requestors for the first time in mid-2000. Users who did not respond to the first request were mailed a second request. Lists of respondents have remained confidential and are separated from data files.

A total of 1063 individuals were included on the list of international requestors, though several names appeared more than once with different crops. Of these, 380 (36 percent) provided usable information. Response rates ranged from 23 to 45 percent by crop, with the lowest response rate in potato and the highest in wheat. For cotton, rice, sorghum and squash the number of responses was small for purposes of statistical analysis. The response rate was nearly twice as high in developed and transitional economies of the former Soviet Union and Eastern Europe as in developing countries, likely reflecting mail service difficulties.

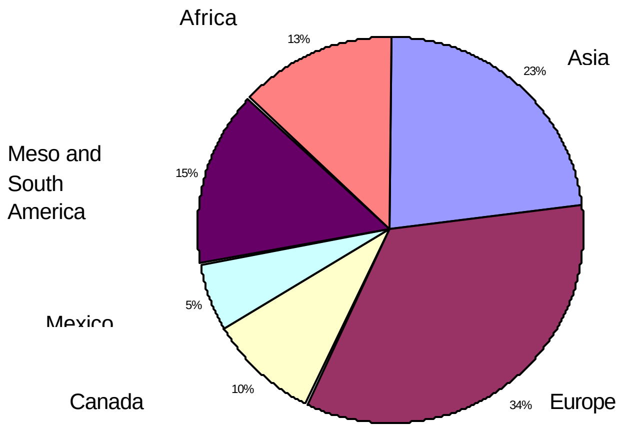
Most of the international respondents had requested more than one seed sample. Since respondents reported the number of germplasm samples they received, we can analyze the information either by respondent or on the basis of germplasm samples. Both approaches are employed in this paper, depending on which is more appropriate for the analysis.

4. FINDINGS

a) Who requests germplasm?

U. S. NPGS in-house distribution data provide a clear picture of who uses public germplasm in the international community. The geographical pattern of distributions to other countries for the 10 crops is shown in Figure 1.

Figure 1--International distribution of U. S. NPGS germplasm for 10 major crops, by region, 1990-1999.

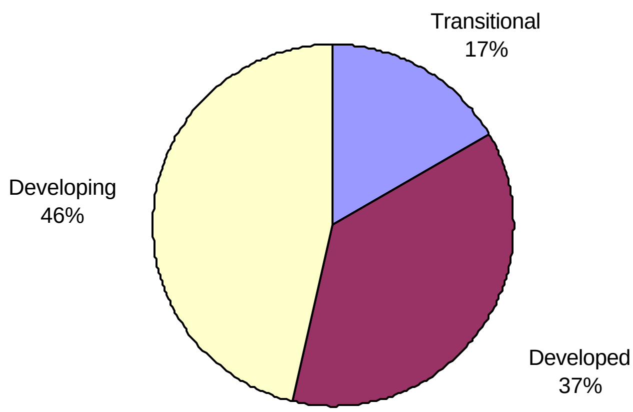


Source: Calculated from data provided by the U.S. Department of Agriculture, National Germplasm Resources Laboratory. Includes all germplasm samples distributed for barley, beans, cotton, maize, potato, rice, sorghum, squash, soybean, and wheat.

According to U. S. NPGS data, about a third of all samples were destined for countries in the Europe region, followed closely by other countries in the Americas (30%). Asia was the next largest regional recipient (23%), while the continent of Africa received only 13% of samples shipped. Geographical patterns reflect a number of factors, including the production zones of the crops in question, and the capacity of local scientists to utilize materials, which is in turn conditioned by their funding and the technologies available to them.

When classified by development status, developing countries as a group were distributed more germplasm (46%) than either developed countries or the transitional economies of Eastern Europe and the former Soviet Union (Figure 2).

Figure 2. International germplasm transfers from U. S. NPGS for 10 major crops, by development status of receiving country, 1990-1999.



Source: Calculated from data provided by the U.S. Department of Agriculture, National Germplasm Resources Laboratory. Includes all germplasm samples distributed internationally for barley, beans, cotton, maize, potato, rice, sorghum, squash, soybean, and wheat.

Together, developing and transitional countries received 63 percent of all germplasm samples sent to other countries during the past decade, or over 100,000 samples. Thus, internationally, this large national genebank is more likely to distribute public germplasm to recipients working in less technologically favorable conditions.

The distribution data also reveals some unexpected patterns with respect to the institutional affiliation of recipients (Table 1). First, as expected, the vast majority (76%) of germplasm samples sent outside the U.S. were distributed to non-commercial organizations. Second, the U.S. national collections clearly supply more samples to public institutions concerned with crop breeding and research than to those dealing with conservation.

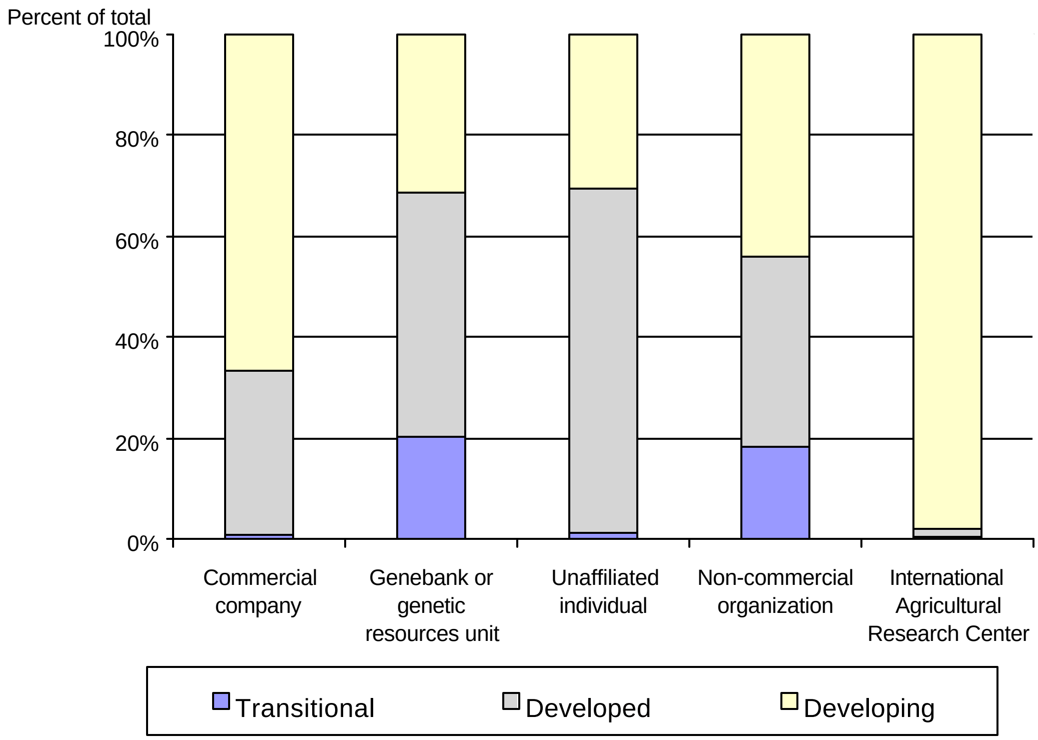
Table 1--USNPGS germplasm distributions to other countries by type of receiving institution, 1990-99

Type of Institution		Percent of all samples distributed outside U.S.
commercial company		4.5
genebank or genetic resource unit		12.8
unaffiliated individual		0.6
non-commercial organization		76.6
International agricultural research center		5.6
	Total	100.0

Source: Calculated from data provided by the U.S. Department of Agriculture, National Plant Germplasm Resources Laboratory.
Crops include barley, bean, cotton, maize, potato, rice, sorghum, soybean, squash, wheat

Genebanks, especially international agricultural research centers, were less important recipients than crop improvement and research programs. Generally, private breeders are thought to rely primarily on their own collections (Mann 1997; Wright 1997), and their use of gene banks is believed to be limited—though in his survey of U.S. breeders, Duvick (1984) found that private breeders make use of all germplasm sources. Indeed, only about 5 percent of the 167, 673 samples U. S. NPGS sent abroad in the past decade were shipped to commercial requestors. Surprisingly, however, commercial companies receiving samples in other countries were twice as likely to be located in developing countries as in developed countries (Figure 3). Unaffiliated individuals were few, and most were found among the developed country recipients.

Figure 3--Distribution of germplasm samples sent from U.S. NPGS to other countries from 1990-1999, by development status of recipient's country.



Source: Calculated from data provided by the U.S. Department of Agriculture, National Germplasm Resources Laboratory, USDA. Includes all germplasm samples distributed for barley, beans, cotton,maize, potato, rice, sorghum, squash, soybean, and wheat.

Among U. S. NPGS users who participated in the study, a similar proportion were affiliated with governments, universities, or publicly-funded research and development institutions (70%). A larger proportion of respondents (15%) worked for private seed, chemical or biotechnology companies or for privately-funded research organizations than is represented in the data on total distributions for the decade. Since the average size of request was significantly greater for publicly-funded than for private-funded institutions (Table 2), however, the proportional balance in terms of numbers of germplasm samples is similar between the two data sources.

Table 2--Average number of germplasm samples requested from USNPGS by international respondents, by type of institution

Type of institution	**Average number of germplasm samples requested per respondent**
Private companies or private R & D	57
Government, university, or public R & D	153**
National, regional, or international genebank	214**
Self –employed, seed savers, or NGOs	30
All respondents	119

Source: Study conducted by International Plant Genetic Resources Institute.
Total number of respondents= 380
Note: Requests (rows) sum to more than 100 percent when requests of more than one material type are made. Pearson Chi-squared tests (two tails, significance level=0.01) show no significant differences in percent requesting material by type of institution. (**) Pairwise t-tests show significantly (0.01) greater average sizes of request for genebanks and publicly-funded institutions relative to other groups.

b) What kind of germplasm is requested?

Like other gene banks, the U. S. NPGS supplies various types of germplasm to requestors. Materials are categorized as: 1) elite or modern, 2) landraces, 3) wild and weedy relatives, and 4) genetic stocks.[7] The first category includes all materials improved by professional plant breeders. This material can be broken into two categories, the first being “cultivars”, which includes recently developed cultivars, and “obsolete” cultivars that are no longer grown. The second kind of elite modern germplasm is advanced breeding material, which includes the advanced lines that breeders combine to produce new cultivars (sometimes referred to as “breeding materials”). Landraces, or traditional varieties, are varieties of crops that were improved by farmers over many generations without the use of modern breeding techniques. Wild or weedy relatives are plants that share a common ancestry with a crop species but have not been domesticated. Germplasm collections may also include “genetic stocks.” Genetic stocks

[7] Another category of germplasm is “unknown.” Such undefined germplasm samples were not included in these calculations.

are mutants or other germplasm with chromosomal abnormalities that may be used by plant breeders for specific purposes.

Different germplasm types serve different breeding objectives. Landraces and wild relatives are often used for resistance traits, and generally require extensive efforts before their genes are usable in a final variety. An earlier survey of international users of wheat germplasm suggested that only a minor percentage of materials used in crossing were landraces or wild relatives, and these were more likely to be used in search of resistance traits than for yield potential. Wheat breeders working in developing countries also used them in breeding for grain quality more often than those working in developed countries (Rejesus et al. 1996). Demand for advanced breeding material implies an active breeding program. Genetic stocks are often used for highly sophisticated breeding, and also for basic research. While the use of cultivars may suggest that instead of breeding, researchers are "fishing for useful final varieties", cultivars may also serve breeders when they are looking for specific traits. Drawing conclusions from requests for cultivars is therefore difficult.

Roughly half of all respondents to the international study requested cultivars, and an equal number requested landraces or wild relatives—suggesting an unexpected demand for exotic materials. Genetic stocks were requested by slightly more than 27 percent of respondents, while advanced materials were requested by about 21 percent of all respondents (Table 3).[8]

[8] Because respondents could request more than one type of germplasm, numbers sum to more than 100 percent.

Table 3—Germplasm type requested from USNPGS by international respondents, according to crop

Crop	Percent of respondents requesting germplasm type			
	Cultivar	Advanced Material	Genetic Stocks	Landraces or Wild Relatives
Barley	59	18	15	54
Beans	50	22	15	65
Maize	20	26	49	30
Potato	31	9	28	75
Soybeans	77	23	35	33
Wheat	60	22	15	56
	**		**	**
All crops surveyed	49	21	27	48

Source: Study conducted by International Plant Genetic Resources Institute
Number of respondents=380
Note: Cotton, rice, sorghum, and squash excluded here because of small subsample sizes. Requests (rows) sum to more than 100 percent when requests of more than one material type are made.
** Pearson Chi-squared tests (two tails, significance level=0.01) show significant differences in percent requesting material by crop.

Demand for germplasm types also depends on the breeding needs for the crop in question. Landraces and wild relatives were most attractive to respondents working with potatoes, a crop with an extremely narrow genetic base, and for which breeders need to broaden the germplasm used to realize any significant improvements (Haynes 2001). Though soybean also has a narrow genetic base in most countries except China, Japan, and Korea, cultivars were more likely to be demanded for this crop than for others.

Genetic stocks were most likely to have been requested by respondents asking for maize accessions, and dominated maize requests relative to other types of materials. The greater level of basic research concerned with maize, combined with features of maize seed industry structure, may help to explain the greater demand for genetic stocks by maize researchers relative to other germplasm types and compared to scientists working with other crops. Virtually all of the maize area in the developed world is planted to hybrid seed that is bred, multiplied and sold by private companies (Echeverria 1991). The same is true in developing countries where maize is commercially grown (Lopez-Pereira and Filippello 1994), though maize seed industries there are highly variable in organization and performance (Morris 1998). In many cases, basic research in maize is conducted by public institutions rather than by private firms. Since private firms dominate maize seed research, an institution like U.S. NPGS may represent the primary source of materials for publicly-employed scientists in other countries who are conducting basic research. Another factor explaining the relative low percentages of requests for cultivars, landraces and wild relatives in maize cultivars is the difficulty of combining tropical and temperate germplasm because of their dramatically different photoperiodic responses (Goodman 1995). A comprehensive survey conducted in 1983 on the use of exotic germplasm in commercial maize revealed that less than 1% of the U.S. germplasm base consisted of exotic germplasm (Goodman 1985). At the same time, the vast majority of the improved maize materials developed for use in the United States, Western Europe, and northern China are of little direct use to maize farmers in developing countries (Morris 1998: 15). Though the findings in Table 3 should be interpreted with caution, a sum of row percentages further suggests that scientists requesting maize accessions tended to focus on fewer germplasm types than did those asking for samples of other crops.

The type of germplasm demanded differed significantly by the development status of the country. Respondents from developed countries were less likely to request advanced materials than those in developing and transitional economies. Respondents from developing countries requested landraces and wild relatives less frequently than did respondents from developed and transitional countries (Table 4). These results suggest that requestors in developing countries sought materials that could be incorporated more immediately into breeding programs, whereas those from developed countries were interested in rarer traits or materials suitable for basic research.

Table 4—International requests for USNPGS germplasm types, by development status of respondent's country

Developmental Status	Percent of respondents requesting germplasm type			
	Cultivar	Advanced Material	Genetic Stocks	Landraces or Wild Relatives
Developed countries	46	16	24	53
Developing countries	51	22	36	33
Transitional economics	59	26	22	48
		**		**
All	49	21	27	48

Survey conducted by International Plant Genetic Resources Institute. Number of respondents=380.

Note: Requests (rows) sum to more than 100 percent when requests of more than one material type are made.
** Pearson Chi-squared tests (two tails, significance level=0.01) show significant differences in percent requesting material type of development status.

It is also possible that when landraces are used by developing country scientists in breeding for resistance or grain quality, they are more likely to look first among the local landraces that are still grown by their country's farmers, when these are available to them, than to distant gene bank collections.

c) Why is germplasm requested?

Purpose of request

Breeders are always seeking an improvement on the status quo. They look for germplasm with certain characteristics, such as better resistance to a pest, or higher yield. Study respondents reported four categories of intended use for germplasm they requested: trait evaluation, breeding or pre-breeding, basic research, and adding to collections. Since samples could be intended for multiple purposes, percentages across purposes may total to more than one hundred.

Samples were most likely to be intended for trait evaluation (55% of samples). Evaluation for specific traits indicates an active breeding program in which scientist do not simply test existing varieties, but work to develop new varieties. Providing material internationally for basic research (36% of samples) also appears to be an important function of the U. S. NPGS, though that role generally receives little attention. Twenty-five percent of samples were to be added to collections, and 23 percent were for breeding and prebreeding. Combined, breeding/prebreeding and evaluation for traits (essentially a subset of breeding/prebreeding) account for 78 percent of the intended use of samples. This reiterates the idea that genebanks supply most of germplasm samples to institutions concerned with breeding, followed by research institutions, and then other germplasm collections.

Respondents in developed, developing, and transitional economies varied somewhat in how they intended to use germplasm. Consistent with our other findings, on average, respondents in developed countries intended a higher proportion of their shipments to be used in basic research, reflecting, perhaps, their technological advantages. Respondents in transitional economies allocated a higher percentage to collections.

Traits sought

The nature of the traits sought provides further insight into scientists' demand for germplasm held in genebanks. International respondents were asked to classify the traits they sought into five categories: tolerance to abiotic stresses, tolerance or resistance to biotic stresses, yield, quality or other. Tolerance to abiotic stress includes drought tolerance, salinity tolerance, and temperature tolerance. Biotic stresses are usually pests, including diseases, which attack plants. Yield, in the pure sense, means an increase in a plants productive capacity, assuming ideal growing conditions. Quality generally means some characteristic of the final agricultural product, such as the gluten content of wheat, or the oil content of maize.

Respondents generally intended to use a higher proportion of samples they requested for biotic resistance or tolerance than for other traits, regardless of the improvement status of the material (Table 5). Since samples may be used to search for more than one trait, totals may exceed one hundred percent for each germplasm type. Thirty-seven percent of germplasm samples were used to search for resistance or tolerances of biotic stresses.

Table 5—Traits sought by international respondents, by improvement status of sample

Materials	Average Percent of Samples used to Search for Trait				
	Abiotic Tolerance	Biotic Resistance or Tolerance	Yield	Quality	Other
Cultivars	17	37	17	22	25
Advanced breeding material	14	44	25	24	20
Landraces	13	35	12	24	27
Wild relatives	13	42	3	14	31
Genetic stocks	12	24	6	11	44
			**	**	
All materials	14	37	13	19	29

Source: Study conducted by International Plant Genetic Resources Institute. Number of respondents=380.
Row totals may exceed 100 if accessions are used to search for more than one trait.
** Pairwise t-tests (two tails, significance level =0.05) show significant differences by germplasm type in average percent of samples requested to search for yield and quality.

This finding was expected, since resistance to pests, including diseases, is thought to be a primary motivation for breeding (Duvick 1992). Quality traits were the desired characteristic in 19 percent of the germplasm. Abiotic resistance was sought for about 14 percent of the germplasm, respectively. A lower proportion of germplasm samples (13 percent) was intended for advancing yield potential. Because many increases in on-farm yield actually come from improvements in resistance, the relatively lower percentage of samples used to seeking yield advances is not surprising. The average percent of requestors intended to use samples for specific "other uses" was also relatively high. When explanations for other uses were examined, most fell into the category of basic research, such as genomics.

The average percent of samples intended for yield or quality advances varied significantly according to the sample germplasm type. On average, respondents intended to use advanced breeding materials for yield potential about twice as frequently as landraces or wild relatives. In addition to advanced materials, a higher percentage of landraces than wild relatives were requested in pursuit of quality traits. Genetic stocks seem to have been intended primarily for the "other" traits of interest; particularly those connected to basic research.

d) Actual utilization of germplasm samples

In assessing the use of U. S. NPGS germplasm, we note that the long-term nature of plant breeding and agricultural research, combined with the reproducible nature of seed, implies that utilization rates calculated over a short period of time underestimate actual use patterns in both temporal and spatial terms. That is, materials may be useful much later in a breeding cycle than when they are first received, and they may be incorporated into research multiple times by different users.

Even so, respondents' perceptions about the usefulness of the samples that they received are a good indicator of the actual utilization of U. S. NPGS germplasm samples in international breeding programs. Within the brief 5-year period covered by the respondents, 11 percent of germplasm accessions had already been incorporated into a breeding program (Table 6). Given the long time period required to breed a new variety, it is not surprising that much of the material is still being evaluated, and it is encouraging that 43 percent of the samples were deemed worthy of further investigation. Respondents considered 19 percent of the samples useful in other ways, leaving only 28 percent of samples not useful at all. Overall, an estimated 72 percent of materials sent from U. S. NPGS to other countries has already been used in breeding, considered worthy of further assessment, or found otherwise useful.

Table 6—Actual utilization of germplasm samples sent to international requestors by USNPGS, 1995-99, by development status of recipients' country

Material type	Used In Breeding Program		Still being evaluated		Useful in Other Ways		Not Useful		Total
	survey %	estimated total 1995-1999	survey %	estimated total 1995-1999	survey %	estimated total 1995-1999	survey %	estimated total 1995-1999	
Developed	6	1220	41	8632	29	6018	25	5175	100
Developing	18	5644	55	17531	8	2516	20	6462	100
Transitional	7	733	24	2473	19	1984	50	5168	100
All recipients	11	6794	43	27299	19	11777	28	17686	100

Source: Study conducted by International Plant Genetic Resources Institute. Number of respondents=380.
Study estimates are applied to actual distributions data provided by the Nnational Plant Germplasm Resources Laboratory.

If we apply the percentages obtained from study responses to the total numbers of germplasm samples distributed from 1995 to 1999, we generate an estimate of the actual numbers of germplasm samples used during that period for the ten crops considered. Our findings suggest that, in other countries alone, over 18,500 germplasm samples from U. S. NPGS have already been used in breeding and in other ways, while another 27,000 are still under evaluation. This is an impressive finding. Of course, it is important to remember that users in developed countries made up a smaller percentage of the study respondents than they did of the total recipients, and researchers working in the private sector were more heavily represented in the study than in the total distributions data. However, we have no indication of whether this difference in representation would bias findings, and the overall response rate was good for mailed questionnaires.

Developing country respondents reported that 18 percent of the germplasm samples they received were already put to use in breeding programs - about three times the percentage reported by respondents in developed and transitional economies (Table 6). In fact, scientists working in developing countries found 80 percent of the samples useful or worthy of further study. Those working in transitional countries found half their samples “not useful”; at least twice the percentage of samples characterized as such by developing and developed countries. Larger numbers of germplasm samples are “useful in other ways” for developed country recipients. While the exact use of such germplasm is unclear, it may reflect the higher levels of the basic research associated with developed economies.

Germplasm can be distributed by the original recipient to additional users, generating secondary benefits. Respondents shared about 20 percent of all germplasm samples with other scientists at their own institution and 10 percent with those in other institutions. These secondary transfers are of a larger magnitude for developing country respondents than for respondents in developed and transitional economies (Table 7).

Table 7—USNPGS samples shared by international respondents with others, 1995-99, by development status of respondent's country

Development status	**Average Percent of Samples used to Search for Trait**			
	at own institution		at another institution	
	survey %	estimated total 1995-1999	survey %	estimated total 1995-1999
Developed	15	3154	4	925
Developing	24	7847	17	5498
Transitional	14	1441	6	584
All countries	19	11768	10	6151

Source: Study conducted by International Plant Genetic Resources Institute. Number of respondents=380. Study estimates are applied to actual distributions data provided by the National Germplasm Resources Laboratory, U.S. Department of Agriculture.

Again, applying the findings from the user study to the total number of samples distributed, our estimates suggest that secondary transfers may represent an additional utilization of as many as 17,000 samples.

One factor affecting the usefulness of germplasm is the presence of data. Accessions may have data that can generate value by speeding the research discovery process. For all 10 crops, respondents reported that 28 percent of samples had useful data for the trait of interest and 18 percent had useful data for other purposes (Table 8).

Table 8—U.S. NPGS samples with useful data, sent to international requestors 1995-99 by development status of requestor's country

Development Status	Seed Samples With Useful Data			
	for trait of interest		for other purposes	
	survey %	estimated total 1995-99	survey %	estimated total 1995-99
Developed	28	5803	25	5204
Developing	31	9935	12	4005
Transitional	22	2232	13	1395
All Countries	28	17620	18	11234

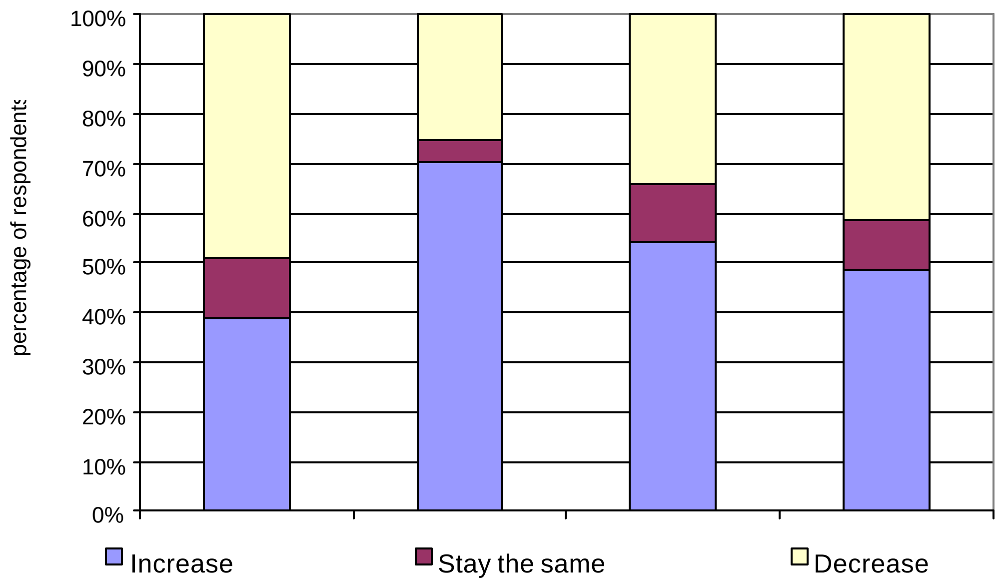
Source: Study conducted by International Plant Genetic Resources Institute. Study estimates are applied to actual distributions data provided by the National Germplasm Resources Laboratory, U.S. Department of Agriculture. Number of respondents =380

The percentage of samples with useful data for the trait of interest was slightly higher among developing country respondents (31 percent). The total samples with useful data for the trait of interest was therefore substantially larger for developing country recipients compared with developed country recipients. Developed country respondents, on the other hand, found that a greater percentage of samples had useful data for other purposes, which would include basic research.

e) Future demand

International respondents' expectations regarding utilization of U. S. NPGS germplasm in the next decade provided some indication of future demand for public germplasm. There were no significant differences by crop or institution type in the percentages expecting to increase, decrease, or maintain their utilization. Again, however, there were statistically significant differences by the development status of the requestor's country. A majority of respondents in developing countries expected to increase their requests from U. S. NPGS in the next decade, and they were more likely to respond positively than those from either developed or transitional economies (Figure 4).

Figure 4--International respondents' expectations for U. S. NPGS germplasm use over the next decade, by development status of country and institutional affiliation .



Source: Study conducted by International Plant Genetic Resources Institute.
Note: Pearson Chi-squared tests (two tails, significance level=0.01) show significant differences in percentages by development status.

f) Problems to solve

Respondents were given the opportunity to state any additional perceptions about the benefits and problems of the U. S. NPGS. While positive statements about the benefits of the U. S. NPGS outweighed comments about problems by approximately 3 to 1 (Table 9), some important limitations were expressed.[9]

[9] Each response was classified into one of eight main categories (based on the judgment of the authors). Those respondents who made comments often offered more than one. In those cases, each comment was considered individually

Table 9—Perceived benefits and problems of using USNPGS, international respondents, 1995-99

Perceptions	Frequency	Percent of responses in category	Percent of all responses
Benefits			
General			
seed or materials	88	24	18
good data or information	48	13	10
acquisition and collection	14	4	3
characterization and evaluation	11	3	2
enhancement and cultivar development	2	1	0
preservation, conservation, maintenance	48	13	10
distribution	78	22	16
NPGS-specific attributes*	73	20	15
Subtotal	362	100	76
Problems			
General			
inadequate resources	12	10	3
material useful only after pre-breeding	1	1	0
regulations inhibiting germplasm exchange	17	15	4
private sector unwilling to contribute	4	3	1
need more in situ conservation	2	2	0
NPGS-specific attributes			
seed did not germinate, samples impure	15	13	3
information incorrect, incomplete, not useful	45	38	9
some germplasm under-represented	4	3	1
distributed problems	12	10	3
communication	5	4	1
Subtotal	117	100	24
All responses	479		100

Source: Study conducted by International Plant Genetic Resources Institute.
Number of respondents=380
* includes size and completeness of collection, reliability, web access, ease of access, etc.

The most common problem, by far, was inadequate or incomplete information about germplasm samples, accounting for 38 percent of all problems cited. Still, positive comments about data/information as a benefit slightly outweighed comments about data/information as a problem. Interestingly, the second most commonly mentioned problem was regulations that affect germplasm exchange. Quarantine restrictions, particularly in the European Union, seemed to cause concern among some of these respondents. This may account, at least in part, for the fact that respondents in developed countries, on average, expected their use of U. S. NPGS germplasm to decline in the next decade. Another U. S. NPGS-specific problem was seed quality concerns, e.g. seeds that were not viable, or which were contaminated. This was the third most frequently cited problem. Insufficient funding for maintaining seed viability, as well as inadequate resources for data assessing the U. S. NPGS accessions was reported by a GAO study (1997). Finally, the fourth-ranking problem was inadequate funding/resources, a factor, like regulation, outside the control of the U. S. NPGS, but one that may lay at the root of data and seed viability problems.

5. CONCLUSIONS

The study findings demonstrate that U. S. NPGS plays an important role in providing public germplasm to developing countries. The total number of samples distributed from 1990 to 1999 among the 10 crops we studied favors developing countries as a group relative to either the transitional economies of the Former Soviet Union and Eastern Europe or developed economies. At least in terms of the relative scarcity of technologies and small sizes of public research budgets in developing countries (as compared to developed countries), it is likely that the relative marginal economic value of these resources to these countries is also higher.

In their earlier study, Shands and Stoner (1997) suggested that requests from non-industrialized countries were constrained, in part, by the lack of adaptation of U. S. NPGS germplasm to certain environments, and in part by the lack of capacity and support in many of these countries for crop improvement programs. Their first conclusion is drawn from their own examination of the geographical pattern of germplasm distributions. The data presented here are consistent with their second conclusion, to some extent. Respondents from developing countries intended to use a lower average proportion of the materials received for basic research than did scientists in developed countries, while more were requested for breeding purposes, trait evaluation, and adding to collections in the developing world. However, the higher percentage of respondents from developing countries requesting advanced materials suggests active breeding programs.

Furthermore, utilization rates in breeding, as reported by respondents during the 1995-1999 period, are much higher among developing country than among developed country respondents. Larger numbers of germplasm samples are still being evaluated, while fewer samples have been shown to be "useful in other ways." Developing country respondents tended to share materials more often with other researchers in their own institution and elsewhere. Finally, respondents from developing countries expect to increase their use of U. S. NPGS over the next decade, while those in developed countries were less optimistic (again, perhaps due to restrictions on germplasm exchange). Our findings indicate developing countries' reliance on the U. S. NPGS is greater than that of developed countries, and that their benefits may exceed those of other countries, at least insofar as direct utilization in breeding programs is concerned.

A second major conclusion concerns the meaning of the term "use." In contrast to the perception that ex situ collections of crop genetic resources are rarely used, our study suggests that national genebanks such as the U. S. NPGS generate multiple, global benefits to users. First, the numbers of germplasm samples distributed are large—and we have accounted for only 10 crops, or approximately half of total distributions over a ten-year period only. The volume of transfers to other countries compares favorably with transfers by other national collections in developed countries and those held at international agricultural research centers.

Multiple benefits are suggested by the extent of utilization by respondents, the breadth of materials they requested, and the range of institutions served. With respect to utilization, respondents stated that 11 percent of the samples received in other countries during the last five years have already been incorporated into breeding programs, while another 43 percent are still being evaluated and 19 percent have been useful in other ways. In addition to the germplasm itself, accompanying data also had benefits in use either for the trait of interest or some "other purpose." In terms of materials, though almost half the respondents requested cultivars, nearly as many respondents requested land races, demonstrating a demand for exotic germplasm. Genetic stocks and advanced materials were also requested by a substantial proportion of respondents, indicating good demand for these types of germplasm that is likely to derive from fairly sophisticated breeding/research programs. This national gene bank also serves a variety of institutions, of which the majority are publicly funded research organizations, though private companies are also represented. The findings presented here demonstrate in simple, unequivocal terms the magnitude and breadth of the benefits generated by the U. S. NPGS collection.

6. IMPLICATIONS

Our third and final conclusion is that the benefits this national genebank likely generates for developing countries should not be underestimated in the current negotiations over future access to publicly-held crop genetic resources. According to respondents, regulations concerning seed exchange are a primary external problem the U. S. NPGS faces. While the problems associated with inadequate resources are easily perceived, the role of germplasm exchange regulations is subtler. However, like funding constraints, regulations affect the operations of the collections in very fundamental ways.

Since the U. N. Food and Agriculture Organization (FAO) established the Commission on Plant Genetic Resources in 1983 (as it was then called), countries have sought to reach international agreement on access to genetic resources and the distribution of the benefits they create. FAO Conference 9/83 established the International Undertaking on Plant Genetic Resources for Food and Agriculture. Acceptance of the Undertaking has not been universal, and the debate has been complicated by efforts to bring the Undertaking into harmony with the Conventional on Biological Diversity.[10] The Convention grants nations sovereign rights over their genetic resources, a change from the traditional "free flow" of what used to be classified as "unimproved" genetic resources and landraces. Sovereign rights are intended to improve the ability of resource holders to collect some of the benefits of their genetic materials, thus increasing incentives for conservation. The exact provisions for access to resources and the sharing of their benefits have been highly contentious (IISD 2001), with much of the debate falling historically along North-South (i.e., developed country-developing country) lines (Kloppenburg 1988).

Many developing countries are considered “germplasm rich”, that is they include or are near centers of domestication. In the past, these countries often supplied genetic resources free of charge, particularly to “germplasm deficient” developed countries where they were used to create modern varieties sold commercially. Such genetic resources included landraces that resulted from generations of effort from farmers who selected and conserved germplasm. Both the Undertaking and the Convention have raised hopes that countries with germplasm needed by

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[10] In addition to the Undertaking and the Convention, we wish to note the Uruguay Round of the General Agreement on Trade and Tariffs (GATT) of 1986. While discussion of it is beyond the scope of this paper, one important component of the GATT is settlement of trade-related aspects of intellectual property rights. The GATT creates minimum standards for the protection of intellectual property rights over commercially developed seed and plant varieties, and through that, has moved closer to more universal recognition of plant breeders' rights.

breeders could establish “farmers’ rights” to much of this germplasm (Cooper 1993). This would allow these countries to collect the some of the benefits arising from such farmer-led efforts, as well as benefits from other genetic resources held.

The implications of our research for such agreements are complex. Our results suggest a healthy demand for all types of germplasm. Countries with genetic resources useful for agriculture may see this as reason to hope that their resources could be marketed and financial returns received. However, because U. S. NPGS provides germplasm free of cost, demand for its germplasm does not necessarily indicate a “willingness to pay” for similar resources. Also, because much of the demand came from developing countries, users of agricultural germplasm may not have the financial resources to pay prices high enough to generate substantial returns for resource holders. “Free” germplasm from places such as U. S. NPGS and international genebanks would likely be a desirable substitute for marketed germplasm. These genebanks themselves can be seen as potential buyers of unique germplasm not already in their collections. However, because genebanks throughout the world face serious budget constraints, as stated earlier, it is doubtful that they would be able to produce significant funds for such acquisitions. Such financial constraints have also impeded the collection of funds through the public sector as part of the process to compensate farmers’ rights. Thus, we conclude that national genebanks probably will not be good sources for compensation funds, and efforts to collect such funds may want to focus on other potential sources.

The clearest conclusion suggested by this study is that, though maintaining public access to the resources housed in the U. S. NPGS serves its national scientists, the international scientific community also benefits greatly. The role played by this bank is complementary to that of the international collections in magnitude and direction, offsetting the view that developed countries continue to benefit disproportionately from the utilization of genetic resources that originated within the national boundaries of today's developing countries.

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