Introduction

Genetic resources provide the fundamental mechanics that enable plants to convert soil, water and sunlight into something of critical value to humans—food. Diverse genetic resources allow humans to select and breed plants and animals with desired characteristics, thus increasing agricultural productivity. U.S. agricultural productivity more than doubled over the last century (Ahearn et al., 1998), and much of this productivity increase came from rapidly rising crop yields. Half the yield gains in major U.S. cereal crops since the 1930s are attributed to genetic improvements (OTA, 1987). But demand for agricultural commodities continues to grow, and environmental conditions change, so continued productivity growth—and the genetic diversity that helps sustain it—remains important.

Genetic diversity can be conserved in the form of diverse cultivated varieties in farmers' fields, ecosystems that contain wild relatives of cultivated varieties, and/or germplasm collections that contain samples of wild and cultivated species. Each method is characterized by different costs and benefits, making it difficult to determine the optimal mix of conservation strategies. But each also shares a common feature. The use of genetic resources by one farmer or plant breeder does not generally preclude their use by another, so private incentives to hold and protect genetic resources are generally lower than their value to users as a group or society as a whole. This means that in the absence of appropriate public measures (and underlying research), private efforts to conserve genetic resources are likely to fall short of the conservation levels that are optimal for society.

Previous researchers have contributed to our knowledge about the use and conservation of genetic resources. The National Research Council published a detailed review of the National Plant Germplasm System that included extensive recommendations to improve the system (NRC, 1991). A second, related book presented a broader look at the management of genetic resources (NRC, 1993) and included chapters on economic value and ownership. However, economic methodology has evolved rapidly since this report was released, as have the policy instruments that are used to protect and exchange genetic resources.

The Food and Agriculture Organization of the United Nations developed a report based on studies submitted by member countries. *The State of the World's Plant Genetic Resources for Food and Agriculture* (1996b and 1998) was a useful snapshot of genetic resource conservation and technological methods, but provided minimal economic information such as incentive structures or policy tools. In 1997, the U.S. General Accounting Office presented a systematic analysis of the management of the U.S. national genebank system. Recently, the International Food Policy Research Institute published a set of research briefs focused on gene bank valuation. These last two reports focused only on gene banks, and not on all three genetic conservation options.

All these previous reports have been useful, but recent developments in the international exchange of genetic resources call for a concise and current summary of genetic resource conservation in an economic framework. This report focuses on our current understanding of the value of genetic resources, trends in genetic diversity (and the economic incentives that affect them), and recent strategies for protecting genetic resources (including the International Treaty on Plant Genetic Resources for Food and Agriculture, which entered into force in June 2004).

Origins of Crop Genetic Diversity

Human selection of plant varieties for desired traits (such as taste, pest resistance, or seed size) dates from the very beginnings of agriculture. For thousands of years, farmers have selected, saved, and replanted varieties of the crops that humans consume today. "Centers of diversity" developed where intraspecies diversity of crop varieties was particularly high. Most centers of diversity are found where crops were first domesticated, primarily in today's developing countries.

The pace of genetic improvement accelerated with the development of modern breeding techniques that facilitated selection of specific desirable traits. Breeders have crossed different parental material and selected traits to achieve high yields and improved quality for all types of crops. Breeders have also sought resistance to pests, diseases, drought, and other stress. In fact, resistance has become the primary goal of breeding for many crops.

Current Challenges

Changes in population, income, and other factors (such as urbanization) drive continuing increases in demand for agricultural commodities. Environmental conditions also change and pests and diseases evolve over time, so breeders continually need new and diverse germplasm from outside the utilized breeding stock, sometimes using wild relatives and landraces, to find specific traits to maintain or improve yields (Duvick, 1986). Maintaining resistance is a continual process, because new varieties are resistant to pests and diseases for an average of 5 years, while it generally takes 8 to 11 years to breed new varieties (USDA, 1990).

But private incentives to acquire and preserve genetic resources outside regular breeding stocks are limited, because genetic resources have strong "public goods" characteristics (Brown, 1987; Brown and Swierzbinski, 1985; Frisvold and Condon, 1994; Sedjo, 1992; Simpson and Sedjo, 1992; Reid, 1992; Swanson, 1996). For example, genetic resources are easily transported and replicated, and intellectual property protection has historically been relatively weak for biological innovations, making it difficult for an individual country, firm, or farmer to exclude others from their use. Furthermore, the usefulness of particular genetic resources is highly uncertain, and time horizons for improving genetic resources are long.

Despite the limits on private returns to their conservation and improvement, diverse crop genetic resources remain critical to agricultural production. Therefore, the public sector has played a pivotal role in their conservation. This raises three questions.

First, **what are genetic resources worth?** Most genetic resources are not market goods; that is, they are not sold as inputs into the breeding process

Definitions

Biological diversity refers to the number, variety, and variability among plant, animal, and microorganism species and the ecological systems in which they live. Biological diversity can be defined at three levels. *Genetic diversity* refers to the different genes and variations generally found within a species. The variation among genes across different wheat varieties is an example. *Species diversity* refers to the variety and abundance of different species in a region. Finally, *ecosystem diversity* is exemplified by the variety of habitats, such as grasslands or wetlands, occurring within a region. The term biological diversity can refer to any or all of the three levels of diversity, but in this report we will focus particularly on genetic diversity in agricultural crops.

Crop genetic diversity can be conserved in its natural setting (i.e., *in situ*), or it can be collected and conserved outside its natural environment (i.e., *ex situ*). Within the context of crop genetic diversity, there are five basic kinds of genetic resources:

1. **Wild or weedy relatives** are plants that share a common ancestry with a crop species but that have not been domesticated. These can also be a source of resistance traits, but these traits may be difficult to incorporate in final varieties.

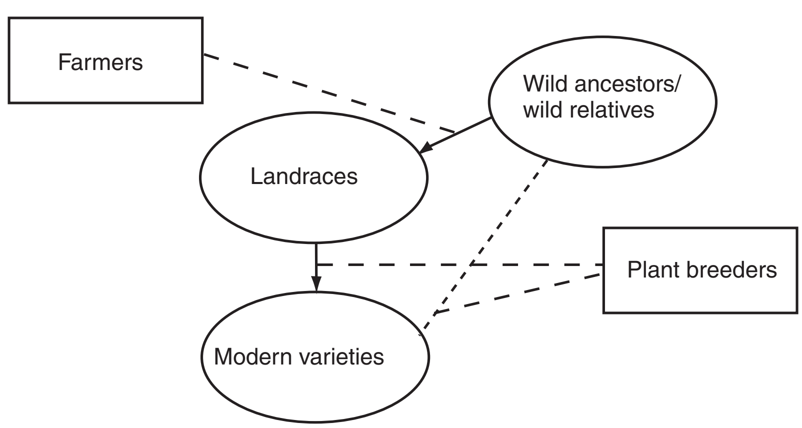
2. **Landraces** are varieties of crops improved by farmers over many generations without the use of modern breeding techniques. These varieties are generally very diverse within species, because each is adapted to a specific environment. Within a modern breeding program, they are sometimes used for resistance traits, and extensive efforts are generally required before their genes are usable in a final variety.

3. **Improved germplasm** is any plant material containing one or more traits of interest that has been incorporated by scientific selection or planned crossing.

4. **Advanced (or elite) germplasm** includes "cultivars," or cultivated varieties, suitable for planting by farmers, and advanced breeding material that breeders combine to produce new cultivars.

5. **Genetic stocks** are mutants or other germplasm with chromosomal abnormalities that may be used by plant breeders, often for sophisticated breeding and basic research.

Figure 1
Farmers, plant breeders, and genetic resources



and so lack simple indicators of their value. As such, policymakers find it difficult to compare investment in conservation with other uses for public funds. The international exchange of germplasm is also complicated, as countries may seek to maximize the returns from the set of resources that they hold.

Second, **how diverse are genetic resources,** not only in gene bank collections but also in the field? Diversity among genetic resources in the field can reduce the prospects for pest and disease epidemics. Farmers generally grow the most productive varieties (in terms of yield or quality), which may or may not be diverse. Society as a whole may prefer a higher level of diversity than farmers do. Incentives for land conservation, the breeding process, and access to modern varieties all can affect diversity in the field. Even the way in which diversity is defined can alter the assessment of benefits associated with different production and conservation decisions.

And finally, **what can be done to ensure we have the crop genetic resources that we will need?** The reliance of agriculture on these resources suggests the importance of continued preservation efforts. Policy instruments such as funding for *in situ* and *ex situ* conservation, intellectual property rights, and negotiated terms of transfer can be used to promote genetic resource conservation. While these policies can be implemented at the national level, genetic resources are found throughout the world. No nation has all the resources it wants or may need in the future. Thus, international coordination of genetic resource conservation is critical to meeting the long-term requirements of agricultural production.