GENES in the FIELD
On-Farm Conservation of Crop Diversity

Edited by
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chapter one

The issues of in situ conservation of crop genetic resources

Stephen B. Brush

Introduction

Domesticated plants have been fundamentally altered from their wild relatives; these species have been moved into and adapted to new environments; they have become dependent on the tiller’s hand; and they have been reshaped to meet human needs and wants. Modern crops are the result of thousands of years of these evolutionary processes. Like all biological evolution, crop evolution involves two fundamental processes: the creation of diversity and selection (Harris and Hillman 1989). Crop evolution is distinguished by two types of selection: one natural and another artificial or conscious. These evolutionary processes must continue in order for agriculture, a living and evolving system, to remain viable. Therefore, an essential criterion of crop evolution is the availability of genetic diversity. Crop evolution has been altered by our enhanced ability to produce, locate, and access genetic material, but this has not changed its fundamental nature. Both farmers and scientists have relied on the store of genetic diversity present in crop plants that has been accumulated by hundreds of generations who have observed, selected, multiplied, traded, and kept variants of crop plants. The result is a legacy of genetic resources that, today, feeds billions of humans.

Genetic diversity is important both to individual farmers and farming communities and to agriculture in general. Individual farmers value diversity within and between their crops because of heterogeneous soils and production conditions, risk factors, market demand, consumption, and uses of different products from an individual crop species (Bellon 1996). Thus a wheat farmer
in Turkey may have different types of wheat for hillside or valley bottom areas, for irrigated and rain-fed parcels, for homemade bread and for urban grain markets, for straw and animal feed (Brush and Meng 1998). Moreover, farmers usually rely on diversity of other farms and communities to provide new seed when crops fail or seed is lost or to renew seed that no longer meets the farmer's criteria for good seed (Louette et al. 1997). The need for diversity at both the farm and regional levels has resulted in a vast store of genetic diversity in crops, a store passed down from earlier generations and maintained for the future. In regions where a crop's evolution has the longest record, where the crop was originally domesticated, and where its diversity is greatest, the local store of genetic diversity in farming communities is also a store of genetic resources for that crop, an invaluable resource for farmers, scientists, and consumers elsewhere (Hawkes 1983).

Unfortunately, this legacy is imperiled by the very conditions it helped to create (Wilkes 1995). Record numbers of humans, agricultural science and technology, and economic integration of the world's many diverse cultures threaten to destroy this legacy, as modern crop varieties and commercial farming diffuse into every agricultural system. A result of these changes is that diversity on individual farms and across wide regions is threatened by modern crop varieties that have been bred for broad adaptation, resistance to disease and other risk factors, ability to better use water and fertilizer, and higher yields. This threat is evidenced by the fact that agricultural development in Europe, North America, and many less developed countries has been accompanied by the replacement of diverse, local populations of crops with a handful of modern varieties.

The importance of crop genetic resources and threats to them has led to the creation of conservation programs to preserve crop resources for future generations. One type of crop genetic conservation is *ex situ* — maintenance of genetic resources in gene banks, botanical gardens, and agricultural research stations (Plucknett et al. 1987). Another type is *in situ* — maintenance of genetic resources on-farm or in natural habitats (Brush 1991; Maxtel et al. 1997a). In actuality, two types of *in situ* conservation can be distinguished. First, *in situ* conservation refers to the persistence of genetic resources in their natural habitats, including areas where everyday practices of farmers maintain genetic diversity on their farms. This type is a historic phenomenon, but it is now especially visible in regions where farmers maintain local, diverse crop varieties (landraces), even though modern, broadly adapted, or higher yielding varieties are available.

Second, *in situ* conservation refers to specific projects and programs to support and promote the maintenance of crop diversity, sponsored by national governments, international programs, and private organizations. *In situ* conservation programs may draw on the existence and experience of the first type, but they are designed to influence farmers in the direction of maintaining local crops by employing techniques that may not be local. This type of conservation faces daunting tasks. It must cope with continual social, technological, and biological change while preserving the critical elements
of crop evolution — genetic diversity, farmer knowledge and selection, and exchange of crop varieties.

In situ conservation practices and projects in agriculture theoretically can concern the wide spectrum of genetic resources relating to crops, from wild and weedy relatives of crop species to the infraspecific diversity within crop species (Maxted et al. 1997b). The focus of this chapter and the others in this book is the latter, the diversity within cultivated species, exemplified by heterogeneous crop populations known as landraces. These are named, farmer varieties that usually have a reduced geographic range, are often diverse within particular types, and are adapted to local conditions (Brush 1995; Harlan 1995). One reason for our focus on diversity within cultivated crops is that science of in situ conservation of cultivated resources is relatively less developed than the science of conserving wild resources such as wild and weedy crop relatives. Another reason is that in situ conservation of cultivated plants requires novel approaches, while in situ conservation of wild crop relatives can draw on theories and methods developed for conserving many different species in their natural habitats. Finally, focusing on variation within cultivated species is warranted by the fact that this type of diversity is arguably the most important one for the future viability of agricultural evolution, as it has been in the past.

The successful planning and implementation of projects for on-farm (in situ) conservation of crop genetic resources require us to answer four questions. First, why undertake this type of conservation, especially when investments are made for ex situ conservation? Second, what scope is necessary or appropriate for in situ conservation of crop germplasm? Third, how can agricultural agencies and organizations promote this form of conservation? Finally, what legal and institutional questions pertain to on-farm conservation of genetic resources? The answers to these questions come from different fields of science, for example, population biology and social science, and from law and politics. Moreover, the answers to these questions seldom are definitive. More important than definitive answers is the ability to seek answers, because new answers will be needed for different times, conditions, crops, and societies. The purpose of this and other chapters in this book is not to answer these four questions but rather to offer guideposts and a context for finding answers in specific regions and for specific crops and cropping systems.

Why in situ conservation?

The invention and development of agriculture was accomplished independently in several places in the world, but within a relatively narrow time period following the end of the Pleistocene period — 8,000 to 10,000 years before the present (Harris and Hillman 1989). Why agriculture arose during this limited time period and only in a few places, and exactly how wild plants were identified, manipulated, and managed for domestication remain mysteries. Although the origins and processes of crop domestication are obscure, its consequences are well known and thoroughly documented —
the creation of an entirely new way of life and eventual rise of urban civilization with all of its wonders and woes. Since the time of domestication, a progression of changes has occurred in farming systems and social systems associated with agriculture. Greater numbers of people than ever before in human history are dependent on a smaller number of crop species; a handful of "mega-crops" have supplanted locally important crops and now feed most of the world's population (Wilkes 1995). The reduction in interspecies diversity of food plants continues the trend of exercising ever greater control over nature and the production process, a trend also supported by the increased use of manufactured inputs in crop production.

Individual social and production systems have been gradually but inexorably integrated into a single, interconnected world system of economic, cultural, and technology exchange, and this integration threatens genetic diversity of crops as much as population increase and modern technology. Until recently, most crop production was intended for local consumption, and it relied mostly on local resources of energy and crop germplasm. Today, however, exceedingly few farming systems function in isolation from markets, national and international political influence, and flows of capital, energy, and technology. Although most farmers still produce their own food, they also sell an appreciable amount into local and national markets. The use of non-local technology and inputs, such as fertilizers, pesticides, and mechanization, is ubiquitous. An increasingly important part of the flow of technological goods to farmers is improved crop varieties, selected from outstanding farmer varieties, developed and released by public crop improvement programs, or sold by private seed companies.

The economic, political, and technological integration of farming systems is generally seen as a positive step that enables development — increased production, income, and well-being (Hayami and Ruttan 1985). Nevertheless, this integration has several negative impacts. Farmers relinquish personal and local control of the production system as they become subject to market and political systems that are not always stable or positive for particular locations or commodities (Chambers 1983; Cernea 1985). Communities and farming systems may become more stratified economically. Increasingly uniform crops may be more vulnerable to pests and diseases. Local knowledge and crop diversity may be lost because of the diffusion of improved, exotic technology. These negative impacts may be ameliorated by policy and technological means, although the knowledge and ability to manage the negative impacts of change are often underdeveloped. Nevertheless, it is important to note that lack of socioeconomic integration also carries potentially serious negative impacts, especially given population growth.

Cultivar diversity in association with wild or ancestral crop species is linked to crop domestication and, most importantly, a broad base of genetic resources that may be useful for crop improvement. The loss of crop varieties from centers of diversity causes genetic erosion or a loss of genetic resources — a negative consequence of agricultural development. Natural historians and biologists have long recognized that particular areas harbored unusually
diverse and rich stores of crop germplasm (Harris 1989). One contribution of N. I. Vavilov (1926) was to perceive that these stores were important resources for crop improvement. Shortly after Vavilov’s observation, it was noted that these concentrations of crop germplasm were vulnerable to loss, as technological and economic change occur (Harlan and Martini 1936). Once the stores of crop germplasm were identified, a worldwide effort was initiated, first to sample and then to conserve the genetic diversity of major food staples (e.g., rice, wheat, maize, potato, cassava, sorghum, millet, barley, common bean, soybean). The conservation effort focused on preserving crop germplasm that is held in the thousands of distinct crop varieties or cultivars. By 1980, a large portion of the estimated diversity of major staples had been collected for preservation in ex situ facilities — gene banks, botanical gardens, and working collections of crop scientists.

During the establishment of the current gene conservation effort (1970-1980), in situ conservation was perceived as a possible alternative strategy for conserving crop germplasm, yet it was dismissed for several reasons (Frankel 1970). Most importantly, it was assumed that progress in achieving economic development in diverse agricultural systems inevitably requires the replacement of local crop populations with improved ones. Because genetic diversity in crops is associated with traditional agricultural practices, it is also linked to underdevelopment, low production, and poverty. The positive relationship between crop diversity and poverty is seemingly confirmed by the fact that agricultural development in many places and at different times occurred with the replacement of local and diverse crops, for example, in the hybrid maize revolution in U.S. agriculture between 1920 and 1950 (Cochrane 1993). A corollary of the relationship between diversity and poverty is that conserving traditional crops and their genetic diversity on-farm is tantamount to trying to stop agricultural development. Another reason for rejecting in situ conservation is the assumption that farmers who grow traditional crop varieties would require a direct monetary subsidy to continue this practice once improved varieties become available. Such subsidies are not only expensive but also unreliable and difficult to manage for any length of time. Finally, crop scientists who promoted conservation were not interested in conservation alone but also in using genetic resources for crop improvement. As long as breeders’ work is confined to experiment stations and laboratories, genetic resources that remain in farmers’ fields are not directly useful for crop improvement.

Several decades of collection and gene bank storage of crop genetic resources and research on agricultural change under modern conditions have changed the views that led to the dismissal of in situ conservation in favor of ex situ methods (Maxted et al. 1997a). One important shift in attitudes is the view that in situ and ex situ methods are no longer perceived as exclusive alternatives to each other. Today, they are seen as complementary approaches rather than as rivals. There is recognition that these methods address different aspects of genetic resources, and neither alone is sufficient to conserve the total range of genetic resources that exist. Second, it is evident that
traditional agriculture and genetic diversity are not inexorably linked and that agricultural development is not incompatible with the on-farm maintenance of diversity. Third, a variety of methods, apart from direct financial subsidies, are available to promote the maintenance of crop genetic resources by farmers.

Five reasons can be cited for promoting in situ conservation of crop genetic resources:

1. Key elements of crop genetic resources cannot be captured and stored off-site.
2. Agroecosystems continue to generate new genetic resources.
3. A backup to gene bank collection is necessary.
4. Agroecosystems in centers of crop diversity/evolution provide natural laboratories for agricultural research.
5. The Convention on Biological Diversity mandates in situ conservation.

**Key elements maintained by in situ conservation**

The complementarity of in situ and ex situ conservation is based on the recognition that crop genetic resources involve more than the alleles and genotypes of crop populations. Besides the genetic raw material of landraces, crop genetic resources also comprise related species, agroecological interrelationships, and human factors. Wild and weedy relatives of crops, as well as perennials and species with recalcitrant seeds, have been recognized as elements of crop genetic resources that cannot be contained in ex situ facilities. In addition, we now recognize that ecological relationships such as gene flow between different populations and species, adaptation and selection to predation and disease, and human selection and management of diverse crop resources are components of a common crop evolutionary system that generate crop genetic resources. The broader ecological view of crop genetic resources, then, includes not only alleles and genotypes of diverse crop populations but also wild and weedy crop relatives, predators and diseases, and systems of agricultural knowledge and practice associated with genetic diversity (Altieri and Merrick 1987).

While ex situ conservation is well suited to capture and store alleles and genotypes, it is not suited to the conservation of the other components of the agroecosystem that generate crop genetic resources. In situ conservation is specifically intended to maintain those components in living, viable agroecosystems. A critical difference between ex situ and in situ conservation is that the former is designed to maintain the genetic material in the state in which it was collected, to avoid loss or degeneration. In contrast, in situ conservation is meant to maintain a living and ever-changing system, thus allowing for both loss and addition of elements of the agroecosystem. Just as the conservation of natural habitats and wild species must be ecologically dynamic, we must accept that the in situ conservation of crops would fail and collapse if it attempted to stop change or to preserve
an agroecosystem in a particular state. Sources of change that can be expected and must be tolerated include the introduction of new crops and crop varieties; exchange of varieties between farmers and localities; the use of inputs to improve the productivity of land and labor, such as fertilizers and pesticides; and commercialization.

The goal of in situ conservation is to encourage farmers to continue to select and manage local crop populations. These embody not only diverse alleles and genotypes but also evolutionary processes such as gene flow between different populations and local knowledge systems such as folk taxonomies and information about selection for heterogeneous environments. The primary method for achieving this goal is to increase the value of local and diverse crop populations to farmers who might otherwise stop growing them. The objective here is to raise the value local and traditional crops so that it approximates the social value of genetic. How agricultural agencies and organizations can support in situ conservation will be described in the third section of this chapter and elsewhere in the book. Practices that would be detrimental to in situ conservation and should thus be discouraged include proscriptions on using particular technology or crops and obligations that bind agricultural credit and other support to the use of particular technologies or crops. An important corollary is that in situ conservation will not succeed through administrative coercion.

The dynamic aspect of in situ conservation is one of its most difficult attributes for planning and evaluation. Rather than presenting an easily quantified and non-moving target, such as the number of alleles or genotypes in a collection, in situ conservation concerns ecological relationships, knowledge, and cultural practices — elements that are difficult to quantify and likely to change over time. The success of in situ conservation cannot be judged only by the number of alleles or genotypes preserved. It might also be measured by the number of farmers within a target area or group who maintain local crop populations and manage those populations according to local criteria and practices. Alternatively, the success of in situ conservation might be measured by the use of local germplasm in breeding programs that result in new crops but do not replace the crop population of a region. Yet another measure might be the exchange and flow of farmer varieties within and among different communities.

Generating new resources

The second reason for promoting in situ conservation is that gene bank collections fail to capture genetic diversity and new resources that are generated after the collection has occurred. The fact that different sampling procedures have been used and documentation is poor in many collections (Frankel et al. 1995) suggest the possibility that much diversity remains uncollected. Estimates of the amount of possible landraces now collected indicate that most diversity of some crops has been captured in gene banks (Plucknett et al. 1987). Such estimates, however, are quickly rendered
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obsolete by continued crop evolution. Moreover, these estimates are derived from a consensus among scientists rather than from a thorough analysis of genes in the bank and genes in farmers’ fields. New resources become available because of a variety of mechanisms — mutation; recombination; gene flow between wild, weedy, and cultivated populations; somatic variation; and exchange from outside the collection region.

Backup to gene bank collection

*In situ* conservation of crop resources has been criticized because of its potential vulnerability to technological innovation and diffusion, economic and political change, and environmental factors (e.g., Hammer 1996; Zeven 1996). Unfortunately, all forms of conservation are vulnerable, and *ex situ* methods are subject to numerous risk factors — genetic drift within collections, loss of seed viability, equipment failure, security problems, and economic instability. Gene banks, like all human institutions, depend on volatile public and political support. Even large and prestigious institutions may suffer sudden reversals of fortune, endangering their collections. A number of observers point out that gene banks are usually inadequately funded, so that storage and regeneration facilities are limited, evaluation is partial, and equipment is obsolete or not adequately backed up. While the purpose of *in situ* conservation is not to preserve alleles and / or genotypes per se, regions where successful on-farm maintenance of genetic diversity occurs provide potential stores for re-collection of genetic resources.

Nevertheless, complementarity between *in situ* and *ex situ* conservation goes beyond a simple backup role for the former. *Ex situ* collections and their associated crop improvement programs give rise to one type of diversity, with selection directed by crop science and commercial and public breeding interests. *In situ* conservation can theoretically generate far more diversity and, perhaps more importantly, selection is directed by farmers in response to local needs and conditions. Thus, *in situ* maintenance of diversity might well produce crops that are adapted to conditions that are not included in the programs of commercial and public crop breeders. New crops resulting from *in situ* maintenance might be especially important to particular farm groups and areas, for instance, in marginal areas such as rain-fed conditions or uplands. *In situ* conservation thus complements *ex situ* maintenance by preserving a stock of genetic diversity that is relevant to farm sectors not reached by commercial and public breeding programs. In this way, *in situ* conservation helps to maintain not only key elements that are missed by *ex situ* methods but also aids in generating new material for areas that are often bypassed by crop improvement programs connected to *ex situ* facilities.

Laboratories for agricultural research

*In situ* conservation areas are important laboratories for two types of agricultural research. First, the understanding of crop evolutionary processes,
such as gene flow between wild and cultivated plants, is best carried out in centers of crop origins, diversity, and evolution. This research is critical not only to the study of domestication and crop evolution but also to identifying new sources of genetic material that has undergone natural and artificial selection. Second, agricultural science has become increasingly aware of the importance of broad ecological processes in the design of technology for sustainable production. Genetic diversity is usually seen as a key component of sustainable technology, to manage risk and reduce reliance on chemical inputs. Genetically diverse agroecosystems that harbor evolutionary processes such as gene flow between wild relatives and cultivated species, adaptation to coevolved pests and pathogens, and traditional knowledge systems and farmer selection offer a unique field laboratory to design and evaluate sustainable technologies.

Convention on Biological Diversity mandate

Finally, the Convention of Biological Diversity provides strong justification for sponsoring in situ conservation. This convention, originally negotiated in 1992 and ratified by over 160 countries, specifically includes crop genetic resources and indigenous knowledge as items that require in situ conservation. Article 2, in defining the use of terms on the convention, includes domesticated or cultivated species as part of biological diversity and genetic resources. Article 8 addresses in situ conservation and, within the article, 8(j) identifies “Knowledge, innovations and practices of indigenous and local communities embodying traditional lifestyles relevant for the conservation and sustainable use of biological diversity …” (Convention on Biological Diversity 1994:9). The Global Environmental Facility (GEF) of the World Bank, UNDP, and UNEP is the interim funding mechanism of the Convention of Biological Diversity. From its beginnings, the GEF has funded projects dealing with the in situ conservation of crop genetic resources, including wild crop relatives, in Turkey, Ethiopia, Peru, Lebanon, and Jordan (International Institute for Sustainable Development). Similar projects are under active preparation and review, for example, for Peru and for countries of the “Fertile Crescent” of the Near East.

The scope of in situ conservation

The need for conservation arises because of two fundamental changes in farming systems within regions of crop origins and diversity: (1) the integration of local systems into larger socioeconomic (e.g., market, political, cultural) and technological (e.g., information, inputs) systems, and (2) the growth of population both at the local level and above to magnitudes far in excess of any previous level. The predicted increase of the world’s population to 8 billion people by 2025 (Harris 1996) will require developing nations to double yields over present levels, and the means for achieving this are rarely available locally. Socioeconomic integration and population growth
represent a sort of continental drift for agricultural evolution, inducing changes that are long term and irresistible.

The production increases required to meet expected population thus inevitably result in the direct competition between local and exotic knowledge, inputs, and crops. Previously, this competition has provoked genetic erosion or the loss of genetic variability in crop populations. The magnitude of the forces behind genetic erosion suggests that it is not a process that can or should be reversed on a wide scale. *In situ* conservation is very likely to be frustrated and fail if it sets as a goal the reversal of the historic and universal trends of integration and economic and technological transformation that have caused genetic erosion in the first place.

Rather, the purpose of *in situ* conservation programs and projects is to conserve specific agroecological, cultural, and biological processes in specific localities so that the historic processes and ecological relationships of crop evolution remain viable therein. In other words, *in situ* conservation is not a sector-wide strategy for a nation’s agriculture but one targeted to a few locations. On-farm conservation is not meant as an alternative to agricultural modernization nor is it appropriate to all farmers.

*In situ* conservation projects imply the selection of specific areas and groups of farmers as participants. While the selection process necessarily involves some centralized decision making, determining size and location of participation for on-farm conservation also requires a high degree of decentralization and exchange between scientists, government officials, and farmers. Possibly, participation in *in situ* conservation projects can be driven by farmer interest rather than by area or location, especially in areas where the ecological and crop information is lacking. Determining the scope of *in situ* conservation requires us to address several criteria: the crop species to be conserved, the physical size of the conservation program, the location and distribution of conservation target areas, and the number of farms and communities that are included. Answering the questions about scope, therefore, involves both biological sciences (e.g., genetics, ecology, population biology) and social sciences (e.g., anthropology, economics, geography). Besides daunting technical issues in determining the scope of *in situ* conservation, financial, institutional, and political factors are also likely to have weight.

Determining the physical size, location of areas, and numbers of farmers of an *in situ* conservation program requires analysis in both the biological and social sciences, and the integration of these fields. One reason for focusing on a single crop species, rather than a complex of crops in a single farming system, is to make this research more feasible and tractable. The purpose of *in situ* conservation, however, is to maintain ecological relationships within centers of crop genetic diversity — within crop populations, between crops and other populations (e.g., wild and weedy relatives, pests and pathogens), and between farming communities and their local crop populations. Because *in situ* conservation concerns itself not only with crop diversity but also with ecological relationships and human factors, determining the scope depends on both population criteria and on human ecological criteria.
Population criteria that are germane to planning in situ conservation are similar to sampling design issues discussed by population biologists (e.g., Marshall and Brown 1975) — the measurement of variation and the number of populations to be sampled. Two critical population parameters are identified by Marshall and Brown (1975): (1) the extent of genetic divergence among populations and (2) the level of genetic variation of a population. Like collectors for ex situ collections, planners for in situ conservation will be concerned with these parameters in selecting target areas. Marshall and Brown (1975) describe divergence among populations according to frequency and distribution of alleles, leading to four different types of alleles, portrayed in Figure 1.1. The critical target for collection is alleles that are locally common. Populations with locally common alleles are thus primary targets for collection and conservation. Common, widespread alleles are likely to be found wherever a crop is grown and rare alleles are hard to capture, given the limits of collecting. These same guidelines form the first criteria for determining the number of populations that should be targeted for in situ conservation. Surveying national collections for distribution and frequency of alleles of target species will be the most direct method of determining the number and location of populations to be considered for in situ conservation.

![Distribution diagram](image)

**Figure 1.1** Genetic divergence among populations.

The number of ecological criteria is potentially very large and not as easily ranked as the population criteria discussed above. Limited research on these criteria in relation to crop diversity poses immediate problems. Three ecological criteria are identified as being critical to crop diversity and evolution — the presence of wild crop relatives, environmental heterogeneity, and seasonality (Hawkes 1983). Environmental heterogeneity is indicated by such variables as altitude variation and/ or a diversity of soils and vegetation biomes within the sample region. Environmental heterogeneity often implies mountainous terrain, a fact that is reinforced by the location of many crops' centers of diversity in such terrain.
Social criteria are equally as important as population and ecological criteria, but they are also numerous and difficult to assess because of their variability and the possibility of rapid social and cultural change. Nevertheless, social scientists have stressed a number of criteria that are associated with the maintenance of crop diversity. Cultural autonomy in terms of local language emphasis and economic autonomy in terms of orientation toward subsistence production are often cited (e.g., Brush et al. 1992; Zimmerer 1996). Subsistence orientation is also expressed in such variables as commercialization, use of purchased inputs, amount of off-farm employment, distance from markets, and access to agricultural extension services.

The population, ecological, and social criteria discussed above can be put into a single matrix that is helpful in determining the size and location of in situ conservation areas, shown in Figure 1.2. Here, ecological criteria are expressed as complexity. Places where altitudes, soils, and biomes are varied with seasonality and the presence of wild crop relatives would be judged maximally complex, while locations without these would be classed as having limited complexity. Likewise, cultural autonomy and subsistence orientation can be expressed as local vs. non-local social integration, an idea that is described as level of sociocultural integration by anthropologists (Steward 1955).

As indicated in Figure 1.2, the selection of locations using ecological and social criteria draws our attention to one type of location, with local sociocultural integration and ecological complexity. These selection criteria can then be weighed against two other criteria that are essential in identifying sites for in situ conservation: crop population criteria and logistical criteria. The selection of regions for an on-farm conservation program might begin with consideration of the population, ecological, and social criteria listed in Figures 1.1 and 1.2 and with consideration of the logistics of the regions. Logistical criteria — physical and social access to the farm region — are also necessary for site selection and scope of on-farm
conservation projects. Figures 1.1 and 1.2 can also be used for selecting among sites that are logistically equivalent.

**Promoting on-farm conservation**

As noted above, the goal of *in situ* conservation is to encourage farmers to continue to select and manage local crop populations, and one method for reaching this goal is to increase the value of local and diverse crop populations to farmers who might otherwise stop growing them. To increase the value of local crop populations and management practices, conservationists must understand the different values that local crops hold for farmers as well as the ways in which changing social and technological conditions will affect those values.

**Valuation**

Value is difficult to assess because of its inherent subjectivity and because different types of values exist. Value of particular local cultivars is most easily understood when viewing the selection of individual varieties, although crop diversity may be an object in itself. For instance, research on potato landraces in Peru shows that Andean culture values diversity as such and partly explains why so many potato varieties are kept in a farming system where environmental and agronomic factors do not explain diversity (Brush 1992; Zimmerer 1996). It is important to stress that farmers themselves may not value crop genetic resources directly but rather indirectly, by valuing practical and perhaps aesthetic attributes of the crop populations which embody crop genetic resources. Three types of value can be distinguished: direct, indirect, and option value. The first type, direct value, is the most obvious and critical to farmer selection, followed by option and indirect values.

Direct values refer to the harvest and use of crop varieties as part of a noncommercial, commercial, and/or industrial process. Direct values for specific varieties or groups of varieties include the agronomic or environmental assets for production as well as consumption benefits. This type of value is most likely to be recognized and articulated by farmers. Examples of production assets provided by diverse varieties in the farm store include the ability to yield well in distinct environments, as defined by soil classes, altitudes, moisture regimes, and pest and disease conditions. Research on variety choice has revealed that farmers maintain local crop varieties in part because they perform better than other varieties in marginal environments (Brush 1995). In addition to yield advantages of local varieties, farmers may also perceive a risk advantage if these varieties are more stable over time than non-local varieties. Diversity itself may provide yield stability and harvest security in the face of pests, diseases, competition, and unfavorable environments (Clawson 1985), but the relationship between diversity and stability is uncertain and cannot be assumed (Goodman 1975; Pimm 1986). Frankel et al. (1995:61) find support for the proposition that
heterogeneity per se is adaptive in offering resistance to pathogens, although the idea that the components of diverse landraces are interactive and stabilizing is not supported.

Direct values have been cited as the basis for maintaining diverse local crops in a number of case studies. In a thorough analysis of maize landraces in a village in southern Mexico, Bellon (1996) describes five concerns of farmers that account for infraspecific diversity — environmental heterogeneity, pests and pathogens, risk management, culture and ritual, and diet. These concerns vary among farmers and are influenced by such factors as wealth, land and labor resources, and government policies. No single variety can satisfy the concerns of all the farmers in the village, resulting in the maintenance of a complex population of maize landraces, even though modern varieties and commercial inputs are available.

Besides environmental and production concerns, consumption and other uses of crop varieties are direct values that also influence farmers to maintain local varieties. Consumption values may be associated with special qualities that can be found in local crop varieties but not in non-local ones. These qualities include taste, cooking characteristics, or better storage. Secondary products, such as straw for animal feed, is another quality that imbues local varieties with consumption value. Other consumption values that might be derived from local crop varieties include their significance as prestige, ritual, or gift items. Research among potato farmers in Peru revealed that local varieties were prized for their "floury" texture and were important as gifts and as a means to recruit labor (Brush 1992). In fact, local varieties in the central Andean highlands of Peru are referred to as "gift potatoes" (papas de regalo). The predominant role of potatoes in the diet of these farmers is reflected in social and cultural embellishments that reinforce the selection of local and diverse varieties.

Indirect values refer to environmental services rendered by crop varieties and benefits that result from biological resources without depending on harvest and consumption. For in situ conservation, the most important asset of local crop varieties is their indirect value in maintaining crop evolutionary relationships. However, these relationships may not be understood or observable to the farmers who maintain local crop populations. Diversity in one crop may, for instance, strengthen polycropping, the cultivation of other crops simultaneously and in the same field. Diversity in one crop may, therefore, add to diversity of others. An example is the association of traditional types of maize in Mexican agriculture with beans and squash, in the milpa system. Beans are beneficial because of their association with nitrogen-fixing bacteria, and both beans and squash add important nutrients to the diet, increasing the overall return to land and labor. Modern maize varieties in Mexico tend to be grown in monocropped fields.

Option values derive from future use of a resource (Krutilla 1967). The option value of a crop variety may be expressed as the desire to bequeath a family or cultural patrimony to future generations or as the potential of a variety to meet future demands or conditions of production. The idea that
local crop varieties represent a bequest to future generations has been noted in places where particular varieties are associated with a family lineage (Sutlive 1974) or as an expression of the farming knowledge and skill of parents (Zimmerer 1996). The potential value of varieties is likely to be recognized by farmers in areas where seed is produced and exported to other regions. Seed production areas have been described for potato farming in Peru (Brush et al. 1981), in Mexican maize agriculture (Louette et al. 1997), and in Thai rice agriculture (Dennis 1987). Such seed producing areas would appear to be excellent choices for in situ conservation programs. Areas that experience a high turnover rate of crop varieties might be appropriate for in situ conservation in connection with seed producing areas. Thai rice farmers, for example, were found to acquire and discard local varieties at very high rates. Using variety names as the basis for turnover, Dennis (1987) found that between 1950 and 1982, only 22 out of 122 rice varieties remained in the inventory of farmers in his study area. Selecting both seed producing and seed receiving areas puts both the generation of diversity and its selection into an in situ conservation program.

In situ conservation programs can most easily address the first (direct) and third (option) types of value. A variety of tools are available to increase the value of local crop varieties, and these tools can be roughly classified into two different categories — market methods and non-market methods. These methods are not unique to valuation of crop genetic resources but are drawn from other agricultural development programs and adapted to on-farm conservation.

**Market methods**

Two general market methods are available for increasing the direct and option values of local crops and management. One depends on developing market channels for local produce to increase the value of crops that have genetic resources. The other relies on legal mechanisms for restricting the supply of genetic resources, thereby raising their value for sale as genetic resources. The first method is a form of “green marketing,” similar to programs to develop products and markets from biologically important areas that depend on sustainable harvest rather than ecological conversion. The second method implies the creation or use of intellectual property for genetic resources that are found in farmers’ fields and farm stores.

The first approach to marketing may be useful in the marketing of landraces with crop genetic resources as consumer goods rather than as germplasm. Most farmers in the world are now involved to some degree in markets. Local and regional markets may be predominant to most farmers who maintain crop genetic resources, but these markets are usually linked to larger national and urban markets. It is not at all unusual to observe small amounts of local or traditional crops or their products for sale in large urban markets, often in the informal sector of those markets. For example, research on the production and use of diverse potato landraces in Peru found that
while local varieties were grown primarily for home consumption, a regular and appreciable amount of the production of local varieties was marketed (Brush 1992). Selected local potato varieties are also grown as commercial crops in fields of single varieties. These selected varieties are in much demand in urban markets, where consumers are willing to pay higher prices for these types than the higher yielding modern varieties. Urban demand contributes to the value Peruvian potato farmers in the highlands attach to potato landraces, helping to perpetuate the Andean chacra system that generates potato resources.

Marketing of products for environmental, humanitarian, and other social causes has proved to be a successful method to support public causes. "Green marketing" has been particularly developed (Wasik 1996; Peattie 1995). This type of marketing identifies the product with particular qualities of consumer interest, such as "organic" or "dioxin free," or with beneficial characteristics, such as "biodegradable" (Wasik 1996). Regulated labeling guarantees the products of this type of marketing in some places and for certain qualities. In many countries, there are systems to certify that organically produced food and products meet state standards to be labeled "certified organic." The growth of both national and international trade associated with environmental or social causes has been sustained and robust for a decade or more, showing that consumers are willing to support these causes.

A green marketing approach has not been directly attempted for increasing the value of landraces with crop genetic resource properties, but the strength of this market for other products, interest in preserving local culture, and the existence of a limited trade in landraces are positive indications. A stronger market for landraces can enhance their value without the cumbersome legal framework required of contracting and appellation. Developing the local and national market for landraces may be accomplished in several ways. The identification of special "niche markets" where landraces are in demand and information on the marketing channels that bring landrace produce to market can suggest bottlenecks and constraints to the market, for example, the lack of adequate storage and transportation facilities or information or inadequate supplies of landraces for market. Supplies may be inadequate because of the lack of credit or other inputs. Market constraints might be overcome directly as part of in situ conservation projects, for example, through supporting facility construction, promotional campaigns for landrace products, and helping to increase production of landraces for market. In situ conservation programs may also work with private manufacturers of food products to incorporate landraces and promote the products as part of national and international effort to meet conservation and development goals.

An example of a successful green marketing program for promoting in situ conservation has been established in the U.S. to maintain and utilize ancestral maize by Cherokee farmers in North Carolina (Brown and Robinson 1992). Maize landraces of the Cherokee had been greatly reduced by the diffusion of hybrid maize and contamination with commercial varieties.
Maize scientists located remnant populations on a few farms and in collections. Through controlled genetic matings, Brown and Robinson (1992) were able to reestablish pure Indian flour maize, which is now grown and marketed by the Cherokee Boys Club in North Carolina.

One approach that might be applied to increasing the value of local crops through the market is the appellation or certification system of restricted labeling. Appellation relies on legal enforcement, on market demand, and willingness to pay additional costs for the guarantee of the appellation. The appellation system is well developed for high quality food products in Europe, for example, for wine, cheeses, and meats (Bérard and Marchenay 1996). To date, the appellation system is based on geographic location or manufacture, to ensure quality and authenticity. In at least one instance, however, a certification system has been developed to guarantee the origin of plants (Meilleur 1996).

It is also possible that an appellation or certification can be attached to genetic resources for the purpose of financing in situ conservation. Crop genetic resources with diversity and evolutionary potential might be covered by an appellation system that could designate crop genetic resources from particular regions. This system might succeed if seed companies or other “users” of genetic resources accepted the social obligation to underwrite in situ conservation as they seek to acquire crop genetic resources. Nevertheless, the limits to a market for crop genetic resources which affect contracting for biological prospecting are also likely to be detrimental to a market for crop genetic resource appellation. There is currently no national or international market for crop genetic resources, and the crop breeding industry is not likely to generate a market. Contracting for genetic resources and labeling for appellation are, therefore, unlikely to be the first or most useful market methods to increase direct and option values of local crops. The transaction costs of establishing and maintaining legal mechanisms to increase the value of local crops are probably high and above the potential market price of crop genetic resources.

The second general market method for increasing the value of local and traditional crops involves the direct sale of genetic resources, either under contract or as intellectual property. Contracting for “biological prospecting” has been used in a limited way for pharmaceutical products (Reid et al. 1993; King et al. 1996), and similar contracts for crop genetic resources from functioning agricultural systems may be possible. Besides the legal framework of contracting, these agreements also involve intellectual property and sharing royalties that derive from the resources (Gollin and Laird 1996). The value of a contract to a farming community is commensurate with the exclusivity that a community can claim for its genetic resources. Given the open exchange of seeds that pervades agriculture, efforts to claim and defend exclusive ownership over genetic resources will be extremely difficult and therefore expensive. The likelihood of contracting for crop genetic resources is also greatly reduced by the existence of large public collections which provide crop germplasm without charge and with information that is usually not available directly from
farmers. Moreover, many seed companies rely on their own working collections and on breeding material from other public and private agencies. The demand for germplasm from farmers’ fields is, therefore, likely to be small and unable to generate sufficient commercial demand to finance conservation (Brush 1996). Surveys of breeders and breeding programs suggest that this is generally the case (Goodman 1985; Peeters and Galeway 1988; Marshall 1989; Rejesus et al. 1996).

Non-market methods

The direct and option value of diverse local crops can also be increased by methods that do not rely on the market. Two non-market approaches have been developed for promoting in situ conservation: (1) educational or promotional campaigns and (2) increased use of local crop resources and farmer participation in crop breeding and improvement programs.

In the Peruvian Andes, a seat of great crop diversity, governmental and non-governmental organizations have sponsored a visible and popular system of “diversity fairs,” which bolster the value of local crops and promote conservation. Farmers from different villages assemble and display the diversity of local crops grown in their villages. Tubers are especially prominent — potatoes (Solanum spp.), oca (Oxalis tuberosa), mashua or añu (Trapaeolum tubersum), olluco (Ullucus tubersus), achira (Canna edulis), arracacha (Arracacia xanthorrhiza), and yacón (Polymnia sonchifolia); but native and introduced cereals, legumes, fruits, and vegetables are also displayed. Natural pride in showing and interest in observing diversity are sufficient to stimulate enthusiasm for the diversity fair. The promoters have also found that public gifts, such as materials for school construction or repair, add to the effectiveness of the diversity fair. Diversity fairs are part of a broader set of activities to promote and enhance the production of local crop varieties, including information on cultural practices to improve production and the development of markets for selected local potato varieties.

Perhaps the most important strategy for increasing the value of local crops is to use them as the basis for crop improvement programs, especially with the participation of farmers who will use the results. This approach is referred to as “Participatory Plant Breeding.” Participatory plant breeding is defined as the formalized cooperation between farmers and plant breeders in such activities as identifying crop improvement needs and priorities, selecting varieties, and evaluating varieties (Eyzaguirre and Iwanaga 1996). The in situ conservation aspect of participatory plant breeding is to offer farmers a viable alternative to using exotic crops and varieties in their quest to increase production or income. Development of local varieties and populations through procedures such as mass selection may be especially suitable for marginal environments where conventional breeding has had limited success. Participatory plant breeding thus provides not only a context for in situ conservation but also one to work in environments where normal crop improvement has been frustrated.
Two distinct levels of participatory plant breeding are distinguished in the literature. Participatory plant breeding is defined as the selection by farmers of "genotypes from genetically variable, segregating material," while participatory varietal selection is the "selection by farmers of non-segregating, characterized products from plant breeding programs" (Whitcombe and Joshi 1996). Participatory plant breeding thus means farmer participation is selection at the F2 level and above, while participatory varietal selection means farmer participation at the Fs level and above. Actually, most proponents of participatory plant breeding refer to what Whitcombe and Joshi (1996) define as participatory varietal selection (e.g., Berg 1996; Eyzaguirre and Iwanaga 1996; Weltzien et al. 1996). A smaller group proposes participatory plant breeding rather than participatory varietal selection, involving cooperation between farmers and breeders from the early stages of selecting segregating populations (e.g., Sperling et al. 1993; Ashby and Sperling 1995; Ashby et al. 1996).

Both participatory plant breeding and participatory varietal selection are likely to have negative impacts on diversity of landraces, because both methods are intended to change local crop population structure to make it higher yielding. Nevertheless, participatory plant breeding is likely to be more beneficial for conservation goals because it works with variable, segregating material that is derived from or similar to material already in the local farming system. Participatory varietal selection, on the other hand, is likely to be negative for conservation goals because it is based on replacement of local populations with new and less variable ones from breeding programs.

**Institutional issues**

This chapter has affirmed that *in situ* conservation is complementary to *ex situ* conservation and that its scope should be modest and specific rather than system-wide for agriculture in less developed countries. The remaining institutional issue is legal — the ownership of and compensation for genetic resources, local knowledge, and new plant varieties. A longstanding debate about "Farmers' Rights" contrasts the interests of industrial countries that use genetic resources against the interests of non-industrial countries that produce them. Industrial countries are concerned with access to genetic resources and with protecting intellectual property that they have recognized. Non-industrial countries are interested in sharing the financial and technological benefits derived from using genetic resources. Conflict between these two parties surrounds the granting of intellectual property, compensation for resources normally considered to be public goods, and the ownership of resources already collected. Because *in situ* conservation provides a pool of genetic resources for future collection, these conflicts necessarily arise.

Biological resources and indigenous knowledge have conventionally been collected under the principle of common heritage (Brush 1996; Fowler
and Mooney 1990). This principle defines genetic resources as public domain goods, like products of nature, scientific theory, and folk knowledge. Public goods are defined by the quality of non-competitiveness — one person’s use of elements within the public domain does not deprive use to others. Public goods, however, can be removed from the public domain through intellectual property.

Although public goods are “free,” they may involve costs — for example, the cost of keeping air and water clean. One problem with public goods is that the costs of maintaining them are difficult to calculate because market pricing is not possible without private or exclusive use provisions. Another problem is that individuals who are directly involved in producing or maintaining public goods may not be fairly compensated. Thus, farmers who soundly manage hillside fields and pastures may not be rewarded for the clear water flowing off their farms, nor are they compensated for protecting water supplies. Likewise, farmers who produce crop genetic resources are not compensated for their costs in maintaining them.

The difference between the social and private values of public goods is problematic because individuals may not have sufficient personal incentive to maintain socially valuable goods, such as clean water or genetic resources. Theoretically, the deterioration of public goods, such as water pollution or soil erosion, is attributable to the imbalance between private and social values of public goods (Sedjo 1992; Vogel 1994). In the case of crop genetic resources, the loss of genetic diversity, or genetic erosion, is analogous to the loss of topsoil from common pastures. In each of these examples, farmers receive little reward for producing socially beneficial goods or compensation for the costs of producing or maintaining those goods.

The genetic resources of crop in centers of diversity illustrate the problems of estimating and rectifying public and private values. Maize farmers in Iowa or Africa receive part of the public value of maize landraces cultivated by Zapotec farmers in Mexico, yet Zapotec farmers bear an uncompensated private cost for keeping maize landraces, the cost of forgoing alternatives to plant modern maize varieties or other crops, or to leave agriculture altogether. Moreover, the fact that seed companies and others in industrial countries can claim exclusive ownership of the results of their use of genetic resource seems unfair, especially because farmers provided the essential resources without compensation.

This chapter has argued that contracts for crop genetic resources are unlikely to generate financial rewards because of the large supply and small demand for them. These same financial constraints are likely to confront efforts by non-industrial countries and / or farmers to gain financially from a novel form of intellectual property, such as Farmers’ Rights. Moreover, there appears to be little opportunity to create a novel form of compensation to farmers. The strength of the movements to extend intellectual property to new geographic areas and to include plant materials has been reinforced and clearly demonstrated by the last (Uruguay Round) General Agreement
on Tariffs and Trade (GATT), with the agreement on Trade Related Aspects Intellectual Property Rights (TRIPs). Nations that do not have systems for intellectual property protection of plant varieties are obligated by GATT and TRIPs to create them, and both the prevailing legal models and political pressure favor conventional Breeders' Rights rather than Farmers' Rights. The international system of intellectual property appears to be moving in the direction of creating more stringent and uniform standards, a direction away from defining novel rights such as Farmers' Rights.

Nevertheless, the issues of ownership of crop genetic resources and compensation to farmers for maintaining and providing crop genetic resources are widely discussed among donors, non-governmental organizations, conservation agencies, and governments. The issues of ownership and compensation are necessarily addressed by national legislation and policy processes, including international treaties and trade, that extend far beyond the purview of in situ conservation. The planning and implementation of in situ conservation must, however, be cognizant of these policy issues and can address them in a limited way by recognizing the contributions of farmers in providing genetic resources and affirming the need to include these farmers as active participants in the worldwide conservation effort.

Conclusion

This chapter has addressed four major questions that confront any program for in situ conservation of crop genetic resources. There are no general or definitive answers to these questions; rather, answers must be context specific, to the country, region, crop, and farming system. The approach here has been to identify guideposts for answering these four questions at the national and local levels. The past decade has seen a burgeoning of research in the ecology and biogeography of crop genetic resources in several countries and for different crops. This research has prepared us to answer these questions, but the novelty of this area of research, its interdisciplinary nature, and the complexity of the topic make it difficult to find ready answers to the questions posed at the beginning of this chapter. In trying to answer these questions, however, agricultural researchers and their farmer partners have taken the first strides in implementing in situ conservation.

References


Genes in the field: On-farm conservation of crop diversity


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