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Demand for Genetic Resources and the U.S. National Plant Germplasm System

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Abstract
Although genetic resources have strong public-goods characteristics, public genebanks often have struggled for adequate funding. A review of economic literature on the value of plant genetic resources indicated that more information is needed about germplasm use. The data compiled in this paper examine patterns of germplasm use for one of the world's largest national genebank networks, the U.S. National Plant Germplasm System (NPGS). Data on 10 major crops, gathered directly from within the NPGS and from end-users, revealed patterns of usage for germplasm during the period from 1995 to 1999. Data were collected describing the characteristics of NPGS users, the types of germplasm requested, the purpose of requests, and, when applicable, the specific traits sought. From these findings, we estimated the utility of distributed materials, their secondary use, and projected future demand for NPGS resources. To explore relationships between the usefulness of germplasm samples and accompanying data in a more systematic fashion, we estimated a linear regression. The regression model suggests that accompanying data make germplasm more useful. We conclude that demand for NPGS resources was substantial and came from broad range of users. Utilization rates were higher than suggested by past studies. Countries with developing economies made greater use of NPGS resources, relatively speaking, than did countries with high-income economies. Finally, demand for NPGS resources is likely to increase, especially among users in countries with developing economies.

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ABSTRACT

Although genetic resources have strong public-goods characteristics, public genebanks often have struggled for adequate funding. A review of economic literature on the value of plant genetic resources indicated that more information is needed about germplasm use. The data compiled in this paper examine patterns of germplasm use for one of the world's largest national genebank networks, the U.S. National Plant Germplasm System (NPGS). Data on 10 major crops, gathered directly from within the NPGS and from end-users, revealed patterns of usage for germplasm during the period from 1995 to 1999. Data were collected describing the characteristics of NPGS users, the types of germplasm requested, the purpose of requests, and, when applicable, the specific traits sought. From these findings, we estimated the utility of distributed materials, their secondary use, and projected future demand for NPGS resources. To explore relationships between the usefulness of germplasm samples and accompanying data in a more systematic fashion, we estimated a linear regression. The regression model suggests that accompanying data make germplasm more useful. We conclude that demand for NPGS resources was substantial and came from broad range of users. Utilization rates were higher than suggested by past studies. Countries with developing economies made greater use of NPGS resources, relatively speaking, than did countries with high-income economies. Finally, demand for NPGS resources is likely to increase, especially among users in countries with developing economies.

With heavy competition for funding among the world's research institutions, genebanks generally have not fared well (Duvick, 1995; McFerson et al., 1996). Questions about the value of germplasm and levels of use have complicated the debate about funding for genebanks. In 1997, Wright identified four fundamental deficiencies in information about genebanks: (i) who uses the genebanks; (ii) why users want germplasm; (iii) what kind of germplasm is used; and (iv) what characteristics users are seeking. The data compiled here address these questions for one of the world's largest national genebank networks, the U.S. National Plant Germplasm System (NPGS). Our findings shed light on patterns of usage for germplasm supplied by the NPGS. While we provide no assessments of their commercial value or price, the quantitative data do help elucidate how germplasm creates value and to whom its benefits may accrue.

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Economic Value of Plant Genetic Resources Conserved in Genebanks

Genetic resources can be used in a number of ways. Direct use by farmers is the most obvious. Other direct uses include seed multiplication and sale and use of genetic resources to improve new varieties. This can involve the use of the genetic resource in a final variety or in the breeding process. Even if it is not incorporated in the final variety, the resource may contribute information to the breeding process. Likewise, genetic resources are used in broader set of research activities such as basic research. Conserved genetic resources may also have economic value, even if they are not currently being used. The option to exploit resources in the future, for uses not presently known, has considerable value. Likewise, the information about a conserved genetic resource may have economic worth.

Many reports in the noneconomic literature document nonquantified benefits to agriculture from the use of genebank collections (see Shands and Wiesner, 1991, 1992). However, few of these values can be measured by a market price. The uses of accessions in advancing scientific knowledge are especially difficult to value. Even if we succeeded in estimating the value of some components of genetic resources held in genebanks, we would generally underestimate their total value. The long-term nature of plant breeding and agricultural research, combined with the reproducible nature of seed, implies utilization rates calculated during a short period of time may underestimate actual use in both temporal and spatial terms. Materials may be useful later in the breeding cycle, rather than when they are first received. They may also be used multiple times by different researchers.

One approach has been to estimate the costs of conserving accessions, which are relatively easy to tabulate compared with the benefits. A suitable methodology and set of cost estimates for international genebanks have been published in a collection of studies (Pardey et al., 2001; Koo et al., 2004). Findings demonstrate that the costs of conserving an accession are lower than any "sensible" lower-bound estimate of benefits. Hence, the authors conclude that the challenging exercise of benefits estimation is not necessary to justify conservation.

Nonetheless, economists have sought to estimate some of the benefits of crop genetic resources. Numerous studies have demonstrated the substantial benefits of genetic enhancement in commercial agriculture (e.g., Thirtle, 1985; Byerlee and Traxler, 1995; Pardey et al., 1996; Frisvold et al., 2003), but the methods applied do not dissociate the value of the research effort from the value of genetic resources. By invoking additional assumptions, it is possible to estimate the current and ex-

pected future benefits from direct use of an accession, such as a breeding line, as a progenitor in the research effort. Algorithms or rules of thumb are used to apportion the genetic contribution of the progenitor to the finished variety. Experimental data are necessary to attribute the proportion of a productivity gain that is caused by genetic change as compared with other sources of farm productivity or to isolate the effects of a single finished variety (Pardey et al., 2004). To predict future benefits, the probabilities of occurrence of particular pests or plant stresses must also be known. Genebank collections are created and maintained especially to respond to unforeseen challenges, however, rather than those with known probabilities.

Several attempts have been made in the economics literature to draw inferences about or estimate the value of accessions conserved in genebanks, combining aspects of these methods with statistical approaches. Evenson and Gollin (1997) related the rice collection maintained by the International Network for the Genetic Evaluation of Rice to farm-level benefits from crop improvement, estimating that the present value of 1000 additional accessions was $325 million (discounted at 10% over a 20-yr period). In this study, the methods by which plant breeders use a collection in crop improvement were not fully articulated. In a later study, Gollin et al. (2000) applied a search of theoretic framework to examine two cases in which accessions from an international genebank contributed resistance to pests and diseases in wheat varieties. They show that optimal search size (and hence the size of a collection) depends on the economic magnitude of the problem addressed through breeding and the probability distributions for the traits, in addition to cost parameters related to transferring the trait successfully into the improved material and the time lag to adoption. Since the payoff can be large for problems of economic importance when the desirable traits are rare, conserving some categories of materials "untapped" for years can be justifiable. Infrequent use of individual accessions by plant breeding programs does not, in itself, imply that an additional accession will have low value. Most recently, Zohrabian et al. (2003) used a maximum entropy approach to estimate the expected value of exploiting an unimproved genetic resource in crop improvement for soybean production in the USA. They found that, though the additional benefits of an accession were modest when only a single trait was considered, the payoff far exceeded the costs of acquiring the accession and conserving it.

Plant breeders prefer to work with their own lines rather than exotic material (Cox et al., 1988; Duvick, 1995). Still, Widrlechner and Burke's (2003) analysis of distributions within selected NPGS collections found that "Contrary to commonly held views… many accessions are distributed frequently and few languish unrequested." However, some economists have asserted that the materials in genebanks are rarely used (Wright, 1997). This has led others to find that their worth is low ("negligible," in the words of Simpson and Sedjo, 1998). The motivation for collecting the data presented in this paper is to address this argument through examining use patterns. Given the lack of empirical evidence to quantify the benefits associated with particular genetic resources, new information about application and useful characteristics may contribute more to our ability to make difficult decisions about conservation than would estimates of monetary value.

Data Sources

The NPGS is the primary multi-institutional network that manages publicly held crop germplasm in the USA. Because the NPGS has such extensive holdings, distributes so much germplasm free of charge, and serves a large international community, data on requests for NPGS germplasm samples can be used to generate both national and international profiles of genebank use.

Data presented here were compiled from two sources. The first was a summary of all NPGS germplasm distributions from 1990 to 1999 for 10 major crops, provided by the U.S. National Germplasm Resources Laboratory, which manages the system's database, the Germplasm Resources Information Network (GRIN, 2001), and coordinates plant exploration and international exchange programs.

The second set of data was developed by gathering information directly from end-users of NPGS resources. This builds on surveys that have assessed the usage of genebanks before [General Accounting Office of the United States (GAO), 1990, 1997; Gao et al., 2000; Peeters and Galwey, 1988; Milne et al., 2002; McFerson et al., 1996].

In our survey, rather than developing data for all NPGS holdings, we focused on 10 crops selected for their economic importance and/or origins in the Americas: barley, beans, cotton, maize, potatoes, rice, sorghum, soybean, squash, and wheat. A study of these same crops by international users of the NPGS was presented by Smale and Day Rubenstein (2002).

Nearly 4000 requests were made for germplasm samples of these 10 crops from 1995 to 1999 by approximately 3860 different requestors. A 5-yr period was chosen, consistent with Widrlechner and Burke's (2003) findings on the importance of using more than a single year of germplasm distribution data because of short-term fluctuations. Each requestor was sent a letter explaining the purpose of the study and a form that asked for information about the recipient's experiences with the NPGS and its collections over the past 5 yr. The International Plant Genetic Resources Institute (IPGRI) of the Consultative Group on International Agricultural Research (CGIAR) conducted the international portion of the study. The information from U.S. users was collected by Auburn University, through the same questionnaire. Since that time, these two sets of responses have been combined for joint analysis by the Economic Research Service of USDA and IPGRI.

Most of the respondents had requested more than one seed sample. Because respondents reported the number of germplasm samples they received, we can analyze the information either by respondent or by

germplasm sample. Both approaches are employed in this paper, depending on which is more appropriate for the analysis.

Findings on the Use of NPGS Germplasm

Characteristics of NPGS Users

Among the combined set of responses, 35% (or approximately 1370) respondents provided usable information. Response rates by crop ranged from 17 to 45%, with the lowest response rate in squash and the highest in wheat. For cotton, rice, sorghum and squash, the number of responses was small for purposes of statistical analysis. Overall, response rates among international and domestic requestors were similar. However, among international respondents, the response rate was nearly twice as high in high-income economies and the transitional economies of the former Soviet Union and Eastern Europe as in countries with developing economies (see Appendix 1 for country designations).

NPGS's in-house distribution figures can be used to create a profile of its user community. The majority of NPGS germplasm was sent within the USA. Between 1990 and 1999, 74% of seed samples were distributed domestically. About 12% of all samples were sent to countries with developing economies. Another 10% were sent to other countries with high-income economies, and about 4% of samples were distributed to the transitional economies of the former Soviet Union and Eastern Europe (Table 1). The relatively smaller proportion of samples sent abroad masks the volume of material distributed internationally. During the 10-yr period, the NPGS sent out more than 160 000 samples to non-U.S. requestors (the NPGS received 38 918 accessions of these 10 crops from other countries during the same period).

Distribution data also offer information about the types of institutions that make use of NPGS germplasm. The NPGS categories of institutional affiliation can be grouped into four sets private, public, other nonprofit, and unaffiliated. Most NPGS germplasm went to public or nonprofit institutions: 80% of samples went to government, university, or other publicly funded or not-for-profit research and development institutions (Table 1). Commercial recipients received 18% of all samples sent by the NPGS. The role of commercial institutions is far more prominent within the USA: almost 23% of samples distributed within the USA were sent to commercial firms. In contrast, less than 5% of the 162 673 samples NPGS sent abroad in the past decade were shipped to commercial requestors. Unaffiliated individuals were few, and most were located in the USA and other countries with high-income economies.

Requestors of NPGS germplasm who participated in the survey were asked about their primary profession. Among those who responded, approximately 36% of the respondents said that their primary profession was germplasm enhancement or plant breeding. Almost as many (35%) gave "other" as their primary profession. Of those offering further clarification, the majority listed research positions, many of which would fall within the broad classification of basic research. Education, perhaps involving both teaching and research, was listed as the profession of 15% of respondents. Only 9% of respondents described their primary profession as germplasm evaluation, and even fewer (2%) were involved with germplasm acquisition, at least as a primary profession. Farming accounted for 3% of those reporting professions.

Types of Germplasm Requested

The types of germplasm distributed reflect a user community that is actively involved in plant breeding and research (Fig. 1). While requests by germplasm type often differed between U.S. and international users, the survey responses indicated that there were few systematic differences by the economic status of the recipient's country. Requestors located in countries with developing economies did request more accessions classified as advanced breeding materials, and those in transitional economies requested relatively few cultivars. Requests for genetic stocks was highest among breeders in countries with developing economies (36%, see Table 2). Both these germplasm types suggest that countries with developing economies have active research and experimental breeding programs and were, as a group, not simply seeking finished varieties for local adaptation and possible use.

Purposes of Requests

The survey data suggested that most users (62%) sought specific traits in the samples they requested (Table 3). This was particularly true for those users lo-

Table 1. Germplasm samples of 10 major crops (barley, beans, cotton, maize, potato, rice, sorghum, soybeans, squash, and wheat) distributed by the National Plant Germplasm System, 1990–1999, by type of recipient institution and country's economic status.

	Samples by institution						Total samples	
	Commercial		Nonprofit‡		Unaffiliated individuals		All institutions	
Economic status†	No.	%	No.	%	No.	%	No.	%
USA	104863	23	343494	75	10208	2	458565	74
High-income economy	2294	4	55796	95	642	0	58732	9
Developing economy	4793	6	72431	93	292	0	77516	12
Transitional economy	83	0	26328	100	14	0	26425	4
All countries	112033	18	498049	80	11156	2	621238	99

† Classification of country by economic status is shown in Appendix 1.
‡ Nonprofit includes all government organizations, universities, publicly-funded genebanks and genetic resource units.

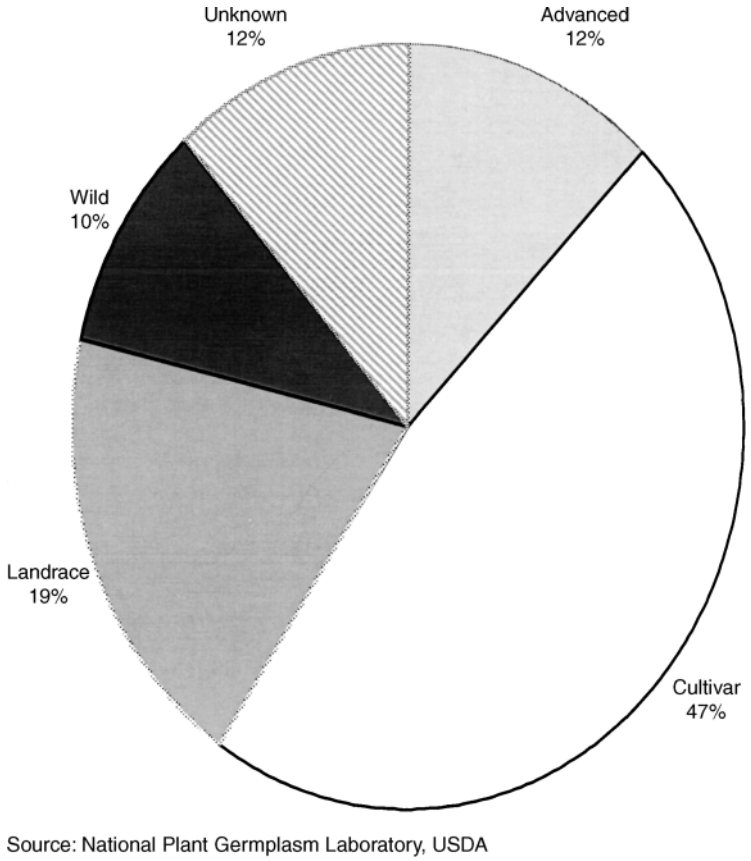


Fig. 1. Type of germplasm distributed by the NPGS, 1990–1999.

cated in the USA. The second most frequently cited reason for requesting germplasm was to conduct basic research (14%). The role of genebanks in providing materials for basic research is rarely mentioned. For example, the State of the World's Plant Genetic Resources for Food and Agriculture (FAO, 1998) does not discuss basic research in its chapter on germplasm utilization. Yet this sector accounted for a substantial volume of respondents' requests, especially because some proportion of germplasm sought for specific traits was also likely employed in support of basic research. Breeding or prebreeding was noted by respondents as the intended purpose for 13% of requests. Germplasm acquisition was the reason given by respondents for 11% of requests.

The purposes underlying requests did appear to vary by crop. For example, respondents most often planned to use maize samples for basic research (42% of accessions), which is not surprising given the diverse range of disciplines that employ maize as a model organism for basic research (Goodman, 1990; Freeling and Walbot, 1994). Approximately 80% of barley accessions, on the other hand, were intended for evaluation of specific traits, while less than 7% of the accessions were intended for basic research (see Table 4).

Table 2. Requests for NPGS germplasm by type and economic status of respondent's country. Requests (rows) sum to more than 100% when requests for more than one material type were made. Survey conducted by the International Plant Genetic Resources Institute and Auburn University and is based on data provided by the National Germplasm Resources Lab, USDA.

	Percentage of respondents requesting germplasm type				
National income	Cultivar	Advanced material	Genetic stocks	Landraces	Wild relatives
USA	60	16	24	25	23
Other high-income economy	46	16	24	31	31
Developing economy	51	29	36	21	18
Transitional economy	59	30	22	28	33
	**	**		**	
All countries	56	18	25	26	24

** Pearson Chi-squared tests (two tails, significance levels = 0.01) show significant differences in proportion of respondents requesting material type by country economic status.

Table 3. Purpose of requests for NPGS germplasm samples by the economic status of the respondent's country. Survey conducted by the International Plant Genetic Resources Institute and Auburn University and is based on data provided by the National Germplasm Resources Lab, USDA.

			%		
National income	Breeding or prebreeding	Evaluation for specific traits	Basic research	Add to collection	All requests
USA	12	68	12	8	100
Other high-income economy	17	32	35	16	100
Developing economy	15	45	15	25	100
Transitional economy	14	39	26	22	100
All countries	13	62	14	11	100

Table 4. Intended purpose of respondents' requests for seed samples from NPGS, by crop. Survey conducted by the International Plant Genetic Resources Institute and Auburn University and is based on data provided by the National Germplasm Resources Lab, USDA.

Crop	Breeding or prebreeding	Evaluation for specific traits	Basic research	Add to collection
Barley	9.7	79.2	6.3	4.9
Beans	16.9	52.0	15.5	15.7
Cotton	14.1	49.9	23.6	12.4
Maize	23.3	24.6	41.6	10.5
Potato	30.3	37.6	25.1	7.0
Rice	6.3	49.1	4.7	39.9
Sorghum	28.6	44.6	11.0	15.8
Soybeans	14.7	63.1	19.8	2.4
Squash	12.6	48.3	25.5	13.5
Wheat	12.1	68.2	14.8	5.0
Mean	13.0	62.4	14.0	10.6

Traits Sought

Of the traits respondents sought to evaluate in the germplasm samples, biotic resistance or tolerance was by far the most frequently cited (37% of samples), regardless of the type of germplasm (Fig. 2). Resistance to abiotic stresses was sought less frequently than resistance to biotic stresses (14% of samples). Quality traits were the object of evaluation in 17% of samples requested by all respondents (11% of U.S. respondents). Yield traits, those contributing directly to expected yield independent of particular stresses, were the focus of only 12% of materials evaluated for a specific trait.

Estimates of Germplasm Utility

These survey data suggest use levels that were substantially higher than have been estimated previously. For example, Goodman (1990) estimated that the percentage of germplasm accessions useful for intensive breeding is almost always less than 5%, and generally less than 1%. Here, requestors were asked how many of the materials that they received during the past 5 yr had been found "useful," and in what way. They reported that 9% of samples had been already been incorporated into active breeding programs (Table 5). Twenty-seven percent of seed samples were still being evaluated, and 14% of materials had proven to be useful in other ways. Respondents found only 50% of the materials not useful. These results resemble those reported by Gao et al. (2000), who found in their survey that 40% of germplasm from the Chinese national system had been used in some way, while 60% had not.

The degree to which NPGS material was reported to be useful varied according to the economic status of the respondents' countries. Respondents from countries with developing economies reported that 17% of NPGS materials had already proved useful in a breeding program, compared with 6% of materials sent to international respondents in high-income economies (U.S. respondents reported a similar percentage of materials, 8%, see Table 5). More than half the materials were still being evaluated by respondents in countries with developing economies, considerably more than the per-

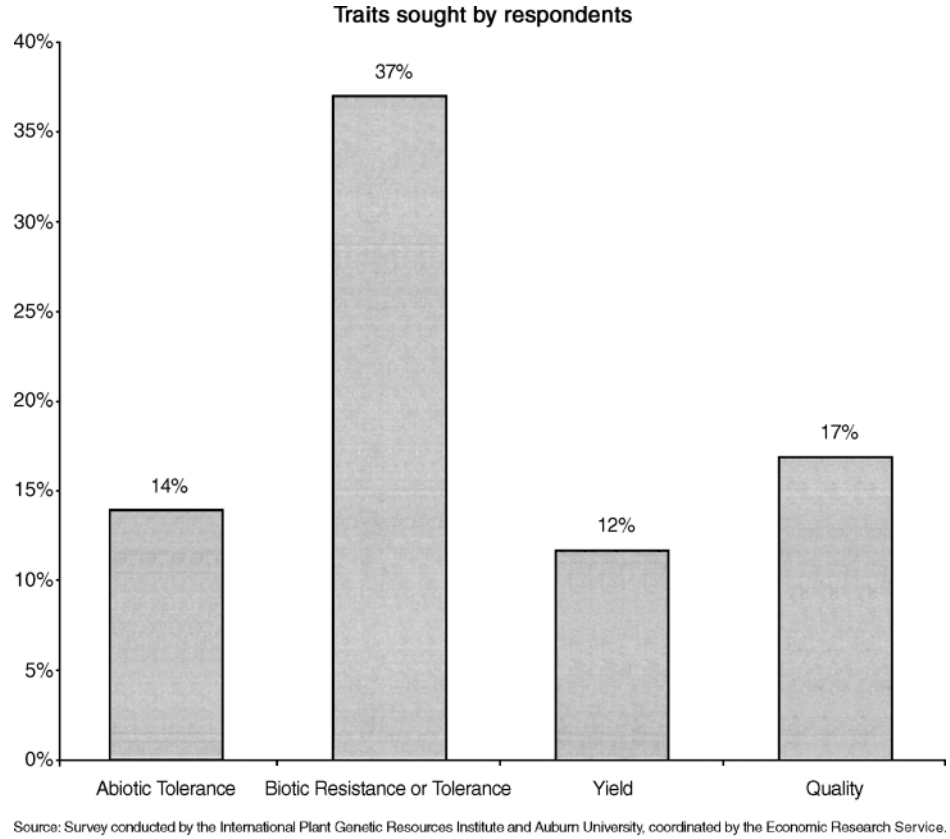


Fig. 2. Traits sought by respondents.

Table 5. Estimated utilization of NPGS germplasm samples, by economic status of the requestor's country. Survey conducted by the International Plant Genetic Resources Institute and Auburn University and is based on data provided by the National Germplasm Resources Lab, USDA.

Economic Status	Used in breeding program	Still being evaluated	Useful in other ways	Not useful	Total
USA	8	23	14	56	100
Other high-income economy	6	39	29	26	100
Developing economy	17	53	8	22	100
Transitional economy	7	23	17	53	100
All countries	9	27	14	50	100

centage being evaluated by respondents in the USA and transitional economies (23%), or even the 39% materials still under evaluation by respondents in non-U.S. countries with high-income economies. Respondents in countries with developing economies reported the lowest percentage of materials not found useful (22%), though respondents in countries with high-income economies outside the USA found only slightly more materials not useful (26%). Overall, these results portray respondents in countries with developing economies as having found the NPGS materials highly useful; they incorporated them in breeding programs and continued to evaluate them at much higher rates than did respondents located in higher income economies.

In terms of respondents' institutional affiliation, private firms had the highest percentage of samples already used in a breeding program: 14% (see Table 6). Private companies generally operate with a shorter time horizon, given the need for financial returns on research outlays, so they are more focused on cultivar development (Frey, 1996; Fuglie et al., 1996). Private firms also reported the lowest percentage of materials not useful, suggesting that this group may have targeted their germplasm requests more carefully. Respondents at nonprofit institutions tended to have incorporated fewer materials into a breeding program than private firms (8% of the total) and had slightly fewer samples still being evaluated or that were useful in the other ways. These results appear consistent with the nature of public-sector breeding, which is longer term and more basic in its perspective (Frey, 1996). Thus, nonprofit scientists are more likely to pursue a broader range of options with less assurance of success, because, when successful, such research is more likely to lead to significant advances in the long run (Fuglie et al., 1996). They also may focus on problems of farmers working on marginal lands, such as drought tolerance or improving yields in low resource environments, which can require considerable time to bring to fruition.

Combining the respondents' data with the NPGS distribution data allowed us to estimate the number of germplasm samples used from 1995 to 1999 for the 10 crops considered. In aggregate, about 25700 samples were used in breeding programs (Table 7). Considerably more were still being evaluated (81000 samples). Approximately 43000 samples were estimated to have been useful in other ways. Thus, a sizeable volume of material has been used in a breeding program, found worthy of further investigation, or has been useful in other ways. While certain materials may never be used, the number of samples estimated to be in use seemed to counter past assertions that the material in a genebank is rarely used (see Wright, 1997, and Widrlechner and Burke, 2003, for differing assessments).

Table 6. Estimated utilization of germplasm samples distributed by NPGS from 1995 to 1999, by respondent's institution. Survey conducted by the International Plant Genetic Resources Institute and Auburn University and is based on data provided by the National Germplasm Resources Lab, USDA.

Institutional affiliation	Used in breeding program	Still being evaluated	Useful in other ways	Not useful	Total
	%				
Commercial	14	29	17	41	100
Nonprofit	8	27	14	52	100
Self-employed or unaffiliated	11	19	8	63	100
All institutions	9	27	14	50	100

Secondary Uses for Requested Germplasm

Another element in estimating the utilization of germplasm is the sharing of NPGS germplasm with other researchers, both in and beyond the original requestor's institution. Approximately 11% of samples received by respondents were shared with others at the respondent's institution, and 13% of seed samples were shared with others at another institution. In terms of the countries' economic status, respondents in countries with developing economies were more likely than others to share NPGS materials, particularly within their institution. Respondents from these countries shared 24% of the materials they received with others at their institutions and 17% of materials with others outside their institutions (Table 8). Overall, although they received only about 12% of the germplasm distributed by the NPGS, we estimate that these requestors were responsible for about 18% of the secondary use of NPGS materials.

Future Demand for NPGS Resources

While the volume of NPGS materials distributed and used has been substantial, a key question for policymakers and genebank managers is the future demand for genetic resources stored in the NPGS collections (Widrlechner, 1997; Widrlechner and Burke, 2003).

Table 7. Estimated utilization of NPGS germplasm samples, by country category. Survey conducted by the International Plant Genetic Resources Institute and Auburn University and is based on data provided by the National Germplasm Resources Lab, USDA.

	Used in breeding program	Still being evaluated	Useful in other ways	Not useful	Total
USA	18276	53312	32603	132571	236762
Other high-income economy	1212	8276	6081	5477	21045
Developing economy	5508	17048	2591	7005	32151
Transitional economy	709	2384	1791	5475	10359
All countries	25705	81019	43066	150527	300317

Table 8. NPGS samples shared with others, 1995 to 1999, by respondent's country status. Survey conducted by the International Plant Genetic Resources Institute and Auburn University and is based on data provided by the National Germplasm Resources Lab, USDA.

	Seed samples shared with others			
	At own institution		At another institution	
	Study	Estimated total	Study	Estimated total
	%	1995–1999	%	1995–1999
USA	8	20271	14	32322
Other high-income economy	14	2967	4	901
Developing economy	24	7613	17	5475
Transitional economy	13	1366	6	577
All countries	11	32218	13	39275

Requestors were asked whether they expected their use of NPGS germplasm to increase, to stay the same, or to decrease. Nearly half the respondents expected their use of NPGS germplasm to stay the same (47%). Increased use was anticipated by about 39% of respondents. Only 14% expected their use of NPGS germplasm to decrease. Overall, these results suggest that demand for NPGS resources will be increasing, though to what degree is unclear.

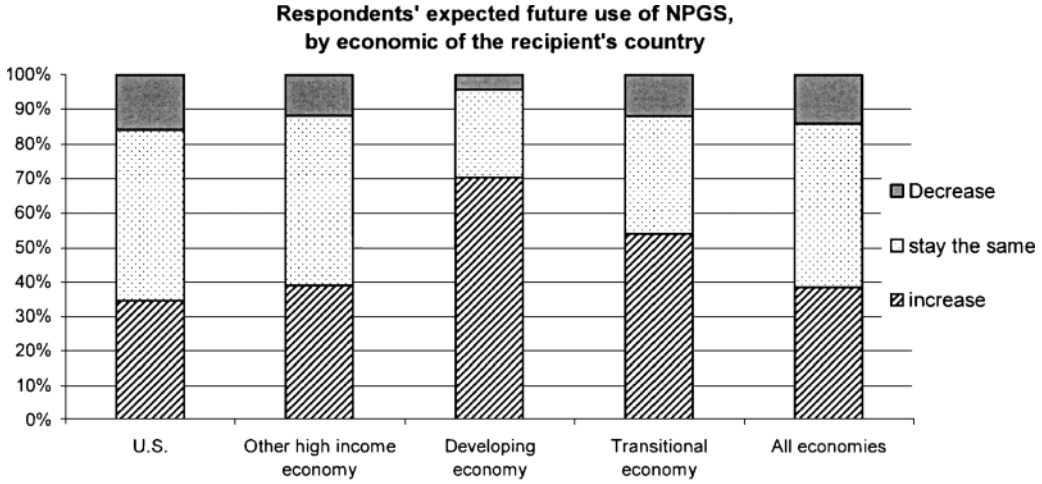
Future use of the NPGS showed pronounced differences by the economic status of the respondent's country. Seventy percent of respondents in countries with developing economies expected to increase their use of the NPGS (Fig. 3). Among all non-U.S. respondents, the percentage of respondents expecting to increase their use of the NPGS was higher than it was for U.S. respondents. Among transitional country respondents, 54% expected their future use of the NPGS to increase, as did 39% of respondents in high-income economies outside the USA. Respondents in countries with developing economies also had the lowest rate of expected decreases in NPGS use: only 4% of respondents expected to make less use of the collections.

Demand may become more targeted over time as increasing amounts of evaluation information are accumulated and disseminated (Widrlechner, 1997). Widrlechner and Burke (2003) found that increases in the quantity and accessibility of evaluation data resulted in declines in the overall distribution of germplasm accessions. Thus, better data leads to more efficient targeting, so fewer accessions may be distributed while the number of requestors or their demand for specific germplasm is actually increasing. The roles that new bioinformatics tools will play in fostering the accessibility of evaluation data and the development of efficient search strategies by links to other resources, such as genomic databases, are likely to accelerate this process.

The Role of Information

Information about genetic resources has value, whether it is a farmer's criterion for selecting which seed to save or a gene sequence used for genomic research. As researchers characterize and evaluate germplasm, they create information that is potentially useful to a broad range of research processes, including breeding. The information, in turn, also aids efforts to further evaluate germplasm. Gao et al. (2000) noted the importance of descriptive information associated with germplasm collections, and how its lack has limited the use of Chinese germplasm resources. Peeters and Galwey (1988) found that European breeders desired more data in terms of both quality and quantity. In the report of the GAO, three-quarters of the Crop Germplasm Committees reported insufficiencies with evaluation information, and almost half found characterization information insufficient for crop-breeding purposes.

Survey respondents stated that about 18% of the samples received had useful data for the trait of interest. Approximately 23% of samples came with other useful data. NPGS requestors were asked to list the main benefits and primary problems associated with the NPGS in their questionnaires. Not all respondents elected to offer additional information; therefore we can only present summary information as a percentage of the



Notes: Pearson Chi-square test shows significant differences (2-tailed, 1%) by development status of country.
Source: Study conducted by the International Plant Genetic Resources Institute and Auburn University.

Fig. 3. Respondents' expected future use of the NPGS, by economic status of the recipient's country.

responses given. Of the problems cited by respondents, the most frequent category (at 39%) concerned insufficient or inaccurate information. The importance of data in these assessments suggested that a relationship exists between data about germplasm samples and their usefulness to respondents.

Another interesting factor was that respondents in countries with developing economies were the most likely to state that their NPGS samples came with useful data for the trait of interest. These respondents said that 30% of seed samples had useful data for the trait of interest, the highest rate of all respondents, though generally non-U.S. respondents more often found that seed samples had useful data than U.S. respondents did (Table 9). The percentage of seed samples with useful data for other purposes seemed to differ by the economic status of respondent's country. Respondents in high-income economies, including the USA, were more likely to state that seed samples had useful data for other purposes; respondents in countries with developing or transitional economies were less so.

To explore relationships between the usefulness of germplasm samples and accompanying data in a more systematic fashion, we estimated a linear regression. The dependent variable was the percentage of samples that had proven useful to the respondent. "Useful" was defined as whether a sample had been used in the respondent's breeding program, was still being evaluated (because the continued valuation of a sample suggested potential future utility), or was characterized as "useful in other ways."

Respondents gave two answers for the usefulness-of-data question: the percentage of materials requested with useful data for the trait of interest and the percentage of materials with other useful data. Determining whether data were for the trait of interest or were deemed "other useful data" was left to the respondent (thus, familiarity with the English language could have played a role in these distinctions). The simple correlation coefficient between these two variables was only 0.169, therefore both variables were included.

Differences suggested by the descriptive statistics led us to hypothesize that the national income of the country affected the institutional and research environment of the respondent, and as a consequence, could influence the relationship between the usefulness of samples and the presence of useful data. GDP dollar estimates for all countries were obtained from the U.S. Central Intelligence Agency (2001), which based them on purchasing power parity calculations. GDP per capita is a continuous variable and adds information to the categorical economic status variables. Additional independent variables were nine fixed effects for the relevant crop and five fixed effects for the respondent's stated profession.

Respondents varied considerably in the number of samples requested. Some respondents worked with large breeding or research efforts; others requested one or two samples for small projects that were sometimes unrelated to breeding or biological research, such as historical research or artistic endeavors. Because respondents who requested large numbers of samples were likely to differ from those who requested only a few samples, we used a weighted least squares model, weights were the number of samples received by the respondent. Respondents who did not report receiving any samples were omitted from the model.

The regression results are shown in Table 10. The hypothesis that regression parameters were constant across country economic status was rejected with a Chow (1960) test at the 0.01 significance level. Thus, regressions were estimated separately for countries with developing, transitional, and high-income economies.

In each model, the reported usefulness of samples was positively and significantly related to the usefulness of data for the trait of interest. The large relative magnitude of standardized coefficients (or z scores) in our models suggested that usefulness of data variables were the most important factors in the models. The models for high-income and transitional economies also indicated that the percentage of samples with other useful data was significantly and positively associated with the usefulness of samples (at the 1 and 5% levels, respectively), suggesting that the role of other useful data may be related to economic status.

Among countries with high-income economies, the higher the GDP per capita, the lower was the share of seed samples that respondents found useful, and the negative effect is of a relatively high magnitude. GDP per capita was not a statistically significant factor for respondents in countries with developing or transitional economies.

In each regression, the professional category of breeder was omitted, serving as a point of reference for the fixed effects associated with the occupational category of respondents. Major differences are apparent in the effects of these variables on the percentage of samples found useful, both among professions within the same economic group and for the same profession across economic groups. Respondents in other professions (acquisition, education, farming, or evaluation) found samples less useful than breeders in high-income economies. The profession of evaluation was also associated with a lower share of useful materials. Among countries with developing and transitional economies, only respondents working in acquisition differed significantly from breeders, reporting lower levels of usefulness. For respondents in transitional economies, farmers and evaluators reported higher percentages of useful materials, though we do note that these categories accounted for relatively

Table 9. NPGS samples with useful data, 1995 to 1999, by economic status of respondent's country. Survey conducted by the International Plant Genetic Resources Institute and Auburn University and is based on data provided by the National Germplasm Resources Lab, USDA.

	Seed samples with useful data	
Economic status	**For trait of interest**	**For other purposes**
	%	
USA	**16**	**24**
Other high-income economy	**26**	**25**
Developing economy	**30**	**13**
Transitional economy	**21**	**14**
All countries	**18**	**23**

Table 10. Regression results in which dependent Variable is percentage of samples used in breeding program, still being evaluated, or useful in other ways. Weighted least squares regression: weighted by number of samples received by each respondent, selecting only cases for which total number of samples classified by the respondents > 0. Crop omitted from the models is wheat. Profession omitted from the models is breeding. Variables crop rice and profession education also omitted for the transitional economies model because no observations occurred.

	Parameter estimates			
Variable name	**All countries**	**High-income economies**	**Developing economies**	**Transitional economies**
(Constant)	0.651** (14.736)	1.048** (9.932)	0.751** (3.862)	0.365* (2.240)
GDP/capita	-7.061×10^{-6}** (−6.113)	-1.179×10^{-5}** (−5.943)	8.995×10^{-6} (0.986)	-2.968×10^{-5} (−1.793)
Barley	−0.131** (−5.147)	−0.119** (−4.470)	−0.642** (−4.125)	−0.172 (−1.688)
Beans	0.051 (0.808)	−0.022 (−0.315)	−0.196 (−1.153)	0.420** (3.138)
Cotton	0.291** (5.047)	0.325** (4.566)	−0.153 (−0.853)	−0.379 (−0.691)
Maize	0.040 (0.765)	0.076 (1.335)	−0.534** (−3.062)	−0.200 (−0.742)
Potato	−0.093* (−2.165)	−0.180** (−3.603)	−0.021 (−0.099)	−0.092 (−0.581)
Rice	0.213** (5.087)	0.242** (5.401)	−0.108 (−0.551)	–
Sorghum	0.067 (0.827)	0.032 (0.366)	−0.234 (−1.052)	0.690 (0.421)
Soybean	−0.098** (−3.527)	−0.094** (−3.229)	−0.314* (−2.520)	0.239 (1.408)
Squash	0.202 (1.319)	0.245 (1.450)	−0.519* (−2.045)	0.102 (0.124)
Percentage material with data for the trait of interest	0.004** (10.547)	0.004** (9.013)	0.006** (5.943)	0.008** (6.470)
Percentage of material with other useful data	0.004** (13.695)	0.004** (13.322)	−0.001 (−0.376)	0.004* (2.635)
Prof = Acquisition	−0.024 (−0.329)	0.010 (0.084)	−0.341** (−3.048)	−0.130 (−0.369)
Prof = Evaluation	−0.029 (−0.855)	−0.087* (−2.361)	0.243 (1.871)	0.387** (4.431)
Prof = Farming	0.183** (4.112)	0.034 (0.643)	0.098 (0.577)	0.467** (3.516)
Prof = Education	0.110 (0.911)	0.094 (0.750)	0.545 (1.713)	–
Prof = other	−0.158** (−6.619)	−0.198** (−7.894)	0.165* (2.128)	0.174 (1.359)
Adjusted R^2	0.487	0.499	0.716	0.752
N	1262	1135	79	48
F	71.547**	67.425**	9.064**	10.521**

* Significant at the .05 level.
** Significant at the .001 level.

few of the respondents. Generally, scientists involved in germplasm acquisition are not searching for specific traits, which may account for lower levels of use. Researchers who conduct evaluations may be more likely to request germplasm that has not been evaluated, therefore making fewer targeted requests.

CONCLUSIONS

Our results suggest the following.

1. Demand for NPGS resources is substantial and comes from a broad range of users.

The volume of material distributed by the NPGS was the most definitive evidence of demand for its services. For the 10 crops studied in this paper alone, more than 600000 samples were distributed during 1990 to 1999 to fulfill recipients' requests. Public institutions, nonprofits and commercial institutions requested, at a minimum, more than 100000 samples each. Thus, not only did public and quasipublic institutions use these collections, but there was substantial use by private firms.

The NPGS also provided germplasm to numerous countries. While U.S. requestors accounted for the majority of germplasm demand, volume was such that, for the 10 crops studied in this paper, more than 150000 samples were distributed to international requestors alone in the last decade.

Findings suggest that the NPGS provided important resources for biological research, particularly basic biological research. The use of NPGS resources for research was particularly strong in the USA. The relatively high rates of return to basic research (Fuglie et al., 1996) suggest that an important component of the value of the NPGS arises from its support of such research.

2. Utilization rates are higher than reported previously.

It has been suggested that many genebank resources are used primarily when other options have failed, and that these "last ditch" efforts have low probabilities of success (Cox et al., 1988; Duvick, 1995). Given the lengthy and serendipitous nature of breeding, this seems a reasonable assumption. However, responses from users of 10 important crops indicated otherwise. Respondents stated that nearly half the materials received from the NPGS had already been used in a breeding program, had been considered worthy of further evaluation, or had been useful in other ways. Estimates of actual use suggested that more than 25000 samples had already been used in breeding programs. Secondary use through sharing within and outside respondents' institutions implies additional use not captured in our numbers.

3. Data make germplasm more useful.

Although publicly available data from germplasm characterization and evaluation are thought to aid research and breeding processes by leading to more highly targeted germplasm requests (Widrlechner and Burke, 2003), empirical evidence to measure the extent that supplementary data increase the utility of public germplasm has been lacking. Therefore, models were developed using responses from NPGS users to evaluate the roles of data in germplasm use. The model results indicated that samples with useful data were associated positively with use in breeding programs, continued evaluation, or other kinds of respondent-assessed utility. These results held both for data for the trait of interest and for

other useful data. Further research that explores types of data and their relative utility would be of interest.

4. Most germplasm does not come with useful data but is still demanded.

While the data accompanying samples increased their usefulness, they were not prerequisite for germplasm demand. The GRIN (2001) web server provides germplasm information, including characterization and evaluation data. Thus, for requestors with Internet access, evaluation and characterization data queries are available. Requestors can screen for such attributes as pest resistance and agronomic traits. Nonetheless, the majority of germplasm received by respondents did not include useful data either for the trait of interest, or other useful data. Offering additional accessions with information might increase demand for that germplasm, but demand appeared to be strongly independent of the data element.

5. Countries with developing economies make greater use of NPGS resources, relatively speaking.

Countries with developing economies constituted a significant portion of the total international demand for NPGS resources, and respondents in these countries already had used a much higher percentage of germplasm from the NPGS in breeding programs and were evaluating still more materials than were respondents in high-income and transitional economies. Respondents in countries with developing economies were more likely to share germplasm with colleagues, thus contributing to secondary use of NPGS resources. In fact, we estimated that recipients in countries with developing economies accounted for 70% of international secondary transfers of NPGS germplasm. The fact that NPGS materials are provided free of charge gives scientists in many countries access to a range of resources that they might not be able to use otherwise, and these resources have been used productively.

6. Demand for NPGS resources is likely to increase.

Nearly half the respondents expected their demand for NPGS germplasm to stay the same (47%). Of those expecting their demand to change, twice as many respondents expected their demand to increase rather than decrease. The expectation of increased future use was particularly high among respondents in countries with developing economies, whose demand, in terms of samples distributed, was the highest among international users of the system. Therefore, within the context of the 10 crops of this study, overall demand for NPGS resources will likely increase.

One of the primary points of contention in the international exchange of genetic resources has been the perceived equity (or inequity) of the use and benefits of germplasm (Wittmeyer, 1996). While such arguments are beyond the scope of this paper, information on usefulness of NPGS germplasm, secondary sharing, and future use expectations may be useful in gauging the benefits of the NPGS system for different groups of users.

The healthy demand seen for landraces and wild relatives suggests that these indigenous resources continue to be of interest to breeders and scientists in countries of different economic status. Still, most materials requested were cultivars, advanced materials, or genetic stocks, all of which involved some modern breeding efforts. Collectively, respondents, regardless of the economic status of their country, made use of all types of germplasm and expected to do so in the future, providing further indication of the interdependence of nations with respect to germplasm.

As noted before, the NPGS offers its resources free of charge. The expectation that this will continue probably contributed to respondents' expectations of their future demand. The new International Treaty on Plant Genetic Resources for Food and Agriculture contains provisions for the sharing of benefits from commercialized products using germplasm provided through a multilateral system (FAO, 2004). The treaty entered into force on 30 June 2004, though it has not yet been ratified by the USA. At the time of this writing, the terms of the standard Material Transfer Agreement, which will govern the exchange for seven of the 10 crops covered in this study, were unclear.

While the mechanics of future germplasm exchange remain uncertain, the overall picture from this study of the NPGS is one of a system providing a diverse array of specialized genetic resources and associated data to a broad range of users. Moreover, these materials appeared to be useful in actual practice.

Appendix 1. Countries receiving germplasm from NPGS, 1995–1999, for 10 crops, and country's economic status.

Country	Economic status	Country	Economic status
Algeria	developing	Liberia	developing
Angola	developing	Lithuania	transitional
Anguilla	developing	Macedonia	transitional
Argentina	developing	Malawi	developing
Australia	high income	Malaysia	developing
Austria	high income	Mali	developing
Bahrain	developing	Mayotte	developing
Barbados	developing	Mexico	developing
Belarus	developing	Moldova	transitional
Belgium	high income	Namibia	developing
Bolivia	developing	Netherlands	high income
Brazil	developing	New Zealand	high income
Brunei	developing	Nigeria	developing
Bulgaria	transitional	Norway	high income
Canada	high income	Pakistan	developing
Chad	developing	Peru	developing
Chile	developing	Philippines	developing
China	developing	Poland	transitional
Colombia	developing	Portugal	high income
Costa Rica	developing	Puerto Rico	developing
Cote D'Ivoire	developing	Romania	transitional
Croatia	transitional	Russian Federation	transitional
Czech Republic	transitional	Rwanda	developing
Denmark	high income	Saudi Arabia	developing
Ecuador	developing	Sierra Leone	developing
Egypt	developing	Slovakia	transitional
Estonia	transitional	Slovenia	transitional
Ethiopia	transitional	South Africa	developing
Finland	high income	Spain	high income
France	high income	St. Vincent and Grenadines	developing
Georgia	transitional	Sudan	developing
Germany	high income	Sweden	high income
Ghana	developing	Switzerland	high income
Greece	high income	Syria	developing
Guatemala	developing	Taiwan	developing
Haiti	developing	Tanzania	developing
Honduras	developing	Thailand	developing
Hong Kong	developing	Thailand	developing

Continued on next page

Appendix 1. Continued.

Country	Economic status	Country	Economic status
Hungary	transitional	Trinidad and Tobago	developing
India	developing	Tunisia	developing
Indonesia	developing	Turkey	developing
Ireland	high income	Uganda	developing
Israel	high income	Ukraine	transitional
Italy	high income	United Kingdom	high income
Japan	high income	Venezuela	developing
Korea, South	developing	Vietnam	developing
Kuwait	developing	Yugoslavia	transitional
Latvia	transitional	Zambia	developing
Lesotho	developing		

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