Factors Influencing Trends in Crop Genetic Diversity

Diverse genetic resources have been a source of large gains in agricultural productivity and, as a result, producer and consumer well-being. Such gains might provide incentives for conservation and efficient use of valuable resources, but these incentives are often muted in the case of genetic resources because returns to their identification and use are not always easily captured by individual farmers, firms, or countries. In fact, the loss of genetic diversity in a species, also called genetic erosion, has been reported in many commercially important crops (National Research Council, 1972; National Research Council 1993; Porceddu et al., 1988).

Genetic diversity is a particular concern because greater genetic uniformity in crops can increase vulnerability to pests and diseases (National Research Council, 1993). Genetic uniformity does not, in and of itself, mean that a particular variety is more vulnerable to pests and diseases or abiotic stresses. In fact, modern varieties often are bred for superior resistance, hence their popularity. Nonetheless, as pests and diseases evolve to overcome host plant resistance, genetic uniformity increases the likelihood that such a mutation eventually will prove harmful to a crop. The evolved pest or disease has a greater crop base that it can successfully attack, which could increase its severity. Instead of a particular disease harming only a small percentage of varieties on limited land, the disease now could affect a greater proportion of a crop's production. For example, genetic uniformity contributed to the spread of the Southern Corn Leaf Blight, which led to a 15-percent reduction in the U.S. corn crop in 1970.

Here, we identify three factors that might contribute to loss of genetic diversity—habitat loss, conversion from landraces to scientifically bred varieties, and genetic uniformity in scientifically bred varieties—and assess how much each factor is operative today. Considerable debate surrounds both the historic and current loss of genetic diversity, due in part to difficulties in defining an appropriate concept of genetic diversity and obtaining accurate measurements. (Formal measures of genetic diversity, as applied both by scientists and by economists, are discussed in the Appendix.) Formal measures of genetic diversity tend to be both wide ranging and data-intensive, and, in most cases, they are not available for long periods (see box, "Measures of Crop Diversity"). As a result, the discussion of trends in genetic diversity is indicative, not precise.

Most of the formal definitions of genetic diversity are applied either at the cross-species level or within a particular species. Within a crop species, these definitions may be related to the number of varieties, the distribution of varieties within a given area, and/or the genetic difference between varieties within a given area or period of time. In the context of crop genetic resources, for example, habitat loss is likely to affect diversity primarily at the cross-species level, where the relevant species are those closely related to the crop of interest. Conversion from landraces to scientifically bred varieties and genetic uniformity in scientifically bred varieties, on the other hand, may affect one or more of these types of indicators *within* a particular crop species.

Habitat Loss

One factor contributing to a decline in crop genetic diversity has been the loss of wild relatives of cultivated crops (National Research Council, 1993). The loss of wild relatives occurs mainly through habitat conversion for agricultural use. When forest and other wild lands are cleared, plant, animal, and microorganism populations generally fall, reducing the level of genetic diversity. Habitat loss is particularly problematic in developing countries, which often face greater pressures for wild land conversion than do developed countries (Houghton, 1994). Population growth and extensive farming techniques are often cited as factors fostering high rates of land conversion to agriculture. Other influences on land conversion are thought to include poverty, international trade, land degradation, and government policies, particularly where land tenure policies are not clearly defined or enforced (Day-Rubenstein et al., 2000).

Because the full economic values of wild relatives can rarely be captured by landowners, the use of land to preserve habitats for wild relatives remains

Measures of Genetic Diversity

Measures of genetic diversity are very numerous, although there are strong similarities and relationships among many of these measures. At a general level, most involve measures of the *number* of species, the *distribution* of species, and/or the *difference between* species within a given area or period of time. More narrowly, similar concepts might be applied within a crop species, with varieties rather than species becoming the relevant unit of observation.

One reason for the wide variety of measures of genetic diversity is that different people have different reasons for studying or using it. Evolutionary biologists might want to study the process of speciation or the formation of new species, or measure the evolutionary distance between species. Ecologists may be interested in the number and distribution of species within a given habitat. Plant breeders usually focus more closely on diversity within a crop species of interest, although they may also wish to tap diversity within the secondary and tertiary gene pools for that species. (The *secondary gene pool* consists of all biological species that can be crossed with the cultivated species, although these crosses are usually sterile. The *tertiary gene pool* consists of those species that can be crossed with the cultivated species only with difficulty, such as with genetic engineering).

Farmers, particularly those cultivating landraces in noncommercialized agriculture, may be interested in morphological diversity—i.e., diversity in certain physical traits. Because traits are influenced by environmental factors, and because, in many cases, many interacting genes contribute to trait expression, morphological diversity may not be considered to be a "true" measure of genetic diversity. Nonetheless, farmers may make their planting decisions based on such morphological diversity, so it is a potential influence on underlying genetic diversity. Policymakers may focus on preserving genetic diversity as a means to continue crop improvement and guard against the risks of pest or disease epidemics. Economists may wish to study the ways in which the variables important to farmers or policymakers interact with the variables important to plant breeders or ecologists. But no single measure fulfills all desired criteria (Meng et al., 1998).

undervalued compared with alternative uses such as clearing for agricultural or urban use. Thus, habitat conversion occurs in part because the private returns to genetic and other biological diversity are lower than the social returns (Hanemann, 1988). Private returns are important because resources are generally held (whether formally or informally) at the individual or local level. Therefore, many decisions that affect conservation of biodiversity, such as land clearing, are made at these levels. By contrast, many of the benefits of biodiversity conservation accrue at the national or global level. These differing returns contribute to biological resource depletion because conservation of habitat competes with alternative uses of land. Since keeping land in its natural state reduces or eliminates the land's earning capacity for its holders, returns to agricultural production form one opportunity cost of wild land preservation. Also, temporal issues come into play: individuals may place a greater value on current consumption, when weighing the tradeoff between present and future use of resources, than does society as a whole. Together, these factors generate private or individual decisions that differ from those that are socially or globally optimal.

Also, because certain genetic materials are easy to transport and replicate once collected, it is difficult for countries to capture more than a fraction of the value that flows from their genetic resources. Moreover, markets do not exist for most of the other environmental services provided by biological resources, such as carbon sequestration. Consequently, keeping land in less intensive uses favorable to the *in situ* preservation of genetic resources is often less profitable than more intensive agricultural production to individual countries as well as to individual landowners.

Although many habitat reserves have been established worldwide, wild relatives of agricultural species tend to be included only by accident (FAO, 1996b). Habitat preserves often focus on areas rich in species diversity—usually wildlife species or all plant species—and not on crop species alone. These areas are not necessarily those with the greatest crop genetic diversity.

Much empirical work has focused on the loss of tropical forests, but continued agricultural expansion onto other land is also expected (Day-Rubenstein et al., 2000), although at rates lower than previously projected (Bruinsma, 2003). Compared with the developing world, the developed world has lower rates of agricultural land expansion. For example, the amount of U.S. land used for agricultural production has remained stable since 1945 (ERS, 2002). This does not mean that the same land has been in production. Urban land expansion has displaced some agricultural lands, which have displaced some wild lands. Still, expansion of the agricultural production area has not been a significant factor in U.S. biodiversity loss in recent years.

Displacement of Landraces by Scientifically Bred Varieties

Crop genetic diversity also declines as landraces are displaced by scientifically developed modern varieties (National Research Council, 1972; Proceddu et al., 1988; Chang, 1994; Kloppenburg, 1988). The ongoing selection process is thought to have narrowed the genetic base of varieties used in agricultural production (Brush, 1992; FAO, 1996b; GAO, 1997;

Goodman and Castillo-Gonzalez, 1991). In particular, the spread of high-yielding "Green Revolution" varieties and associated changes in crop management practices beginning in the 1960s is thought to exemplify this transition from landraces to modern varieties (Frankel, 1970; Tilman, 1998). Far less area is planted to landraces worldwide than a century ago. But in many cases, the transition to modern varieties predates the Green Revolution. Improved crop varieties, such as hybrid corn or semi-dwarf wheat or rice, often replaced other varieties that were already the products of scientific crop improvement (see Smale, 1997, for an example). In the broadest sense, alteration and narrowing of crop genetic diversity began with the first domestication of wild plants. For example, the corn plant has been completely dependent on humans for reproduction for thousands of years, because farmer selection has resulted in kernels that can no longer disperse without human intervention.

Farmer choice is a key driving factor behind the replacement of landraces with scientifically bred varieties. When choosing varieties, farmers consider yield potential as well as other production and consumption attributes. Sometimes landraces offer superior yields or resistance to biotic and abiotic stresses, but often they do not. Landraces often provide consumption characteristics traditionally preferred to those of modern varieties (such as maize better suited for tortillas), but even this advantage is not absolute. While maintenance of a diverse set of landrace varieties may prove valuable to current or future plant breeding, individual farmers do not directly capture these benefits, so they have little incentive to account for them when selecting seed for planting. Landraces become extinct through disuse if farmers stop planting and maintaining them, unless stored *ex situ*. Even if many landraces are stored in gene banks, genetic diversity might be lower than if these landraces were planted by farmers, because in the gene bank they are not subject to ongoing evolutionary pressure.

The rate of landrace replacement by scientifically bred varieties differs by crop, world region, and environment. In most industrialized nations, commercialized crops—i.e., crops grown solely for the market, not home consumption—consist almost completely of scientifically bred varieties, although isolated use of landraces may occur.[9] In developing countries, genetic resource specialists often have information about the location of crop landraces and the rate at which they are being replaced by scientifically bred varieties, but published information that is accurate and aggregated is difficult to find.

[9] For example, certain isolated areas in Mediterranean Europe grow wheat landraces. Faro, or Triticum dicoccum, is grown in Italy.

Some information is available, however, for use of landraces of the three major world cereals, rice, wheat, and corn (maize). In the 1990s, approximately 15 percent of the global area devoted to rice was planted to landraces. Rice landraces are concentrated in southeast Asia, with some also found in the Indian subcontinent (Cabanilla et al., 1999). Use of rice landraces varies by environment and is much lower in the irrigated lowlands than in the more difficult rain-fed lowland and flood-prone and upland environments.

About 10 percent of the developing world's wheat area was planted to landraces in the 1990s. Wheat landraces were concentrated in West Asia and North Africa, with some also found in Ethiopia, China, the Indian subcontinent, and small areas in Latin America. The proportion of wheat area planted to landraces also varied by wheat type and environment. For example, 23 percent of the area planted to durum wheat and 12 percent of the area planted to winter bread wheat was sown to landraces, while only 3 percent of the spring bread wheat area in developing countries was still planted to landraces (Heisey et al., 2002).

Unlike wheat and rice, which self-pollinate, corn cross-pollinates, which means that one plant is often fertilized by another. Because of this feature, corn populations are inherently less stable genetically. Therefore, corn landraces may be very diverse genetically. Furthermore, if farmers continue to replant seed (even from hybrids or other scientifically improved corn varieties) rather than buying new seed, the resulting progeny may also be quite genetically diverse. As a result, it is more difficult to define and measure what constitutes a landrace and what is "improved germplasm" for corn than it is for rice or wheat (Morris et al., 1999). That said, it is clear that a far higher percentage of the developing world's corn area (just under 40 percent) is planted to landraces than is the case for either wheat or rice. If developing countries that produce primarily temperate corn or countries that market "commercialized" corn[10] are excluded, nearly 60 percent of the developing world's corn area is planted to landraces (Morris, 2002). As with the other cereals, corn's wild relatives tend to concentrate in their zone of origin (in the case of corn, in Mexico and Central America), and landraces are most diverse in this zone. Nonetheless, corn landraces are found in many parts of the developing world.

[10] This refers to countries for which a large proportion of the corn produced enters the formal market.

Genetic Uniformity in Scientifically Bred Varieties

In situations where most or all landraces have been replaced by scientifically bred varieties, crop genetic diversity may also decline with (1) reductions in total numbers of varieties, (2) concentration of area planted in a few favored varieties, or (3) reductions in the genetic distance between these varieties. The National Research Council (1993) concluded that the genetic vulnerability of U.S. wheat and corn has become less of a problem since 1970, in part because of efforts to breed in greater diversity. However, the Council also determined that genetic uniformity of rice, beans, and many minor crops is still a concern.

Information for other countries is not readily available. Relatively little attention has been paid to genetic uniformity of scientifically bred varieties in developing countries, perhaps because there more focus has been placed on habitat conversion and displacement of landraces. One major study, however, analyzed trends in modern spring bread wheats planted in the developing world, both in the genetic diversity of varieties released and varieties planted in farmers' fields (Smale et al., 2001). This study was representative of over 50 million hectares of wheat planted in the developing world. Both pedigree analysis and molecular analysis suggested that the genetic diversity of these modern wheat varieties had increased, not decreased, over the past 30 years. Trends in genetic diversity for other crops in developing countries, however, as well as for crops in industrialized nations outside the United States, would likely vary by crop and region.

Whatever the trends in genetic diversity, the genetic uniformity of many crops has raised concerns that crop yields and production will become more variable from season to season (Swanson, 1996). As with other drivers of genetic erosion, individual farmers have limited incentives to consider the wider potential consequences of genetic uniformity, and, when choosing which varieties to plant, may perceive the benefits of uniform varieties to be greater. Farmers may be willing to accept the risk of greater variability if they expect to receive higher average yields.

Thus far, despite concerns about genetic uniformity, yields for many major crops have been relatively stable. An important reason may be that temporal diversity has replaced spatial diversity (Duvick, 1984). Although there may be greater spatial uniformity of crops planted at any given time today (compared with 100 years ago), modern plant breeding provides a steady release of new varieties with new traits for pest or disease resistance over time.

The ability of plant breeders to keep ahead of evolving pests and diseases through temporal diversity depends directly on the quality and accessibility of germplasm collections in public gene banks and in private breeders' collections. Because many of the benefits of raw germplasm cannot be appropriated, private breeders rely on the public sector to collect, characterize and perform pre-breeding enhancement of genetic materials to make them accessible for private use (Duvick, 1991).