A Training Guide for *In Situ* Conservation On-farm

Version 1

D.I Jarvis, L. Myer, H. Klemick, L. Guarino, M. Smale, A.H.D. Brown, M. Sadiki, B. Sthapit and T. Hodgkin

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IPGRI is a FUTURE HARVEST Centre

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Preface

Objectives of this guide

This manual is intended for national programmes interested in supporting *in situ* conservation of agricultural biodiversity maintained on-farm by farmers. It was written to provide a range of actors, including Ministries of Agriculture and the Environment, universities, research and extension institutions, non-government organizations (NGOs), and community based groups, with a comprehensive view of factors involved in designing and implementing a programme to support the *in situ* conservation of crop genetic diversity on-farm.

In situ conservation on-farm is a diverse and complex topic, and as a result any training guide can not cover every detail of the disciplines involved. Instead, this guide is geared to give national programmes basic technical skills and tools to build institutional capacity and partnerships to implement an on-farm conservation programme. It discusses the information necessary and the practical steps for the implementation of on-farm conservation, as well as the importance of such an initiative. Equipped with the baseline information from this guide, the reader should then be able to identify and access more detailed information on specialized topics.

Who should use the Training Guide?

Those working toward the objectives of:

- Expanding the mission of a national PGR conservation programme beyond *ex situ*
- Linking farmers into national conservation and breeding efforts
- Designing total agroecosystem conservation programmes
- Improving small farmers' livelihoods through the use of local crop resources
- Identifying national centres of high crop genetic diversity
- Increasing agricultural production using local crop genetic resources.

Such an audience may come from national agriculture research and breeding programmes, universities and research centres, extension services, NGOs and other organizations working in plant genetic resources, sustainable agriculture and rural development.

It is assumed that the people using this guide will be part of, or collaborating with, a national plant genetic resources system with existing *ex situ* conservation programmes, who wish to expand their conservation options to include supporting *in situ* conservation of crops on-farm. As *in situ* conservation involves the linking of diverse disciplines, some of which are not involved in the typical *ex situ* activities which have been the focus of many national plant genetic resources conservation programmes in the past, we envision that this guide will help a country include on-farm conservation as a national-level initiative, although partners will range from local to international institutions.

Organization of the Training Guide

Chapter 1 introduces *in situ* conservation on-farm, detailing why it is important and how it differs from *ex situ* conservation strategies. The following five chapters present an overview of the types of information necessary in the design of an on-farm conservation programme. Chapter 2 discusses the "human" side of crop genetic resources management, including the social, cultural, and economic influences on **farmer decision-making**. Chapter 3 covers **agroecological** factors and their role in shaping crop genetic diversity. Chapter 4 highlights the importance of farmer selection of **agromorphological characteristics** in the cultivation of intraspecies crop diversity and the measurement of the characters through field and lab trials. Chapter 5 covers the role of **crop population genetics and breeding systems** in on-farm conservation. **Seed systems**, including supply and storage, are discussed in Chapter 6.

The next four chapters focus on the practical design and implementation aspects of on-farm conservation. Chapter 7 discusses the national institutional and disciplinary frameworks necessary for the creation of an on-farm project, based on partnerships between diverse personnel and institutions. The process of implementing research and conservation by diverse disciplines and documenting the results for use by managers, policy-makers, and communities is detailed in Chapters 8 and 9. Potential strategies to support farming systems engaged in conservation are discussed in Chapter 10.

The disciplines referred to in the Guide range from genetics to ecology to anthropology, and topics covered include sampling, data analysis and participatory methods. Science, project management and development are all involved. This Guide only presents the most basic and essential concepts. Examples illustrate key concepts throughout the text, drawn from either the countries participating in IPGRI's Global *In Situ* Conservation of Agricultural Biodiversity project or other PGR research or conservation projects worldwide. Suggested recommended reading points the reader in the direction of published material to broaden knowledge in each area.

In a classroom setting, we anticipate that participants will enhance the course with their own disciplinary backgrounds. We hope that the users will incorporate examples from their own experiences into the Guide where relevant and provide feedback of their results to the authors at IPGRI.

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Chapter 1 Introduction

1.0 Objectives of this chapter

By the end of this chapter, the reader should have an understanding of:

- Basic terminology and concepts related to on-farm and *in situ* conservation
- Why on-farm conservation is important
- How on-farm conservation relates to other approaches to pgr conservation.

1.1 *In situ* conservation on-farm

In situ conservation on-farm, sometimes referred to as "on-farm conservation," has been defined as "the continuous cultivation and management of a diverse set of populations by farmers in the agroecosystems where a crop has evolved" (Bellon *et al.* 1997). On-farm conservation concerns entire agroecosystems, including immediately useful species (such as cultivated crops, forages and agroforestry species), as well as their wild and weedy relatives that may be growing in nearby areas. Within this definition, it is possible to identify a wide range of objectives that may shape an on-farm conservation programme. These include:

- To conserve the processes of evolution and adaptation of crops to their environments
- To conserve diversity at different levels – ecosystem, species, within species
- To integrate farmers into a national plant genetic resources system
- To conserve ecosystem services critical to the functioning of the earth's life-support system
- To improve the livelihood of resource-poor farmers through economic and social development
- To maintain or increase farmers' control over and access to crop genetic resources.

1.2 Why *in situ* conservation on-farm?

Understanding *why we want to conserve genetic diversity on-farm* is important because it can help to identify the specific needs of an on-farm conservation programme. In addition to preserving plant genetic resources, on-farm conservation has six major benefits which make it unique among the options available to conservationists. These benefits relate not only to genetic diversity but also to ecosystem health and human well-being.

1.2.1 Conserving the processes of evolution and adaptation

The conservation of agrobiodiversity at all levels within local environments helps ensure that the ongoing processes of evolution and adaptation of crops to their environments are maintained within farming systems. This benefit is central to *in situ* conservation, as it is based on conserving not only existing germplasm but also the conditions that allow for the development of new germplasm. This idea of *dynamic conservation* extends to all aspects of the farming system, including the wild and weedy plant species that may interact with their cultivated relatives (Maxted *et al.* 1997).

1.2.2 Conserving diversity at all levels

In its maintenance of farming systems, on-farm conservation applies the principle of conservation to all three levels of biodiversity: ecosystem, species and genetic (intraspecific) diversity. In conserving the structure of the agroecosystem, with its different niches and the interactions among them, the evolutionary processes and environmental pressures that affect genetic diversity are maintained. When species – plants, animals and microbes – within the agroecosystem, and genetic diversity within the species are maintained, the diverse interactions of crop populations are preserved. Moreover, the conservation of these three levels of agrobiodiversity, and the various interactions that they support, contribute to the overall principle of ecosystem health in local farming systems.

1.2.3 Integrating farmers into the National Plant Genetic Resources Conservation system

Farmers are likely to know the nature and extent of local crop resources better than anyone through their daily interactions with the diversity in their fields. Given their expertise, incorporation of farmers into the national PGR system can help create productive partnerships for all involved. This integration can happen in several ways, including:

- Seeing farmers as partners in the maintenance of selected germplasm
- Establishing a national dialogue on biodiversity conservation, sustainable use and equitable benefit-sharing between farmers, genebanks and other partners
- Assisting the exchange of information with – and among – farmers from different sites and projects
- Farmers visiting genebanks or seeing demonstrations by genebanks
- Developing systems to make genebank material more easily accessible to farmers.

1.2.4 Conserving ecosystem services

On-farm conservation may be an important way to maintain local crop management systems for agroecosystem sustainability by ensuring soil formation processes, reducing chemical pollution and other waste emissions from farms, and restricting the spread of plant diseases.

1.2.5 Improving the livelihoods of resource-poor farmers

In situ conservation programmes also have significant potential to improve the livelihoods of farmers at the local level. On-farm conservation programmes can be combined with local infrastructure development or the increased access for farmers to useful germplasm held in national genebanks. Farmers will benefit from the continued agricultural diversity and ecosystem health that on-farm conservation supports. Local crop resources can be the basis for initiatives to increase crop production or secure new marketing opportunities. By building development efforts on local resources and through the empowerment of farming communities, they can lead to sustainable livelihood improvement. Resource-poor farmers, in particular, may benefit if development initiatives are not based on external inputs that may be costly or inappropriate for marginal agroecosystems.

1.2.6 Maintaining or increasing the control and access of farmers over genetic resources

On-farm conservation also serves to empower farmers to control the genetic resources in their fields. On-farm conservation recognizes farmers and communities as the curators of local genetic diversity and the indigenous knowledge to which it is linked. In turn, farmers are more likely to reap any benefits that arise from the genetic material they have conserved.

1.2.7 Public and private benefits (socioeconomic, ecological and genetic)

The importance of conservation of agrobiodiversity for the future of global food security lies in its potential to supply crop breeders' and other users' future needs for germplasm. On-farm conservation will allow the processes of evolution and adaptation to continue in crop plants, ensuring that new germplasm is generated over time, rather than limiting conservation to a finite set of genetic resources conserved in genebanks. In addition to these "public" genetic benefits, on-farm conservation can provide other benefits to society and to the farmers who maintain crop diversity. Society can benefit from the agroecosystem stability and decreased use of chemicals in agriculture promoted by the use of diverse local varieties. Socioeconomic benefits might include empowerment of rural communities. For farmers, on-farm conservation could serve to support cultural traditions, fit household labour and budget constraints, mitigate the effects of pests, diseases and other environmental stresses, and provide an insurance of new genetic material in the face of future environmental or economic change (see summary of benefits in Table 1.1).

Table 1.1. Some possible benefits accruing from on-farm conservation (adapted from Jarvis 1999)

	Economic and sociocultural benefits	**Ecological benefits**	**Genetic benefits**
Farmer household	• Manage risk and uncertainty • Fit different budget constraints • Avoid or minimize labour bottlenecks • Fulfil rituals or forge social ties • Fill nutritional needs	• Minimize use of chemical inputs • Soil structure amelioration • Manage pests and diseases	• Insurance against environmental and socioeconomic change
Society	• Global food security • Empowerment of local communities • Social sustainability	• Reduction of chemical pollution • Restriction of plant diseases • Regulation of hydrological flows	• Insurance against environmental change, pests and diseases • Use for the agricultural industry

1.3 Complementary strategies for conservation

In situ conservation is one of two possible strategies to conserve plant genetic resources. The *ex situ* approach to conservation includes methods such as cryopreservation, field genebanks, *in vitro* conservation and live plants in botanical gardens. Traditionally, *in situ* conservation has been used for the conservation of forests, wild species and areas valued for their wildlife or ecosystems, while *ex situ* conservation has been a predominant approach for the conservation of plant genetic resources for food and agriculture (Brown 2000). This is changing, however, as scientists recognize that each approach has particular advantages and disadvantages in the conservation of crop genetic resources.

1.3.1 Advantages and disadvantages of two strategies

***Ex situ* conservation**

Ex situ conservation has several important advantages for plant genetic resources conservationists. It is relatively easy to identify the genetic diversity conserved in a genebank or botanical garden, as the material is usually fully documented for the use of plant breeders and other scientists. Moreover, the genetic diversity maintained by these methods is directly controllable: as long as accessions are kept in suitable conditions and regenerated periodically, the likelihood of losing material is relatively low. In general, access is also relatively straightforward.

There are also disadvantages associated with *ex situ* conservation, however. Foremost among these is the inevitable fact that *ex situ* conservation removes genetic material from its natural environment. This halts the ongoing evolutionary processes which help to make landraces unique and adaptable to changing environments. Moreover, *ex situ* conservation can be a highly expensive endeavour, making it unsustainable in some settings. These costs affect the choice of which crops are collected for *ex situ* conservation, as only major crops or those of high economic value as determined by breeders and scientists are likely to receive attention.

***In situ* conservation**

There are significant advantages to *in situ* conservation. One is its conservation of both genetic material and the processes that give rise to diversity. The long-term sustainability of breeding efforts may depend on the continued availability of the genetic variation that can be maintained and developed in farmers' fields. In addition, *in situ* conservation can address the conservation of a large number of species at a single site, while this might be difficult for *ex situ* conservation owing to species' different requirements for *ex situ* maintenance (e.g. different seed storage behaviour, multiplication requirements, etc.). Under certain circumstances, depending on the crop or type of genetic resources to be maintained, interventions supporting their continuing evolution on-farm may be cheaper and more effective than *ex situ* storage. As Stephen Brush notes, "Potentially, far larger amounts of germplasm may be conserved on-site than is economically feasible off-site. While habitat protection does not *per se* facilitate the utilization of germplasm that is preserved, the long-term sustainability of breeding efforts may depend on continued availability of larger amounts of germplasm than can be effectively stored off-site" (Brush 1991:154).

However, there are also distinct problems associated with *in situ* approaches to conservation. It may be difficult for scientists to identify and access the genetic material being conserved, which can be a problem for plant breeders who wish to use material with particular characteristics for their work. Moreover, on-farm approaches rarely allow the close control of germplasm by scientists that *ex situ* approaches facilitate. The same factors that allow for dynamic conservation may serve to threaten the security of landraces. Genetic erosion can still occur due to unforeseen circumstances like war and natural disasters, while social and economic change may either foster or hinder on-farm biodiversity conservation over time. Indeed, one of the challenges of *in situ* conservation research is to evaluate how economic development is affecting farmer maintenance of diversity so as to account for this process in the implementation of conservation initiatives.

1.3.2 Integrated approaches to conservation

Because each conservation approach has distinct advantages and disadvantages, the most effective conservation system will incorporate elements of both. This combination is referred to as an integrated approach to conservation. Focusing on a single species, such an approach can combine any number of available *ex situ* and *in situ* conservation options. *In situ* conservation approaches should not be in competition with *ex situ* initiatives for resources or prioritization, but rather complement each other within institutional frameworks to maximize the sharing of information and the benefits of conservation (Brush 1991).

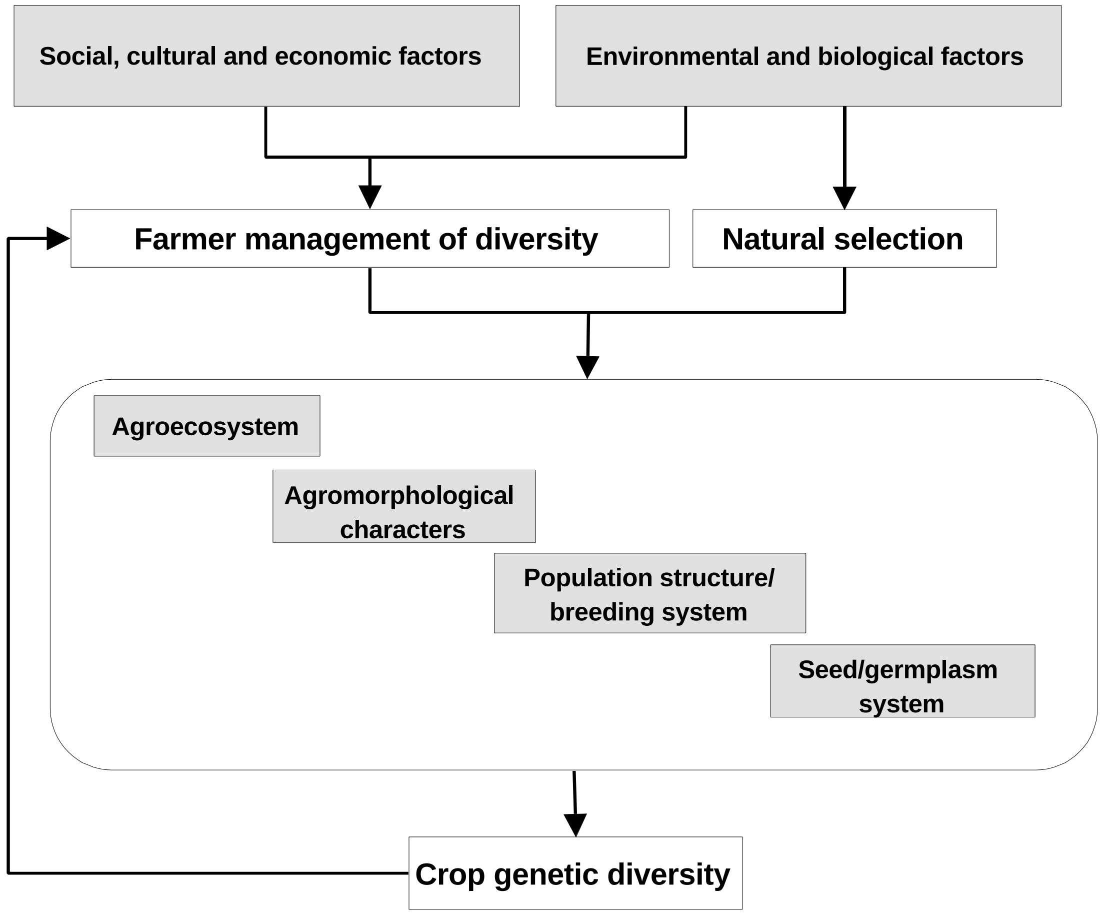
Any integrated conservation strategy should of course be guided by the objectives of the conservation. Some of the questions to address in the design of an appropriate integrated conservation strategy are shown below. This list of questions is not exhaustive, but it begins to address the factors that must be taken into account when developing an integrated approach to conservation.

1.4 Research into the scientific basis of on-farm conservation

Before implementing an *in situ* conservation programme, a thorough understanding of the factors that influence the level of crop genetic diversity on-farm is needed. While *ex situ* conservation is primarily a technical issue of how best to preserve germplasm, the conservation or erosion of genetic diversity in farmers' fields is shaped by a complex range of factors over time. These range from farmers' decision-making to local environmental change to interactions between and within crop populations. Research is required to answer the following key questions:

1. What is the amount and distribution of genetic diversity maintained by farmers over time and space?
2. What processes are used to maintain this genetic diversity on-farm?
3. What factors influence farmer decision-making to maintain diversity on-farm?
4. Who maintains this diversity on-farm (men, women, young, old, rich, poor, certain ethnic groups)?

Answering these questions will provide a scientific basis for the design of effective, long-term strategies to conserve crop genetic diversity on-farm.



Link between farmer decision-making, natural selection and measures of genetic diversity.

1.5 Terms

Accession: A plant sample held in an *ex situ* setting for conservation and use

Adaptation: The evolutionary process by which species change over time in response to their environment

Agroecosytem: A site of agricultural production, including all organisms and environmental factors within it, which functions with human assistance as a stable system with circular flows of material and energy (Gliessman 1998).

Agroforestry: The integration of trees and shrubs into agricultural practices

Agromorphological characteristic: A phenotypic trait of a plant, which may be morphological, agronomic or use-related, used by farmers or scientists to identify a crop variety

Biodiversity: The total variability between and within species of all living organisms (Friis-Hansen and Sthapit 2000).

Character: The phenotypic expression, as a structural or functional attribute of an organism, resulting from the interaction of a gene or group of genes with the environment (IBPGR 1991).

Characterization: Assessment of plant traits that are highly heritable, easily seen by the eye and equally expressed in all environments in order to distinguish phenotypes; contrasted with **evaluation.**

Conservation: The management of human use of the biosphere so that it may yield the greatest sustainable benefit to current generations while maintaining its potential to meet the needs and aspirations of future generations. Thus conservation is positive, embracing preservation, maintenance, sustainable utilization, restoration and enhancement of the natural environment. (Friis-Hansen and Sthapit 2000)

Cultivar: A cultivated variety of a domesticated crop plant; synonymous with **variety** (Friis-Hansen and Sthapit 2000)

Evaluation: Assessment of plant characters, such as yield, agronomic performance, abiotic and biotic stress susceptibility, and biochemical and cytological traits, whose expression may be affected by environmental factors; contrasted with **characterization.**

***Ex situ* conservation**: The removal of germplasm from the place where it is found growing and storage off-site as seeds in a genebank, vegetative material in *in vitro* storage, or plant accessions growing in a botanical garden or field genebank.

Farming system: All elements of a farm that interact as a system, including people, crops, livestock, other vegetation, wildlife, the environment and the social, economic and ecological interactions between them (Friis-Hansen and Sthapit 2000)

Gene: The functional unit of heredity. A gene is a section of DNA that codes for a specific biochemical function in a living organism in a laboratory. (Friis-Hansen and Sthapit 2000)

Geneflow: The exchange of genetic material between populations. This may be used in the sense of plant reproduction (i.e. due to the dispersal of gametes and zygotes) or due to human influences, such as the introduction of new crop varieties by farmers.

Genepool: The total amount of genetic diversity present in a particular population.

Genetic diversity: The genetic variation present in a population or species

Genetic drift: the unpredictable changes in allele frequency which occur in populations of small size

Genetic erosion: Loss of genetic diversity between and within populations of the same species over time, or reduction of the genetic base of a species

Genetic resources: Germplasm of plants, animals or other organisms containing useful characters of actual or potential value (IBPGR 1991)

Genotype: The genetic composition of a plant, comprised of heritable traits.

Germplasm: The genetic material which forms the physical basis of heredity and which is transmitted from one generation to the next by means of the germ cells (IBPGR 1991)

High-Yielding Variety (HYV): A crop variety developed by modern plant breeders, designed to maximize yields (often in high-input conditions) at the expense of diversity or local environmental adaptation. HYVs are commonly promoted by agricultural development projects, and are often seen as threats to locally developed landraces of the same species.

***In situ* conservation**: "The conservation of ecosystems and natural habitats and the maintenance and recovery of viable populations of species in their natural surroundings, and, in the case of domesticated or cultivated species, in the surroundings where they have developed their distinctive properties" (Reid *et al.* 1993:305); *in situ* conservation of domesticated resources focuses on farmers' fields as part of existing agroecosystems, while other types of *in situ* conservation are concerned with wild plant populations growing in their original habitats (genetic reserves).

Inbreeder: A plant with a self-compatible reproductive biology; opposite of **outbreeder**

Indigenous Knowledge (IK): The understandings or traditions that exist in a local community

Landrace: a crop variety bred and cultivated by farmers and adapted to local environmental conditions.

Modern Variety (MV): A crop variety developed by modern plant breeders; synonymous with **high-yielding variety**

Natural selection: Is selection exerted by biotic and abiotic environmental factors and is the principal mechanism of evolution. It may act at the level of the gene, cell, clone, individual, population of species. (IBPGR 1991)

On-farm conservation: One approach to *in situ* conservation of genetic resources, focusing on conserving cultivated plant species in farmers' fields

Outbreeder: A plant with a self-incompatible reproductive biology; opposite of **inbreeder**

Phenotype: The sum of physical characteristics of a plant. A plant phenotype is the result of the interaction between genotypic traits and environmental conditions. This process is summarized by term *GxE interaction* (i.e. Genotype X Environment = Phenotype)

Population: A group of individuals of the same species living in the same geographic region (Gliessman 1998)

Selection: Any process, natural or artificial, which permits an increase in the proportion of certain genotypes or groups of genotypes in succeeding generations, usually at the expense of other genotypes (IBPGR 1991)

Species: A group of actually or potentially interbreeding natural populations which are reproductively isolated from other such groups (IBPGR 1991)

Variety: A subdivision of a species below subspecies and in classical taxonomy, a heterogeneous grouping, including non-genetic variations of the phenotype; synonymous with **cultivar** (IBPGR 1991)

Wild relative: A non-cultivated species which is more or less closely related to a crop species (usually in the same genus); it is not normally used for agriculture but can occur in agroecosystems (e.g. as a weed or a component of pasture or grazing lands)

Definitions of *in situ* conservation on-farm

- "*In situ* conservation of agricultural biodiversity is the maintenance of the diversity present in and among populations of the many species used directly in agriculture, or used as sources of genes, in the habitats where such diversity arose and continues to grow." (Brown 2000).
- "*In situ* conservation specifically refers to the maintenance of variable populations in their natural or farming environment, within the community of which they form a part, allowing the natural processes of evolution to take place." (Qualset *et al.* 1997).
- "*In situ* conservation refers to the maintenance of genetic resources in natural settings. For

crop resources, this means the continued cultivation of crop genetic resources in the farming systems where they have evolved, primarily in Vavilov Centres of crop origin and diversity.” (Brush 1991).

- “*In situ* conservation means preserving, in their original agroecosystem, varieties cultivated by farmers using their own selection methods and criteria” (FAO 1989; Bommer 1991; Keystone Centre 1991; in Louette and Smale 1996).
- On-farm conservation is "the sustainable management of genetic diversity of locally developed traditional crop varieties, with associated wild and weedy species or forms, by farmers within traditional agricultural, horticultural or agri-silvicultural cultivation systems" (Maxted *et al.* 1997).

What is a landrace?

“Landrace populations are often highly variable in appearance, but they are each identifiable and usually have local names. A landrace has particular properties or characteristics. Some are considered early maturing and some late. Each has a reputation for adaptation to particular soil types according to the traditional peasant soil classifications, e.g. heavy or light, warm or cold, dry or wet, strong or weak. They also may be classified according to expected usage; among cereals, different landraces are used for flour, for porridge, for “bulgur”, and for malt to make beer, etc. All components of the population are adapted to local climatic conditions, cultural practices, and disease and pests.” (Harlan 1975)

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Chapter 2 Social, cultural and economic factors and crop genetic diversity

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[1] Photo credits: Pp. 14, 16, 18, 24, 27: D. Jarvis; P. 16: J.-L. Chávez-Servia; P. 24: D. Hines.

2.0 Objectives of this chapter

By the end of this chapter, the reader should have an understanding of:

- Social, cultural and economic factors that shape farmers' decisions regarding crop diversity
- A way of testing relationships between these factors and on-farm diversity
- Some methods to assess the value of local crop diversity / populations for farmers and markets.

A challenge undertaken by on-farm conservation research is to quantify the effects of social, cultural and economic factors on farmers' actions with regard to the maintenance of crop genetic diversity. Understanding these relationships will provide insights into the conditions fostering landrace conservation and better enable the design of formal *in situ* conservation strategies. Social research investigates how people group together in institutions and organizations for collective action. Cultural research focuses on the customs and values through which a society or group defines itself. Economics deals with the decisions people make regarding the allocation and use of resources, based on their market and non-market values.

2.1 Social and cultural context

Social institutions and cultural traditions provide the context that shape farmer seed and crop management choices. Social and cultural factors influencing the decisions a farmer makes include his or her traditional practices, local ways of life, or the identity of the group to which he or she belongs. Anthropologists have long recognized the role of culture in determining the varieties farmers choose to grow and their spatial allocations.

The value of a landrace in the lifestyle or identity of a particular social group may encourage its maintenance. Landraces may have specific valued traits that cannot be obtained from exotic sources. Landraces may be valued because of their place in local traditions – for major events such as religious festivals and more everyday occurrences such as meals or medicinal practices requiring specific crop varieties. Often the consumption traits associated with certain landraces reflect the cultural importance of the dishes they are used to prepare. Brush (1995), Zimmerer (1996) and Gonzales (2000) have described the role of cultural preferences for diversity in the continuing cultivation of landraces.

Because of their use in particular foods and traditions, traditional crop varieties can play an important part in how a community, or a group within a community, perceives itself. This leads to a widely observed parallel between cultural diversity and crop genetic diversity. For example, ethnobotanist Hernández X. conceptualizes maize in the Americas as the "centre of a series of cultural traits illustrative of the interrelationships between man and plants" (1985:416). He explains both cultural and maize diversity as a function of the patterns of historical human migrations and of ecological variation within the Americas; maize diversity reflects cultural diversity and variation in cultivation, use, and ceremonial practices.

Social organization and institutions in a community influence farmers' access to and management of household and community level resources, affecting their actions regarding crop genetic diversity. **Land tenure** is a social institution that refers to the way land is distributed among people and the norms that regulate rights of access and ownership. The spatial distribution of cultivation across a landscape is influenced by tenure, as well as topography and the history of settlement. Land tenure and ownership systems vary between and within communities in terms of private or communal ownership, equability of distribution of land, size and number (fragmentation) of household land parcels, and intra-household access to land. A farmer's landholdings and how they are distributed in size and quality may influence his or her decisions about variety choice and the allocation of area among varieties. By determining population sizes and the propensity for geneflow, these in turn affect the allele frequencies on which measurement of crop genetic diversity is based.

In Ethiopia, a change in the land tenure system from communal to private ownership resulted in farmers' adoption of more sustainable land management practices, including terracing and aforestation (Omiti *et al.* 1999). Although these practices may not directly affect crop genetic diversity, they may have implications for the effects of land tenure on the crop and seed management practices through which farmers do shape agrobiodiversity on-farm.

Louette *et al.* (1997) found land access to be a significant determinant of farmers' seed sources in a maize-cultivating Mexican community. Sharecroppers and farmers with small landholdings consumed all or most of their maize crop each year and so had to obtain seed elsewhere each planting season. Consequently, farmers planting mostly their own seed cultivated on average twice as many varieties as those obtaining all of their seed from others.

The patterns of size and distribution of landholdings in a community also may be significant in biodiversity conservation through their influence on the way farmers structure their crop populations spatially. For example, Brush (1995) found that farmers' access to different types of plots promoted conservation by enabling farmers to conserve landraces in one plot, while utilizing modern varieties in the majority of their cultivated area.

2.1.1 Social roles and maintenance of crop diversity

Social and cultural contexts also shape the roles of different individuals or groups within a household or community, for example, based on gender, age or social status. These socially determined roles affect farmers' knowledge, actions and access to resources regarding the maintenance of crop diversity. Studying the relevance of these social roles to on-farm crop diversity will help us to understand who is involved in maintaining this diversity.

Age: Indigenous Knowledge, including knowledge of crop diversity, is often held by the older members of a community. This link can be a precarious one, as knowledge can be lost if elders do not pass IK down to younger generations. Although IK is often positively associated with age, the young may also have unique IK regarding crops and associated wild plants.

Gender: Gender is a particularly important social category relevant to crop diversity, particularly when it determines individuals' roles and responsibilities regarding crop and seed management. The knowledge held exclusively by women or men may vary between crops or even between different landraces within a species. These differences can result from varying uses, preferences or labour regimes associated with the sexes. Because of the gendered nature of IK, collecting data from both men and women, and keeping it in a disaggregated format, is of central importance to on-farm research.

Example: Gender and land use in Burkina Faso

The Burkina Faso component of the IPGRI on-farm conservation research project has identified differences in women's and men's land ownership and use. Men take responsibility for the main, family field, in which all household members work. In addition, men and women may have their own smaller plots, in which crops are grown for market sale. Women cultivate their own plots after the family fields have been tilled, where they grow ochra, peanut, voandzea, sesame and hibiscus. The cash generated by the sale of these crops is used by the women for household needs.

Source: Belem 2000.

Burkinabé farmer in her pearl millet field.

Wealth: The link between wealth and IK is variable. Depending on the ecosystem and local socioeconomic context, wealth can be either positively or negatively correlated with agricultural diversity. The wealthy may be able to afford to maintain landraces and associated knowledge for purely aesthetic reasons, such as the maintenance of tradition. At the same time, the poor may have special knowledge of the crop diversity adapted to marginal and low-input agroecosystems.

Example: Wealth status and maintenance of selected varieties in Nepal
Research from the Nepal component of the IPGRI *in situ* conservation on-farm project revealed wealth as an important socioeconomic factor affecting the rice varieties maintained by households in three ecosites in Nepal. While resource-poor households cultivate more coarse-grained, drought-tolerant varieties, resource-rich households grow high-quality varieties for premium market prices and special food preparations.

Resource-poor farmers in Nepal must start husking earlier in the season than wealthier farmers because of lack of adequate grain stores from the previous harvest.

Characteristics of selected varieties from Begnas ecosite, Nepal (Source: Rana *et al.* 2000)

Landraces/modern varieties (MV)	Socioeconomic variables	Agroecological features
Jetho Budo/Pahele	• Aromatic fine type with premium price in market • Grown by resource-endowed households • Grown in area = 0.12 ha/HH • Number of HHs growing = 53	• Grown under irrigated conditions • Mainly under high-fertility conditions • Productivity = 2.58 t/ha
Anadi	• Glutinous rice valued for preparing *Latte, Siraula* and *Khatte*[†] • Grown mainly by resource-endowed households • Possesses medicinal value • Grown in area = 0.02 ha/HH • Number of HHs growing = 99	• Grown under rain-fed conditions • Medium to high fertility conditions • Productivity = 2.40 t/ha
Mansara	• Medium coarse grain type • Grown mainly by resource-poor households under larger area than resource-rich HHs • Grown in area = 0.12 ha/HH • Number of HHs growing = 43	• Grown exclusively under rain-fed conditions • Drought tolerant • Mainly adapted to low-fertility conditions • Productivity = 1.74 t/ha
Kathe Gurdi	• Medium fine grain type • Grown by all resource groups but resource-poor grow in larger area than other groups • Grown in area = 0.1 ha/HH • Number of HHs growing = 47	• Grown under rain-fed conditions • Drought tolerant • Mainly grown under medium-fertility conditions • Productivity = 2.03 t/ha
Mansuli (MV)	• Medium fine grain type with good market price • Most commonly grown variety in Nepal • Grown area = 0.2 ha/HH • Number of HHs growing = 59	• Grown under irrigated and rain-fed conditions • Mainly grown under high-fertility conditions • Productivity = 3.35 t/ha

[†] Latte = Latte is prepared by soaking rice (de-husked) for about 12-24 hours then cooked in ghee or oil; sugar is added while continuously stirring. Unlike normal cooking of rice, no water is added while cooking Latte. It is mainly consumed during 'Saune Sakrati' – festival celebrated in the month of July and 'Pandra Poush' – festival celebrated in the month of December.
Siraula = Anadi rice (husked) is soaked then roasted till they are popped, which is left to cool followed by de-husking either by a huller machine or manually operated paddle pounder. Siraula is mainly consumed as snacks, or mixed with milk and then consumed to add taste.
Khatte = Khatte is prepared by light soaking rice (de-husked) in water then roasted. Khatte is also consumed as snacks.

Social status: Social status may be linked to wealth but also may merit separate consideration. Individuals or families with particular social or political status may exercise control over specific aspects of agriculture, such as the testing of new varieties, crop husbandry variables such as timing of harvest, etc. Individuals with specific ritual or cultural roles may have unique knowledge of crop diversity, as may farmers with expertise in the production of seed or other specialized tasks, regardless of wealth status.

Ethnicity: Ethnicity can be thought of as encompassing a range of social and cultural differences between groups. Ethnic groups are often associated with distinct traditions, histories and 'food culture' which can be a basis for the maintenance of local knowledge and diversity. Despite similar environmental conditions, different ethnic groups may cultivate distinct crop varieties, and possibly employ unique agroecological management approaches.

Example: Indigenous Knowledge and Ethnicity in a Tanzanian Village
Ethnicity and corresponding cultural history is a primary determinant of indigenous knowledge in Mkulula, Tanzania. Use and maintenance of sorghum diversity differs between ethnic groups, based on each group's historical subsistence strategies. Farmers of the Gogo tribe, who migrated to Mkulula from a traditional sorghum-growing region of Tanzania, cultivate more than twice as many landraces as do farmers of other groups. By contrast, the Bena and Hehe tribes are from areas where maize predominated, and the Masai people's livelihood was traditionally based on pastoralism. Accordingly, farmers from these groups now living in Mkulula cultivate fewer sorghum varieties than Gogo farmers.
(Friis-Hansen 2000)

Gender Analysis
Gender refers to the roles and social responsibilities in a specific cultural context, which are learned and changeable and may vary widely within and between cultures. Gender is not the same as sex, which refers to differences between men and women which are both biological and fixed.
Gender roles are learned behaviours in a given society, based on social conditioning about which activities are considered appropriate for males and which are appropriate for females. Gender roles and relationships are not fixed; they can and do change in response to changed societal conditions.
Gender analysis is a tool for discovering useful data about the characteristics of a population. It works by examining the activities, responsibilities, opportunities and constraints in the life of each member of the population, including the relationships between and among men and women. To give an idea of how it works, the key questions are: WHO does WHAT and WHEN, and under what circumstances? How are relationships among and between men and women changing? How do these changes affect the way women and men manipulate agricultural environments? (IPGRI 1991)

Example: Women's knowledge of food processing in the Milpa farming system, Yucatán, Mexico

Rural families like the Cuxim family in Yaxcabá, Yucatán survive thanks to traditional technologies for food preparation. The photograph shows 3 generations of women (grandmother, mother and daughter) preparing maize tortillas. Tortilla preparation can take up to 6 hours a day, including the grinding and processing of grain.

The social and cultural factors that shape individuals' roles and surroundings change **over time**. For example, restrictions associated with religious practices may be modified, armed conflicts may turn farmers into refugees, health education and other factors may alter preferences associated with the taste, texture or colour of food. As the traditional practices and local ways of life that provide the context for farmers' decisions change, so will the crop and seed management practices that affect crop genetic diversity.

2.2 Role of economic analysis in on-farm conservation

Economic analysis can contribute to the scientific basis of on-farm conservation because it can be used to study how to choose the best means of achieving a predetermined social goal. Value derives from human use, though "use" can refer to aesthetics, ecosystem support functions, or the recognition that genetic resources are mutable stocks that are important for the future of mankind. As the role of a crop in its agroecosystem is important for us to understand in studying genetic diversity, so is the farmer's place within a social and economic system. This is because the benefits of crop genetic resources, like other natural resources such as air and water, are shared with other people. The seed a farmer plants each year yields two types of value at the same time. The first, "private" value is the harvest the farmer enjoys. The second, "public" value is related to the germplasm from which future generations of farmers and consumers will benefit.

Ironically, some of the most genetically diverse plant populations of potentially great value to global society are grown by some of the poorest human populations in the world. As long as farmers themselves find it in their own best interests to grow these populations, both farmers and society will benefit at no extra cost to anyone. But to what extent do farmers have an "incentive" to keep growing them?

When we refer to farmers' "incentives" to grow crop populations, we mean the extent to which these populations provide the traits that satisfy farmers' objectives, as they define them. Since most small farmers produce food crops for their own consumption, these traits often include not only agronomic characteristics such as tolerance of biotic and abiotic stress, but also some consumption characteristics – such as their suitability for the preparation of special dishes that are "valued" in local communities. When markets are not well developed, the value of varieties is directly related to the extent to which they meet the needs of farm households. Even when markets develop, there may still be a number of attributes over which farmers define their needs that cannot be obtained through the market. In many areas of the world, markets are imperfect.

One hypothesizes that the changes that accompany economic development reduce the interest farmers have in growing diverse crop populations. As agriculture intensifies and becomes commercialized, farmers tend to specialize in the crops and varieties that they can sell for a profit on the market, gearing their choices toward the tastes and preferences of distant urban consumers and buying what they need for their own consumption. Farms become fewer and larger, and labour moves to urban areas. In some cases, specific government policies serve to encourage such changes.

Only some farmers will have the economic "incentives" to maintain diversity as the economic, social and cultural environment in which they grow their varieties changes. In an advanced, industrialized economy, and in the absence of special government programmes, we hypothesize that landraces will only be grown when they have unique qualities that urban consumers or export markets value, and only if these same qualities cannot be easily transferred into modern varieties. Where genetic diversity is considered to be important in a target area but farmers are revealed to have few social, cultural or market-based incentives to maintain it, then specific publicly funded initiatives may be needed. Public funds are those generated by taxes or donations, transferring income from one segment of the world population to another. Economists generally believe that these forms of interventions are more "costly" to society than market-based incentives.

These are general hypotheses that need to be refined and tested in each specific context. The first step in testing them involves relating indicators of economic change, market development and government policies to the prospects that farmers maintain genetically diverse crop populations. We discuss one way of testing this relationship below. Another step is to document how the populations we seek to conserve are valued—either by the farmers who produce and consume them or by the consumers who purchase them on the market; this topic is discussed in Section 2.4. These steps guide us toward the options that are appropriate in a given social, economic and biological context for "adding value" to the populations we wish to conserve. When we proceed to test these options, economic analysis can provide one among several possible indicators for assessing their success.

2.3 Factors influencing farmer variety choice

Farmers' decisions affect the genetic diversity of the crops they grow. The most visible decision, and that most extensively reported in the social science literature, termed **variety choice,** is the choice of how many and which varieties to grow and on what proportions of crop area. Empirical research has identified several major types of factors that influence the probability that landraces survive in a given area. The first set of factors relates to **agricultural intensification**, or technical change that increases output per unit of land. Modern varieties are one form of agricultural intensification. An example examining the relationship between agricultural intensification and variety choice is found in Bellon *et al.* (1998). The second set of factors is associated with **agroecology** (which is discussed in detail in Chapter 3). In extreme, heterogeneous and highland growing environments, traditional farmers' varieties are still more likely to be grown than modern varieties since the germplasm developed by centralized breeding programmes may not be well adapted to these marginal areas and their microclimates. The third set of factors, mentioned above, relates to the development of **market infrastructure**, or the integration of communities and individuals into markets for seed and crop output.

Farmers plant cold-tolerant alfalfa varieties adapted to the low winter temperatures of Morocco's Atlas Mountains.

Lack of access to markets owing to transportation constraints may be one factor affecting a farmer's choice of variety. This Nepalese farmer carries barley on foot in Jumla, Nepal.

Example: Agricultural intensification and variety choice
Bellon *et al.*'s (1998) comparison of rice farming systems in the Philippines reveals differences in farmers' use of landraces versus modern varieties based on agroecological conditions and levels of agricultural intensification. In upland and rain-fed lowland (less intensive) ecosystems, landraces persist in farmers' fields, while in the irrigated (more intensive) ecosystem, modern varieties have completely supplanted landraces. The opportunity cost of maintaining landraces thus increased with an agroecosystem's potential for intensification.

Any single variety typically has both desirable and undesirable attributes, and "no variety alone satisfies all of the farmers' concerns" (Bellon and Brush 1994: 202). In relatively few economic analyses of variety choice have **variety traits** other than yield and yield variance been considered, even though in many parts of the world, farmers still need to satisfy many of their requirements for food and feed from their own production. Some varieties produce higher ratios of fodder to grain than others, while others produce grain that is more suitable for on-farm processing or specialized dishes than others. A recent example of an attempt to incorporate variety traits in a variety choice analysis is given in Smale *et al.* (2000).

Example: Incorporation of variety traits into a variety choice analysis

Smale *et al.* (2000) analyzed farmers' decisions to allocate maize area among landraces in southeast Guanajuato, Mexico, as related to variety attributes in addition to household, agroecological and market factors. Hypothesis tests demonstrated the importance of variety attributes such as suitability for preparation of certain foods, relative to price and costs or socioeconomic characteristics of the household, in determining the percentage of maize area that farmers allocate to a variety. This makes sense given that costs and returns differed little among the landraces—less so, for example, than would be apparent between landraces and modern varieties.

These external factors condition or limit the decisions made by individual farmers – they are beyond their immediate control. Hypotheses related to intensification, agroecology and market development can be tested only when there is observable variation in these factors across a statistical sample of communities. A convenient way to test hypotheses related to diversity is to begin by stratifying the sample by these factors. Then, data can be collected on household characteristics within each stratum, including some of the social and cultural variables discussed in Section 2.1. For example, variables might include income level, status as surplus or deficit producer, reliance on off-farm income, labour supply, ethnicity, and land tenure and quality, which are hypothesized to shape farmer demand as producers and consumers for certain varieties. Farmer demand for varieties and their traits is conditional on the types of external factors we have discussed. Examples are shown here of how variables might be measured and how data is collected with a structured survey instrument.

Survey questionnaires

Survey questionnaires, completed by a personal interview, are a means of gathering quantitative data directly from informants. They function as an "interpersonal role situation in which an interviewer asks respondents questions designed to elicit answers pertinent to the research hypotheses. The questions, their wording and their sequence define the structure of the interview" (Frankfort-Nachmias and Nachmias 1996: 232). Interviews can vary in their level of flexibility in order to answer the questions under study; in a more structured interview, questions should be phrased in the same way with each participant and questions should be asked in the identical order to prevent varying interpretations of the question.

When these data have been collected, farmers' decisions can be analyzed in the context of microeconomic theory of variety choice. This theory has been applied using econometric models. An econometric model is one in which economic theory is used to postulate causal relationships and test them with **multiple regression analysis**. Using multiple regression, the dependent variable representing variety choice or variety diversity is related to the factors cited above, which are independent variables. Multiple regression allows us to test the separate effects of each independent variable, or groups of variables, while controlling for the effects of others.

In analyses of on-farm diversity, the dependent variable can be measured as a choice between two types of crop populations, a choice of how many varieties to grow, a choice of area allocation among varieties, a spatial diversity index for named varieties, or in other ways. Adapting econometric models from the variety choice literature to the analysis of crop genetic diversity usually requires some innovative approaches. Examples of such models are found in Brush *et al.* (1992), Meng (1997), Bellon and Taylor (1993) and Smale *et al.* (2000).

Example: Econometric analyses of variety choice

Brush *et al.* (1992) defined potato diversity in the Andes as the number of landrace types cultivated by a farm household, relating both diversity and the area planted in modern varieties to farm size, land fragmentation, distance to markets and socioeconomic status of the farmer. While farm size and proximity to markets were positively associated with the adoption of modern varieties, adoption did not necessarily decrease the number of landraces grown. Off-farm employment was also a significant factor, although negatively associated with the maintenance of diversity, indicating that the opportunity cost of cultivating many varieties – which requires labour-intensive seed selection and procurement tasks – is significantly higher where other employment opportunities exist.

In the Turkish Western Transitional Zone, Meng (1997) demonstrated that multiple factors, including missing markets, risk and agroclimatic conditions, influence the probability that a farm household will grow a traditional variety. A change in any single economic factor is unlikely to cause farmers to cease growing traditional varieties.

Bellon and Taylor (1993) have shown that differences in the adaptation of varieties to soil quality and farmers’ perceptions of these soil qualities (their folk taxonomy) can explain why farmers grow both modern and traditional varieties in Chiapas, Mexico. Lower wealth status, off-farm employment and land fragmentation were also associated with higher levels of diversity, a factor that is itself determined by a combination of agroecological and social conditions such as inheritance and land tenure systems.

Example: Explanatory factors and variables for farmer variety choice

Explanatory factor or concept	Variable measured			
	Nepal	**Morocco**	**Turkey**	**Mexico**
Agroecology	latitude; longitude; elevation; land use; soil type; fragmentation	temperature variability; length of growing period; rainfall distributions; soil type	land quality	length of growing period; soil type
Market infrastructure	distance to nearest market; distance to nearest road		price differentials; percent of district output marketed	road surface; electricity and water supply; number of health clinics, schools, and business establishments
Household characteristics				
economic status and objectives	caste; farm size; sharecropped area; number of months food self-sufficient		has refrigerator, tap water, electricity, own livestock; total land	own tractor; own oxen; have irrigation; percent of harvest sold
income sources	seasonal migration	crop share of farm income; farm share of total income	off-farm income	remittances from migrants
human resources	family size; years of education	household composition; years in school	number of household members over 13; years in school; age of head	household composition; years in school
land resources	fragmentation		land quality	soil types; fragmentation

Sources: Meng 1997 (Turkey); Aguirre *et al.* 2000 (Mexico); Rana *et al.* 2000 (Nepal); Nassif 2000 (Morocco); Jarvis *et al.* 2000.

2.3.1 Linking farmer variety choice to on-farm diversity

Farmer-named varieties may or may not be distinct genetic units. Consequently, the variety choice model is of limited utility for understanding the prospects for on-farm conservation unless it is possible to relate the varieties (as they are named and chosen by farmers) to the genetic structure of the crop populations (discussed in Chapter 4). In addition, the extent to which crop genetic diversity is determined by variety diversity is closely related to the plant population genetic structure and mating (breeding) system (i.e. outcrossing, inbreeding, clonal) (discussed in Chapter 5). An example of the attempt to predict variety choice as a function of agroecology, market access and household variables, and then relate the predicted choice to morphological diversity is found in Meng (1997).

Other aspects of farmer choice that affect on-farm crop diversity are their plot management practices and their seed selection, procurement and storage practices. These practices have not yet been linked in a formal way to variety choice models. Information on farmers' seed selection, procurement and storage, as well as crop and plot management practices, should be collected, which will also be of use to answer research questions raised by the other disciplines involved in on-farm research (as discussed in Chapters 3 through 6). The criteria on which farmers select seed and choose to grow their varieties should be recorded, along with their perceptions of the extent to which various crop populations supply the traits they consider to be important.

Modern varieties and on-farm genetic diversity
A negative relationship between the presence of modern varieties and crop genetic diversity is typically assumed, but empirical examples suggest that the relationship is more complex. For example, in some cases the presence of modern varieties among a set of crop populations in a community enhances the breadth of the traits available to farmers (Dennis 1987). Some researchers have found that when modern varieties serve for generating cash, they can support the production of more traditional varieties which satisfy other consumption needs in farm households (Zimmerer 1996). Testing the relationship between modern varieties and crop genetic diversity in other cases, with a good statistical design and sound economic and biological principles, would advance scientific knowledge of these issues.

2.4 The value of local crop diversity to markets and to farmers

Markets in the target area may value the traits associated with the crop genetic resources we wish to conserve. If so, a **hedonic analysis** can be conducted based on market prices. If not, we can elicit farmers' perceptions of variety performance as indicators of non-market values, combining these, if necessary, with information on relative costs of production. In either case, methods are available which can be applied, but results are meaningful for on-farm conservation only when linked to knowledge about the structure of genetic diversity among the crop populations in the target area.

2.4.1 When markets value traits

When the crops farmers produce are marketed in towns and cities, the tastes and preferences of the urban consumers who purchase them for food play a big role in determining the price. These tastes and preferences determine the demand for the crop, and these change with the income levels of the consumer. Often, demand varies by the quality of the crop. Quality depends to some extent on the variety, though production and harvesting conditions, post-harvest handling and processing, are also important. Consumers express their preferences through paying price premiums for what they like, and when these signals are transmitted back to the farmer, the farmer has an "incentive" to grow the variety that earns the premium.

To determine whether this is true in our target area, we can begin by identifying the qualities for which consumers pay a premium in the market using the "hedonic price model." Though based on economic theory, the approach involves a relatively straightforward estimation of a linear regression relating prices taken on market samples to characteristics measured on those samples. The sign and significance of the regression coefficients give an estimate of the marginal value of each characteristic. Relating observed characteristics for which consumers pay a premium (aroma, colour, cooking quality) to physical attributes of the seed requires the knowledge of chemists and crop scientists. Other related economic analyses might include assessments of processing or handling costs, and market efficiency.

Whether the trait is one associated with the crop populations that are identified as genetically desirable for on-farm conservation, and whether these traits can be easily transferred into modern varieties, are empirical questions that need to be resolved. We may find, for example, that the market-value traits are more prevalent in modern varieties, which implies that there are market "disincentives" for growing traditional varieties. Alternatively, we may conclude that the market values of a trait are unique to a particular landrace, and that landrace is of particularly interest genetically. Then there is a market "incentive" for growing the landrace.

Example of market valuation of traits in rice. [Findings from *Consumer Demand for Rice Grain Quality,* edited by L.J. Unnevehr, B. Duff and B.O. Juliano. 1992. IRRI and IDRC]

This volume is a compilation of a number of studies conducted on economic aspects of rice quality in Asia, including an overview of the relevant economic theory. One of the findings reported in the volume was that Philippine consumers paid a premium for varieties labelled "traditional" (which may have been modern varieties, in fact). The "traditional" label signalled to Philippine consumers that these rices have desirable characteristics. In addition, the income elasticity for quality was also positive: urban/high-income consumers tend to pay higher premiums for quality and for a larger number of quality characteristics than rural/low income consumers.

Significant determinants of price at the retail level and their relationship to price

Characteristic	**Philippines**	**Indonesia**	**Thailand**	**Malaysia**	**Bangladesh**
Head rice	*(+)	*(+)	*(+)	*(+)	ns
Foreign matter	*(–)	*(–)	*(–)	*(–)	ns
Shape or length	*(–)		*(+)	*(+)	*(+)
Translucency	ns	*(+)	*(+)	*(+)	
Whiteness	ns	*(+)	ns	ns	
Amylose	*(–)	*(+)	*(–)	*(–)	ns
Gelatinization temp	*(+)	*(+)	ns	ns	
Aroma			*(+)		
Polish		*(–)			*(–)
1000–grain weight					*(–)
Moisture content					*(–)
Cooking time					*(–)
Imbibition ratio					*(–)

A blank means the variable is not included in the regression. ns=not significant. *=significant at the 5% level. Source: Unnevehr *et al.* (1992)

2.4.2 When markets do not value traits

In many parts of the world, for many reasons, the attributes that matter to rural households cannot be obtained through exchanges on markets. Then, the farmer is both a producer and a consumer of the crop. When this is the case, how do we estimate the "value" to farmers of the varieties they grow?

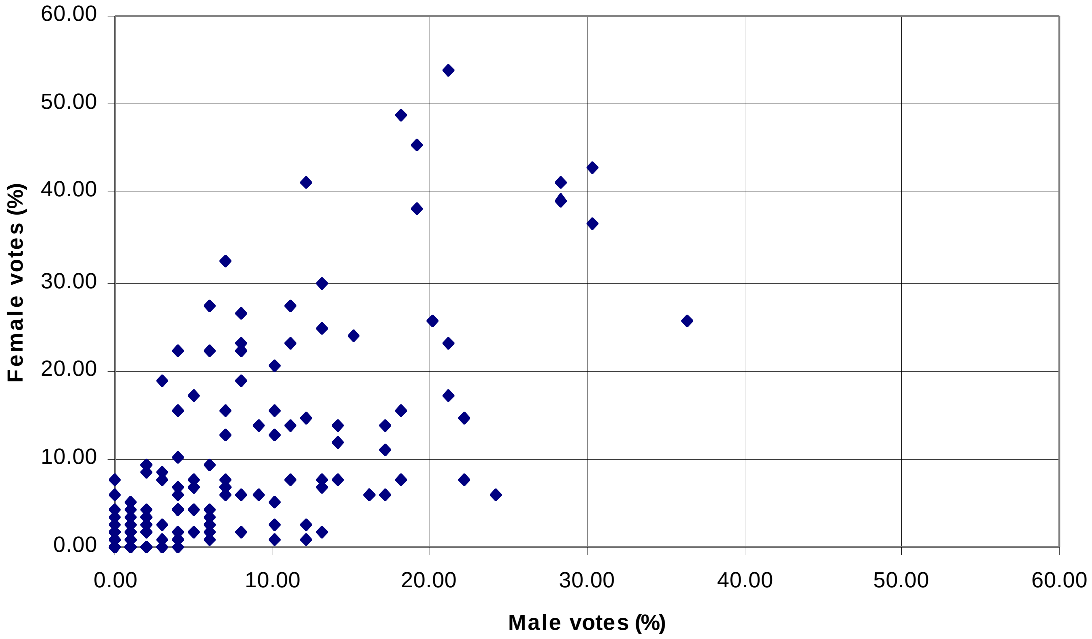
Though there are a number of ways to do this, the simplest is to use ranking or rating methods (for example, Chamber and Childyal 1985; Guerrero *et al.* 1993) to: (1) elicit from farmers the characteristics that matter most to them, including both production and consumption characteristics, and (2) ask them to assess the extent to which each variety of interest satisfies these characteristics. Production and consumption characteristics might include "costs" of production in terms of hours of crop management including on-farm processing.

These methods are simple to operationalize since farmers know their varieties and can rate them according to their features. There are some recognizable limitations to these methods, however. The first is that we need to have some notion of how the abstract "characteristics" farmers identify for us relate to the crop's physiological traits as recognized by scientists. Second, we often have a long list of characteristics, which may make it cumbersome to use the results in other types of statistical analysis. If the purpose of the analysis is to identify the pros and cons of different varieties from the viewpoint of farmers who both produce and consume the crop, these methods are likely to be sufficient. Women and men may have distinct perceptions.

It may not be possible to obtain varieties with certain value characteristics through markets. Farmers may prefer legume varieties with shorter cooking time where access to fuel wood is a constraint, as shown here in Kenya.

In Nepal, farmers value varieties that require less labour and time to process.

Example of non-market valuation: gender, variety characteristics and preferences
This figure compares the votes of men and women participants for maize landraces grown in demonstration plots during field days held in the Central Valleys of Oaxaca, Mexico. Each point is a landrace. The x-axis represents the percentage of men who voted for any particular landrace, while the y-axis represents the same information for women. If there were perfect agreement in the voting patterns of men and women, all points would fall on a 45° line from the origin. Divergence from this line demonstrates that men and women vote differently. The least desirable landraces are those chosen infrequently by both men and women, located in the lower left portion of the graph. The landraces located in the upper right of the graph are the most desirable, but rarely coincide for men and women.
Source: Bellon *et al*., Identifying maize landraces for participatory breeding: a case study from the central valleys of Oaxaca, Mexico. Unpublished manuscript. CIMMYT.



If costs of production vary substantially among varieties, it is worthwhile to record them systematically. For partial budget analysis to be useful, there need to be differences in management and seed costs, as occurs, for example, when a modern variety is adopted with new planting densities and fertilizer applications. Often production costs vary negligibly among landraces, or among modern varieties. This form of analysis embodies some simplifying assumptions about farmers' objectives, however (CIMMYT 1988).

2.4.3 Linking valuation to genetic diversity

In order to analyze the prospects for on-farm conservation, the results of the hedonic analysis or analysis of farmers' perceptions must be related to the genetic structure of the crop populations in the target area.

Candidate crop populations for on-farm conservation in a reference area can be classified along two axes: (1) the probability that farmers will maintain a population and (2) the contribution of the population to the overall genetic diversity in an area (see Fig. 2.1). The best candidates for on-farm conservation are those that are both most desirable from a genetic resources standpoint and have the highest "private" value to farmers, when expressed either in price premia or in utility rank.

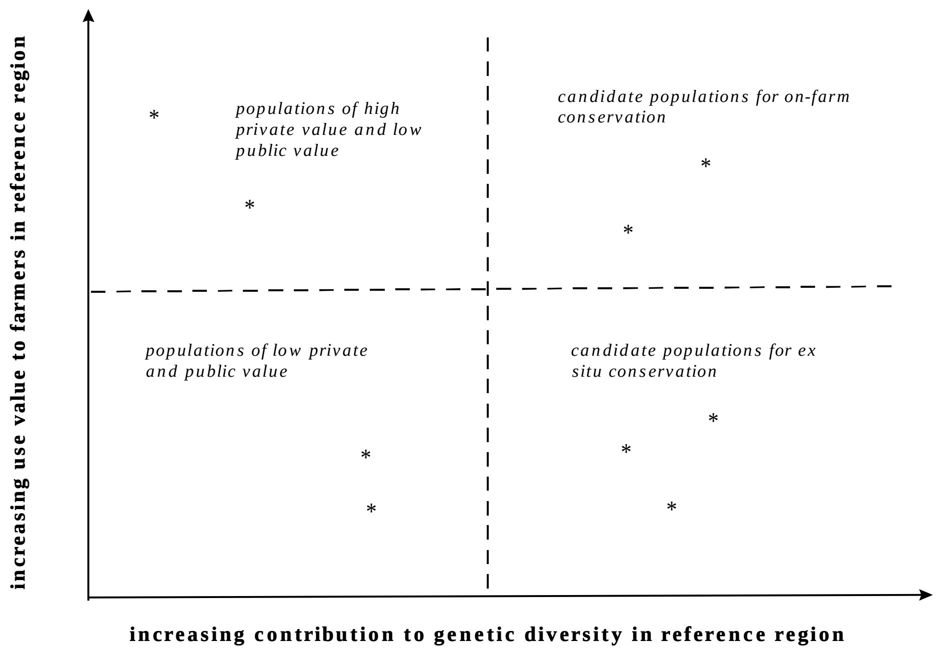
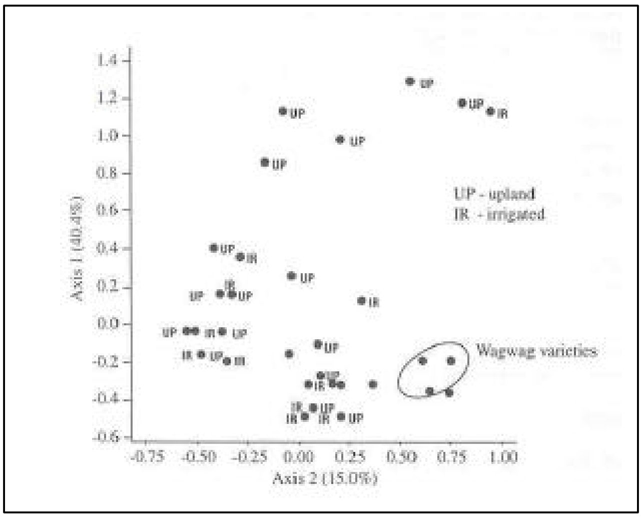


Fig. 2.1. Classification of candidate crop populations for on-farm conservation (Smale and Bellon 1999).

Example: Linking valuation analyses to genetic analyses

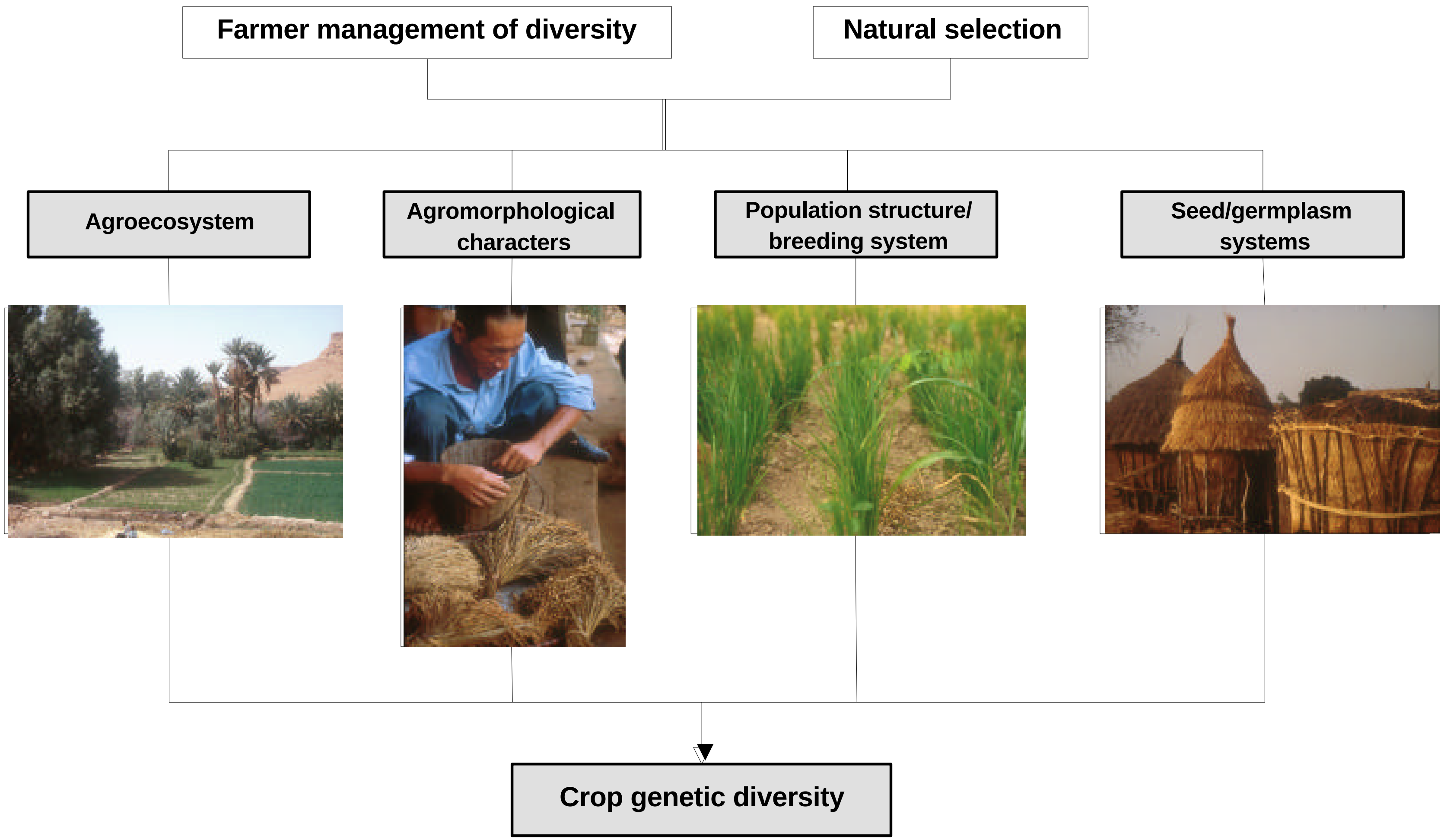
When the perceptions of the farmers are related to the genetic structure of the populations, it may be possible to identify target crop populations for "add-value options". For example, an IRRI team found that the Wagwag group of traditional non-glutinous varieties, collected in the rain-fed lowland system of the Philippines, accounted for most of the responses regarding positive traits of traditional varieties in that ecosystem. They were more likely to be rated as aromatic, with good volume expansion. The results of the correspondence analysis reproduced in this figure also showed that the Wagwag group is genetically distinct from all other varieties, in both the irrigated and rain-fed lowland ecosystems. The prominence of the group is supported by data on polymorphism measured with both isozyme and microsatellite techniques.

Unfortunately, the varieties of this group have longer duration and lower yield than the modern varieties. The team concluded that a breeding or management intervention aimed at decreasing the duration of Wagwag varieties might enhance their attractiveness to farmers (add value) while contributing to on-farm conservation of rice genetic diversity (assuming no major changes in allele structure).



2.5 Farmer management of diversity

The level and structure of crop genetic diversity in the farmer's field are a result of a number of actions and external influences extending beyond the farmer's choice of how many and which varieties to plant. Farmers exert influence on the genetic diversity of their crops through a range of actions, while the agroecosytem and the biology of the crop also affect the outcome in ways the farmer cannot always control. The local practices of **agroecological management**, including soil preparation, irrigation, plant management and use of inputs create micro-environments favouring certain adaptations. Farmers' seed-selection decisions are based on the range of **agromorphological characteristics** that their crops exhibit. These qualities include the phenology or morphological characteristics of the plant, unique aspects of its adaptation, or particular uses of the plant parts. These characteristics help farmers, as well as scientists, identify landraces. Farmers influence the **population structure** of a crop by determining the proximity of the crop population to potential breeding partners, and thus how genetic material is exchanged between and within fields. New genetic material may be introduced through the system of **seed flows**, in which seeds are acquired from a variety of channels or stored on-farm for later use. The ways in which these factors shape genetic diversity on-farm are discussed in Chapters 3 through 6.


Farmer management of diversity
Natural selection
Agroecosystem
Agromorphological characters
Population structure/ breeding system
Seed/germplasm systems
Crop genetic diversity

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Chapter 3 Agroecosystem factors: natural and farmer-managed

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3.0 Objectives of this chapter

By the end of this chapter, the reader should have an understanding of:

- Key influences of the agroecosystem on crop diversity
- The different ways in which farmers adapt to and manipulate agricultural environments
- The potential implications of different management practices on genetic diversity.

3.1 Overview of agroecosystem influences on crop genetic resources

Agroecosystems are comprised of the non-living (abiotic) and living (biotic) components in a human-managed, agricultural system. Agroecosystems provide the arena in which crop evolution occurs, presenting stresses, but also opportunities, to which crops must adapt in order to thrive. **Abiotic** components of agroecosystems include temperature, soil, water, relative humidity, light and wind. **Biotic** factors include parasitic and herbivorous pests, competition from other plants, and favourable (symbiotic) relationships with other organisms. The farmers who manage these factors in terms of irrigation, nutrient input, pest control, land preparation, mixed/relay cropping and other practices are also a biotic component of agroecosystems. These factors vary over time, with seasonal, annual and stochastic changes, and in space, from the micro-environmental to the ecoregional scale. As a result, local landraces adapt to the particular conditions of their immediate ecogeographic setting. These adaptations to local environmental stresses are likely to be reflected in the genetic composition of landraces over time.

Farmer management of diversity – an alfalfa, faba bean and barley farming system in Morocco's Rich oasis area.

3.1.1 Abiotic influences

The variations in the abiotic components of an environment can act as stress factors on plants. In a genetically diverse population, some individuals will be better adapted to these stress factors and thrive, while others may not survive. In this way, environmental influences exert selective pressures on crop populations. The range of influences and the adaptations they can encourage are presented in Table 3.1.

Table 3.1. Abiotic influences and the adaptations they can induce

Abiotic factor	***Plant stress***	***Type of adaptation***
Temperature		
Extreme cold	Basic biological functions	Cold tolerance
Extreme heat	Basic biological functions	Heat tolerance
Soil (edaphic) factors		
High clay content/poor drainage	Basic biological functions	Tolerance to flooding
High sand content/rapid drainage	Basic biological functions	Drought tolerance
High gravel/rock content	Root development	Root structure, drought tolerance
High pH	Toxicity	Alkalinity tolerance
Low pH	Toxicity	Acidity tolerance
High aluminium content	Toxicity	Al tolerance
High salt content	Toxicity	Salt tolerance
Low nutrient content	Basic biological functions	High nutrient use efficiency
Water/Precipitation regimes		
High precipitation/Waterlogged soils	Basic biological functions	Flood tolerance
Low annual precipitation	Basic biological functions	Low water requirements
Low seasonal precipitation	Basic biological functions	Drought tolerance
Light		
Low light intensity	Photosynthesis	Shade tolerance
Long/short photoperiod	Reproductive phenology, Photosynthesis	Photoperiod adaptation
Wind		
Strong local winds	Evapotranspiration, structural stress	Stem/leaf/flower strength, increased water retention
Altitude		
Low carbon dioxide availability	Basic biological functions	Decreased stomata retention

Examples of research undertaken to date describe genetic adaptation in crop plants to saline soils, drought and cold

Salt Pakniyat *et al.* (1997) demonstrated genotypic differences in salt-tolerant and salt-sensitive varieties of barley. Jafari-Shabestari *et al.* (1995) observed varying phenotypic responses to soil salinity in hexaploid wheat.

Drought Weltzien and Fischbeck (1990) documented significant variations in yield potential both between and within landraces of barley grown in drought conditions. In addition, Blum and Sullivan (1986) demonstrated genetic variations associated with drought tolerance among landraces of sorghum and millet.

Cold Singh and Jana (1993) demonstrated varying resistance to low temperatures among chickpea accessions from around the world.

Habitats located at higher altitudes are commonly associated with particular abiotic factors, including low carbon dioxide availability and high variation in precipitation, light, soils and temperature. Likewise, other ecogeographic niches are likely to contain ‘portfolios’ of abiotic factors. For instance, semi-desert regions are associated with shallow sandy soils, low rainfall and temperature extremes. Just as these abiotic factors can be clustered in various ecogeographic regions, so corresponding adaptations may appear in portfolios of genetic diversity.

Highly weathered soils, such as the one pictured here, are often deficient in the nutrients that plants need to thrive.

Nutrient deficiencies or **toxicity** may be particularly important in determining the survival and productivity of crop varieties in the agroecosystem. Soils may be deficient in nitrogen, phosphorus or potassium, as well as secondary micronutrients such as magnesium, sulphur, zinc and boron. In contrast, iron, manganese and aluminium may occur in such high quantities as to cause toxicity. Nutrient availability may be related to soil pH and precipitation regimes. Information on soils can help identify soil-related constraints and explain current management practices (Mutsaers *et al.* 1997).

Some of these factors, such as parent rock and altitude, are unlikely to change over the course of a plant's life cycle. On the other hand, many of the factors mentioned above fluctuate seasonally or from year to year. For instance, regular changes in temperature, daylength and precipitation occur seasonally in temperate regions. Extremes in climatic conditions, such as severe drought, may occur only once in a plant's lifetime. This has implications for the nature of adaptations in a local setting, as well as scientific efforts to document abiotic factors.

3.1.2 Biotic influences and the adaptations they engender

The other organisms that comprise the biotic component of agroecosystems also have great potential to shape crop genetic diversity. Interactions with other organisms may be positive, negative or neutral for the crop plant; all have the potential to influence crop genetic diversity through exerting selection pressures or conferring selective advantages on individual crop plants. **Competition** is an interaction resulting from limited resources in an ecosystem; both organisms are worse off as they each use resources that both need. Competition may occur between organisms of the same or different species (Liebman and Gallandt 1997). **Mutualism** is an interaction in which two organisms impact each other positively; neither is successful in the absence of the other. **Commensalism** is an interorganism interaction in which one organism is aided by the interaction the other is neither benefited nor harmed (Gliessman 1998). By contrast, **amenalism** describes an interorganism interaction in which one organism negatively impacts another organism without receiving any direct benefit itself. A **parasitic** relationship involves one organism benefiting from and perhaps depending upon the interaction, while it harms the other organism. Finally, **predation** is when an organism benefits through killing and consuming another.

Perhaps the biotic interactions of greatest concern to farmers are those between crops and their pests. Herbivorous animals, including mammals, birds and arthropods, may act as predators on crop plants, while viral, bacterial and fungal diseases harm crops through parasitic relationships. Crop genetic diversity is an important means of minimizing the threat of these pests in an agroecosystem. Crop plants' vulnerability to particular pests may vary with agromorphological characteristics like plant height, pubescence or time to maturity, in addition to the variability in specific genetic traits for pest resistance. Crop genetic variation, and hence phenotypic variation, may also attract a diversity of other organisms into the agroecosystem, including the natural enemies (predators or parasites) of pests (Gliessman 1998).

Crop plants and their pests have adapted to each other over time in a process called **co-evolution**. One of the most important aspects of co-evolution for on-farm conservation is crop plants' resistance to pests (and conversely, the ability of pests to overcome host resistance), which depends upon the development of new genetic diversity (Finckh and Wolfe 1997). The genetic diversity evolved by crops and pests through co-evolution is particularly complex because both are genetically variable over time and space (Le Boulc'h *et al.* 1994). Indeed, the diversity of pest-induced stresses on a particular crop is often closely correlated with diversity in the crop's resistance.

In the Yucatán, Mexico, a maize-bean intercrop creates a mutualistic interaction between the two crops: bean plants enrich the soil through their association with nitrogen-fixing bacteria, while tall maize stalks provide support for the beans to climb higher, accessing more sunlight.

Example: Genetic adaptations for pest resistance
Allard (1990) observed a link between an increase in the frequency of resistance alleles in barley populations and the selective advantage of those populations in resisting scald. "Different pathotypes differ widely in their ability to damage the host," Allard noted, "and different host-resistant alleles differ widely in the ability to protect the host from the pathogen" (1). These findings are supported by Le Boulc'h *et al.* (1994) in their research on powdery mildew among various populations of winter wheat.

The complexity of crop-pest interactions in agroecosystems is increased by their seasonal or annual variability. Pest populations fluctuate with changing climatic conditions, farmer inputs and host resistance. In addition, pests can be highly mobile, especially with assistance from humans. This ease of mobility, coupled with favourable conditions, may engender widespread epidemics, with severe effects on host populations.

Competition with other organisms may also foster crop genetic diversity. Weeds are the primary competitors of crop plants of concern to farmers (Liebman and Gallandt 1997). Weeds can reduce or inhibit growth. Crops and weeds within the same agroecosystem can have similar requirements in terms of water, light and nutrients – the essential resources plants need to survive.

In Ethiopia, a durum wheat landrace (right) is preferred to the modern variety (left) because of its higher tillering, which suppresses weed growth and allows farmers to plant fewer seeds per plot.

Example: Allelopathy
Allelopathy is one mechanism through which crops and weeds compete against each other for the resources in their agroecosystems. It is defined as, "the production of a compound by a plant that when released into the environment has an inhibitory or stimulatory impact on other organisms" (Gliessman 1998:156). Allelopathic compounds can be produced in different plant parts and released into the agroecosystem through all manner of mechanisms, such as being washed off the plant into the soil, released during plant decomposition, or leached out of roots. They may be produced by crops or weeds as a means of inhibiting the growth of their competitors, so as to access more of the essential resources in the agroecosystems for themselves (although they may also stimulate the growth of neighbouring plants, in symbiotic or commensal relationships). Crops with allelopathic weed-suppressing potential include beets, lupine, maize, wheat, oats, peas, buckwheat, millet, barley, rye and cucumber. Different varieties of these crops may have varying allelopathic potential. Indeed, varieties with greater similarity to their wild relatives exhibit greater allelopathic character. (Gliessman 1998).

Organism interactions within an agroecosystem are not always competitive and may be neutral, commensal or mutualistic. Crops cultivated together in an intercropping system may have faced selection pressures to develop complementary needs, using different resources or using them at different times. Crops have also adapted to take advantage of symbiotic relationships with non-plant organisms, such as insect pollinators and, in the case of leguminous plants, nitrogen-fixing *Rhizobium* bacteria.

Finally, human beings are the most significant biotic factor shaping agroecosystems. The ways in which they manipulate agricultural environments are discussed in Section 3.2.

Ecologists have long pondered the paradox of biological diversity: why numerous species are able to persist in the same habitat. As Tilman and Pacala (1993) note, multiple species inevitably arise in situations where two or more environmental factors constrain fitness and where unavoidable trade-offs exist in the ways in which organisms respond to constraints.

Research on wheat landrace selection in Turkey suggests that farming systems do not differ markedly from natural ecosystems. Turkish farmers face numerous environmental factors which constrain the fitness of a single wheat variety (e.g. soil heterogeneity, water availability, altitude), and they seem to face unavoidable trade-offs as they select for a particular trait (e.g. yield, risk, taste). (Brush and Meng 1998)

3.1.3 Farmer characterization of the agroecosystem

Farmers live within an environment composed of soils, climates, vegetation types, landforms (e.g. hills, rivers and other geographical features), stages of ecological succession, pests and diseases, weeds, competition, mutualism and other ecological domains. Through their experiences and perceptions, farmers may characterize and form classification systems for some or all of these domains (Martin 1995).

Understanding farmers' systems of classification for the different features of their ecosystems may yield insights into the processes fostering conservation of diverse landraces. Farmers may classify these features based on their physical and chemical properties, such as the texture and colour of soils or the temperature and rainfall of climates, and as such, farmers' classification systems may correspond to scientific ecological classification (see example). Farmers also may classify ecological features based on their historical or cultural significance (Martin 1995).

Farmers may use these classification systems to determine where or when to plant which variety, cultivating particular varieties in association with specific topography, soils, stages of succession, and even varieties of other crop species, as in intercropping regimes. In a slash and burn agroecosystem, farmers may plant different varieties (or species) in a plot, depending on the number of years since the fallow period. In an intercropping system, genetic diversity in the keystone crop species may be correlated.

Farmers' ecological classification systems may serve as an indication to the researcher of which features are particularly important in the agroecosystem or relevant for the cultivation of diverse varieties. For example, a highly detailed system of rainfall classification may indicate that rainfall is a defining feature of the agroecosystem and is a determining factor in farmers' choice of varieties.

The effects of cultivating different varieties under particular agroecological conditions is further discussed in Sections 4.7.2 and 4.7.3 (On-station and on-farm trials).

Example: Farmers' soil classification and maize diversity conservation in Yucatán, Mexico.

Soil[†]	**Tsek'el**	**Box-lu'um**	**Pus-lu'um**	**Ek-lu'um**	**Chac-lu'um**	**Kankab**	**Ya'axom**	**Ak'alche**
Litosol	v							
Rendzine		v	v		v	v		
Cambisol				v	v	v		
Luvisol				v	v	v	v	
Nitosol						v		
Vertisol							v	v
Gleysol								v

[†] FAO 1990.

This detailed soil classification system is an important aspect of landrace cultivation in Yaxcabá village, Yucatán, Mexico, where farmers plant different maize varieties to land area with specific soil and topography types, based on the varieties' time to maturity. Long-season maize is planted to higher, rockier soil, while early maturing varieties are planted to level areas of red, organic soils, such as in home gardens (Arias *et al.* 2000). The diversity of soil types in this village may thus be a contributing factors to the continued maintenance of diverse maize landraces.

3.1.4 Variation in environmental influences over time and space

Understanding the potential for variation in environmental influences through time and space is crucial to examining their impacts on crop genetic diversity. As mentioned above, both biotic and abiotic factors will vary in their presence and severity across fields, communities and regions, and the presence and degree of adaptation in local landrace populations is likely to mirror this spatial variation. Meanwhile, the adaptations developed by populations exposed to constant environmental pressures will be very different from the adaptations engendered by radical environmental stresses.

Such radical environmental stresses are known as **stochastic events**. These are periods of abiotic or biotic stress that represent a significant departure from regular environmental conditions, such as the droughts or rains caused by an El Niño event or severe blights or plagues. Stochastic events typically present severe stress to crop plants and can significantly reduce the size of a crop population. The landraces that survive a stochastic event are likely to be well-adapted to the particular stress, and future generations may possess that adaptation.

Through time, stochastic events and other types of environmental influences are an important factor in the evolution of crop populations. In diverse crop populations, the impacts of environmental stress factors will gradually favour landraces that thrive in adverse conditions.

- The evolutionary processes that take place in genetically variable populations propagated under conditions of cultivation can be highly effective in increasing the frequency of desirable alleles and useful multilocus genotypes. This enhances the value of the evolving populations as sources of genetic variability in breeding for disease resistance and other characters that affect adaptedness (Allard 1990: 1)
- In a genetically heterogeneous population, competition between individuals creates selection forces which change depending on the genetic structure of the population and the environmental conditions…the diversity of environments creates and maintains genetic diversity (Le Boulc'h *et al.* 1994: 225-226)

3.1.5 Limiting factors

Agroecosystems contain a multitude of environmental and biological factors affecting plant survival and productivity, and it would be impossible to measure all of them. Therefore, it is important to have some criteria to reduce the number of variables for analysis to those that are key in influencing plant survival in a given agroecosystem. The use of **limiting factors,** or key constraints to survival and plant productivity, is one way to reduce the number of variables collected. In areas of high soil salinity, the key limiting factor to crop productivity may be the amount of salt in the soil. In desert environments, it may be water, or the availability of water at a particular stage of the plant's life cycle. Determining which are the key limiting factors can be accomplished through discussions with the farming community and with the knowledge of experts who have worked in the region. It will be important to know the number of farmers affected by each limiting factor, the effect of this factor to plant productivity, and the risk of this factor increasing in the future (Mutsaers *et al.* 1997). Once the key limiting factors are known, it is also important to elicit from the farming community the management practices used to reduce their negative impacts.

Some abiotic and biotic factors to consider

General site data:
Topography: the differences in elevation of the land surface on a broad scale, varying from flat to mountainous, measured using estimates of the proportion of change in altitude (adapted from FAO 1990):

Flat	0-0.5 m
Almost flat	0.6-2.9 m
Gently undulating	3-5.9 m
Undulating	6-10.9 m
Rolling	11-15.9 m
Hilly	16-30 m
Steeply dissected	>30, moderate range of elevation
Mountainous	>30, great range of elevation (>300 m)

Site slope and aspect: an estimate of the slope of the site, measured in degrees (°), and the direction the slope faces (N,S,E,W or NW, SE, etc.).
Altitude: the approximate altitude of the site, measured in metres above sea level, using either an altimeter or an estimate from local maps

Climate data:
Temperature range: measured either monthly or seasonally; in both cases, mean, minimum and maximum values should be provided, and the distance to the nearest weather station should be provided if known
Incidence of frost: presented either as estimated number of frost days per year, or as first and last frost of the year
Rainfall range: this should be based on annual or seasonal averages
Winds: wind strength can be measured as frequency of hurricane force winds, or the annual maximum wind velocity (km/s)
Light: this may a qualitative measurement based on exposure to sun (such as no shading, partially shaded or completely shaded), and also can be measured in photoperiod at a specific point in the growing season (mean, maximum, minimum)
Major climatic events: local residents will be able to recount the historical occurrence of major climatic events (particularly those which may serve as stochastic events for local populations)

Soil data:
Soil drainage: the relative ease with which soil drains when watered, from very poorly drained to well drained or excessively drained
Water availability: crops may be completely rain-fed, irrigated (regularly or occasionally), flooded, or located near groundwater (lakes, streams, rivers, sea, etc.)
Flooding: or temporary inundation, described according to its estimated frequency, duration and depth
Groundwater depth and quality: Groundwater depth is measured as the distance from surface to groundwater table (cm), and any significant fluctuations if known. Groundwater quality can be characterized as: saline, brackish, fresh, polluted, oxygenated or stagnating
Soil salinity: is a quantitative measurement of the percentage of dissolved salts in the soil (ppm)
Soil colour: can be measured at a range of root depths using a standard soil guide (e.g. Munsell)
Soil moisture: can vary from dry to slightly moist to wet, and should be presented according to depth
Soil pH: the actual value of the soil, measured at a range of depths
Organic matter content: can range from nil (as in arid zones) to high (as in never cultivated, recently cleared forest) to peaty
Rock content: described according abundance of rock and mineral fragments (>2mm)
Stoniness/Rockiness/Hardpan/Cementation: surface hardness gauged according to the relative ease of tillage, from tillage unaffected, affected or difficult to tillage impossible or essentially paved
Soil texture: characterized according to relative content of clay, silt, loam and sand
Soil type: may incorporate many other factors, and is usually based on a standardized classification system
Nutrient deficiencies/toxicity: N, P, K, Mg, S, Zn, Bo, Fe, Al, Mn

Biotic factors
Diseases: measured as the frequency and diversity of a disease among sampled crop plants
Pests: measured as the frequency and diversity of a pest and among sampled crop plants
Pollinators: specific pollinators available
Competition: measured as the frequency of a weed or competitor in a field or sampling thereof
Weedy and wild relatives: the size and proximity of populations of wild relatives should be noted
Mutualism: benefit of interaction versus grown separately.

Example: Environmental stress factors in Milpa agriculture, Yucatán, Mexico

Traditional empirical knowledge is transmitted from father to son to cultivate under the conditions of environmental stress presented by the present-day slash and burn Milpa farming system in the Yucatán, Mexico. The photograph shows Don Celso Cob (54) teaching his son Lico (14) how to sow maize, bean and squash in stony soils. This crop will provide the family with a year's food supply. The sowing day is difficult, as the rainy season has started and weeds have started to grow, creating competition with crop plants for essential resources. In addition, population pressures have reduced the fallow period in the Milpa system from 50 to 8 years, lessening soil fertility.

3.2 Farmer management of the agroecosystem

Farmers shape the distribution and degree of genetic diversity in their crops both directly, through selection, and indirectly, through management of biotic and abiotic agroecosystem components.

Farmers make decisions in the process of planting, managing, harvesting and processing their crops that affect the genetic diversity of crop populations. Over time they will modify the genetic structure of a population by selecting for plants with preferred agromorphological characteristics. Farmers will influence the survival of certain genotypes by choosing a particular management practice of planting a crop population in a site with a particular micro-environment. Farmers make decisions on the size of the population of each crop variety to plant each year, the percentage of seed to save from their own stock, and the percentage to buy or exchange from other sources. Each of these decisions, which can affect the genetic diversity of cultivars, is linked to a complex set of environmental and socioeconomic influences on the farmer. (Jarvis and Hodgkin 2000).

Sometimes human behaviour has accidental or unforeseen effects on the genetic diversity of crops. Far more often, the ways in which farmers shape crop diversity are well thought out. Although they may not understand the nuances of plant population genetics, reproductive biology and environmental adaptations, farmers are likely to draw on these indirectly to identify, develop and maintain useful genetic diversity within local agroecosystems.

By altering the environmental selection pressures that crop plants face, farmers' crop management practices can impact the genetic diversity within local populations. For instance, in dry areas, irrigated crops face far less natural selection for drought tolerance than those relying solely on rainfall. Sadiki (1990) has shown that irrigated and rain-fed populations of faba beans in Morocco have distinctive genetic profiles in keeping with the different natural selection pressures facing each population.

However, because plant development is based on both the plant's genotype and its environment, the precise effects of farmer manipulations of agroecosystems on local genetic diversity are not entirely understood. There are numerous hypotheses as to the impacts of various farmer inputs on genetic diversity, such as the quantity and content of fertilizers (Silvertown *et al.* 1994). However not every farming practice will play a significant role in shaping local genetic diversity (Snaydon 1984). The challenge facing scientists working in on-farm conservation is to determine what manipulations of the environment farmers practice, and in turn what the precise effects of these practices are on crop genetic diversity.

Farmer plot management practices, such as the use of mechanized vs. livestock-powered ploughing, may exert selection pressures on different crop varieties. Donkeys are used as draught power in this plot in Morocco.

3.2.1 Farmer management of environmental stress

Farmers have developed ways of manipulating the environment to respond to the abiotic and biotic stresses their crops face. The threats can be associated with local climates, seasonal changes, or the effects of pathogens; the responses may be simple or complex, temporary or permanent, traditional or modern. Table 3.2 reviews the various types of environmental stresses facing farmers and gives examples of the environmental manipulations which may be used to reduce their impact on crop plants.

Table 3.2. Environmental stresses and possible responses by farmer

Environmental factor	Possible farmer response to alter environment
Extreme cold	Crop sheltering, frost coverage
Extreme heat	Crop shading
High clay content/poor drainage	Removal of hardpans, addition of drainage lines
High sand content/rapid drainage	Addition of water retention lines
High gravel/rock content	Removal or rock material
High or low pH	Fertilizers, soil additives
Low nutrient content	Fertilizers, soil additives, intercropping, crop rotation with legumes
High aluminium or salt content	Fertilizers, soil additives
High precipitation/Waterlogged soils	Addition of drainage lines
Low annual precipitation	Irrigation systems/ water harvesting
Low seasonal precipitation	Temporary/seasonal irrigation systems
Desertification	Sand barriers
High erosion potential	Flattening field slopes, developing terraces
Low light intensity	Thinning possible shade
Long/short photoperiod	Agroforestry, crop rotation
Strong local winds	Plant/build windbreaks, agroforestry
Pests	Pesticides, physical barriers, intercropping, crop rotation
Diseases	Avoidance of conditions favourable to disease, fungicides, crop rotation
Plant competition	Weeding, reduced plant spacing, herbicides

Example: Farmer management of irrigation systems for temperature control in Jumla site, Nepal

In Jumla, the high-altitude ecosite of the Nepal component of IPGRI's global on-farm conservation project, farmer manipulation of the irrigation system also serves to raise the water temperature for earlier flowering of rice. Farmers re-route cold water from the main valley river so that it is warmed by the sun before used to irrigate the rice crop; the warmed water induces flowering at the appropriate point in the season to enable timely maturation and harvest of the crop.

Across this range of options, the exact *timing* and *type* of farmer manipulations, and thus their impacts on crops, can vary considerably. An alteration to the agroecosystem can be permanent, such as terraced fields to reduce erosion, or short-term, such as a day's weeding to remove crop competitors. Interventions can come at various stages during a crop development over a season, and their impact may vary at different stages. Temporary interventions like weeding may take place many times over the course of a season. Also, the precise type of farmer response can vary in its degree or quality. For example, different amounts of weeding or crop rotation practices may have various effects on crops. Inputs such as pesticides, fertilizers and herbicides may be natural or synthetic, and the effects of each of these may be different.

3.2.2 Using crop genetic diversity as a natural resource to mediate stress

One important agroecosystem management strategy is the use of inter- and intraspecific crop diversity to mediate potential environmental stresses. If a crop population has a diverse genetic make-up, the risk of its being entirely lost to any particular stress, such as temperature extremes, droughts, floods, pests and other environmental variables, is reduced. Different crops and varieties may differ in their vulnerability to specific threats (e.g. traits for resistance to a specific disease). In addition, vulnerability to stresses may vary with the crop's level of maturity, from the planting to post-harvest stages, particularly in the case of pests, to which even post-harvest yields may still be at risk. Crops with different planting times and times to maturity give the farmer the option to plant and harvest crops at multiple points in the season to guard against total crop loss to environmental threats.

3.3 Analyzing agroecosystem factors that affect crop diversity

The site for on-farm conservation may have a diversity of agroecosystem factors, different soils, incidence of weeds, disease and/or management practices. **Alpha** diversity refers to the diversity within the ecosite. **Beta** diversity refers to the change in species composition from place to place, for example from one farmer's field to another, or along environmental gradients, and **gamma** diversity refers to the diversity of a region or landscape.

3.3.1 Characterizing the diversity of the agroecosystem

A typical set of agroecosystem data might document dozens of factors (abiotic, biotic and management factors), and it is impossible for the mind to simultaneously contemplate the dimensions of such a data set. One of the first steps of any analysis is therefore to simplify the data set by determining which dimensions are most important to describe the overall variation within the data.

Two common statistical techniques for reducing the dimensionality of complex data sets are classification and ordination. These multivariate methods can be used to explore the relationships among study sites or fields based on their multiple abiotic, biotic and management characteristics, but also the relationships among crop samples based on morphological traits and/or genetic markers (Chapter 4 and 5), and among households based on social and economic characteristics (Chapter 2).

Classification methods group entities with similar characteristics into categories. Methods may be hierarchical, resulting in a dendrogram, or non-hierarchical, resulting simply in groups of similar samples. For each of these, there are numerous different clustering algorithms, which often lead to quite different results with the same data set. Non-hierarchical classification is significantly faster and thus often better for large data sets (Gauch 1982).

Ordination methods arrange samples spatially in a two- or three-dimensional plot in such a way that their positions reflect their similarity. Similar samples, such as farmers' fields with similar characteristics, are located close to each other, while increasingly dissimilar ones are located increasingly further apart. If two variables are highly correlated with one another, either one could be used as a proxy for the other, indicating that there is **redundancy** in the data (Causton 1988). Ordination techniques can be used to identify these correlations to reduce the number of variables under consideration.

In addition to multiple regression analysis, discussed in Chapter 2, other techniques are used to relate a group of dependent variables to a group of independent variables. The technique may be used to link the distribution of varieties to a certain set of agroecological factors, or a certain type of household, or a certain ethnic or gender group. Some other common methods to link dependent to independent variables include **Canonical Correlation Analysis**, a special kind of multiple regression**, Binary Discriminant Analysis** and **Multiple Discriminant Analysis**.

Relating dependent variables to a group of independent variables

Multiple Regression is used to learn more about the relationship between several independent, or predictor, variables and a dependent, or criterion, variable. Multiple regression is discussed in the context of econometric models in Chapter 2. It also can be used to allow the researcher to ask, and perhaps answer, the general question, "What is the best predictor of…?"

Canonical Correlation Analysis (CCA) is used to relate a group of dependent variables to a group of independent variables.

Binary Discriminant Analysis (BDA) is used to relate species patterns to environmental data. Environmental data need only be expressed by multistates, and plant data in the form of presence/absence data. BDA is useful for data that cover a large geographic scale or when only presence/absence data are available.

Multiple Discriminant Analysis (MDA) is used on predetermined groups, which may be specified by earlier classification or ordination methods. MDA is used to characterize the differences and overlaps between these predetermined groups, as well as their diagnostic taxa.

Ordination

Distance based:
Polar Ordination (PO) and Multidimensional Scaling or **Principal Coordinates Analysis** (PcoA) are common distance-based ordination methods, i.e. relying on a square, symmetric distance or similarity matrix.

Correlation based:
Principal Component Analysis (PCA), **Reciprocal Averaging** (RA) and **Detrended Correspondence Analysis** (DCA) are ordination methods based on covariance or correlation matrices rather than distance or similarity matrices.

See http://www.okstate.edu/artsci/botany/ordinate/motivate.htm for an excellent overview of definitions and statistical packages for ordination and classification techniques and their use in exploratory- and hypotheses-driven data analysis tests.

3.3.2 Geographic Information Systems: mapping relationships

Many phenomena in nature show some form of spatial autocorrelation. That is, the value of an environmental factor at a particular location is strongly correlated to its value at neighbouring locations. Such spatial relationships within and among factors may be explored using Geographic Information Systems. A GIS is a database management system which can simultaneously handle spatial data in graphics form – i.e. maps, or the “where” – and related, logically attached, non-spatial attribute data – i.e. the labels and descriptions of the different areas or points within a map, or the “what.” Howard (1996) discusses how spatial information on species richness, distribution and abundance of an endangered species, disturbance and distribution of timber resources within a forest can be used to develop a zoning plan for a forest reserve, including different use areas, buffer zones and a core. Application of GIS to on-farm conservation presents the challenge of integrating demographic, socioeconomic, cultural and other data on the human population with data on the biophysical environment and the target taxon. Harmsworth (1998) describes an attempt to manage, within a GIS, information on the cultural values of different features of the landscape, flora and fauna, with a view to developing resource and environmental management plans more in tune with the requirements of local people.

3.3.3 Reducing variables through farmers's knowledge of limiting factors

Farmers are good guides in deciding which variables to collect for agroecological data. Their experiences can provide unmatched insights into the local environmental factors that affect crop production and the measures that can be taken to minimize the impacts of these factors. These may be stress factors to which landraces have adapted, or limiting factors that prevent further production. In essence, we are interested in:

- Identifying key abiotic or biotic gradients that influence crop genetic diversity
- Characterizing abiotic or biotic factors which farmers perceive as constraining or limiting
- Understanding the manipulations of the agroecosystem which farmers undertake to minimize the impacts of these factors.

Generally, it is best to collect information on the variable that is most likely to be the direct cause of a plant's adaptive response. Farmers can guide the researcher to the main limiting factors within their agroecosystems. Care should be taken in understanding not only the factors but the timing in the life cycle of the plant (e.g. from seedling to flowering to storage) when the constraint has its greatest effect on plant survival or productivity. Certain constraining factors may occur over longer periods of time.

Recommendations from the Global IPGRI *in situ* project (Jarvis *et al.* 2000) are to limit the variables to be analyzed to no more than five key *biotic and abiotic factors* that farmers and researchers have identified as limiting and favourable factors to plant adaptation (e.g. slope / aspect, rainfall onset, growing season, disease), and to five key *management factors* that characterize the limiting and favourable factors to plant adaptation (e.g. high N input, irrigation type, terracing, tillage practices). It is important that these key, farmer-identified, constraints are evaluated. For example, where soil nutrient deficiency has been identified as a key constraint, it is important to confirm through soil analysis that the reason is simply lack of nutrients, and not soil-nutrient deficiency combined with a particular pest affecting the plant productivity.

3.3.4 Measuring the impact of farmer management practices

Measuring the impacts of farmers' manipulations of the agroecosystem can produce a particular challenge because measurements must include two sets of data, with and without the farmer's intervention (the difference between these two being the impact of human manipulation). Ideally, data are collected from one point before and after the intervention. However, if necessary, data collection may be from two points, one with and one without the intervention (it is important to have the points as close together as possible to help control for spatial variation). Chapter 4 gives more details about trials on-farm and on field stations to test the effect of management practices on crop diversity.

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Chapter 4 Agromorphological characters, farmer selection and maintenance

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[1] Photo credits: Pp. 50, 56, 58, 59: D. Jarvis; P. 53: E. Ellis.

4.0 Objectives of this section

By the end of this module, participants should have an understanding of:

- The different types of agromorphological criteria used to distinguish varieties
- How farmers may select them to affect crop genetic diversity
- The relationship between farmer varieties and genetic units.

4.1 Farmer management of agromorphological criteria

Farmers use many of the **phenotypic** features of plants to identify and select their crop varieties. These **agromorphological criteria** may take a wide range of forms and are usually linked to the genetic diversity of a crop. They are used by farmers to distinguish and **name** crop varieties and are commonly the basis for farmers' **selection** of planting seed. Because of this, we can say that species' agromorphological characteristics are the link between farmers and the crop genetic diversity in their fields.

It is important for us to understand how farmers make use of their crops' agromorphological characteristics in three different capacities. First, agromorphological traits are used by farmers to **identify**, or distinguish, varieties; these identifying characteristics are often the basis for the names farmers give to varieties. Second, some of these traits are **preferred**, or valued, by the farmer; that is, the farmer chooses to plant a particular variety because certain of its distinguishing characteristics are desirable. Third, farmers **select** among the plants in the crop population to maintain these desirable characteristics and to increase the prevalence of other valued traits in the population over time. For instance, a farmer may identify a named variety of maize by its colour, leaf shape and region of origin, value it for its cooking quality, and select for higher-yielding plants to increase the yield potential of the variety.

Burkinabé farmer selecting sorghum seeds with preferred characteristics in the field.

4.2 Farmer variety names

Recognizing the names farmer give to varieties is important because the "farmer-named variety" is the unit that farmers manage and select over time. The name or description of a farmer's variety may be related to the **original source** of the material and the **morphology** of the plant (colour, shape, height, growth habit, etc.). Both names and the traits that define these names also may be related to **agronomic performance** of the variety, such as flowering time, earliness and yield with or without inputs, or to the varieties' **adaptation** to particular **environmental factors**, such as to type of soil or resistance to certain diseases. Names and traits also may be related to the **use** of the material, such as rapid cooking time, taste, use for straw or other parts of the plant, or role in a religious ceremony. Farmers perceive these factors at various stages in a plant's development, from seedlings to flowering to fruiting. Thus, the factors which farmers use to identify and shape farmers' varieties are complex and interrelated, as sets of agromorphological criteria combine to define a landrace.

When collecting information from farmers it is important to note down the exact name of each variety as given by the farmer, without modifying it, using the local alphabet if possible.

Category	Possible agromorphological criteria
Origin/source of the material	village, region, county, farmer, local market
Morphology	colour of stem, leaf or seed shape of leaves, seed or fruit, disposition of flowers and fruits on the stems plant height pod/cob/ear/rhizome length or width
Agronomic performance	yield and yield stability flowering time earliness seedling vigour growth habit
Environmental/ecological adaptation	resistance to pests and diseases tolerance of water stress and harsh conditions tolerance to salinity tolerance to cold and high temperatures
Use	taste cooking time nutritional value fodder type of preparation association with religious ceremony

Example: Farmer characterization of sorghum varieties in Mkulula village, Tanzania. Farmers ranked the performance of their varieties; data were collected during group interviews in Mkulula village.

	Variety						
Characteristic	**PN3**	**Msabe**	**Kasao**	**Sanyagi**	**Kilezilezi**	**Tegemeo**	**Mihenduno**
Grain yield	good	average	good	good	good	good	average
Grain size	average	average	good	average	average	large	good
Head size	good	average	loose, large	good	large	loose, large	average
Drought tolerance	good	good	very good	good	very good	very good	good
Time to maturity	very early	medium	medium	medium	early	early	medium
Stover yield	poor	good	good	good	average	poor	average
Use of stem	poor	good	good	good	food	average	good
Bird resistance	poor	good	good	good	good	poor	good
Disease resistance	poor	poor	good	poor	good	good	good
Insect resistance	poor	poor	good	poor	good	good	poor
Threshing ease	good	average	good	average	average	good	average
Dehulling ease	good	poor	good	poor	average	good	poor
Grain colour	white	dark red	white, black	red	dark red	cream	pink
Grain taste	very good	poor	good	good	average	good	average
Grain storability	good	good	good	good	good	good	good
Brewing quality	very good	good	good	good	good	good	good

Source: Friis-Hansen 2000.

4.2.1 Consistency in naming varieties

Farmers may or may not be consistent in naming and describing landraces. One farmer's name for a landrace may well be the same name that other farmers in the village give to the same variety. This consistency may only be at the level of the village and not any wider. In contrast, it may happen that even within a village, different farmers may have different names for the same landraces.

The name may vary with gender or age or ethnic group. It is important to investigate across the area of study whether what farmer A calls landrace X is genetically the same as what farmer B calls landrace X. Likewise, two farmers might use different names for their landraces, although genetically they are highly similar. For this reason it is important to understand what specific agromorphological traits farmers use to name a landrace and to answer the question: do all farmers recognize the same local cultivar with the same name using the same traits? Cross-checking information and data is critical to link plant features to the name of a landrace. This requires intensive investigation with farmers and visits to the field during all stages of crop development. Clarification of what constitutes a landrace at each scale (village, community, region) is the first step toward defining the amount and distribution of crop diversity maintained by farmers.

Example: Mayan maize variety names in Yaxcabá, Mexico.
In Yaxcabá, Yucatan, Mexico, farmers' Mayan terminology for their maize classification system identifies maize varieties by grain colour and time to maturity.

Racial type	Variety (Mayan name; grain colour)	Cycle	Field trial[†]
Nal-tel	Kan-nal; yellow	7 weeks	Nal-tel
	Sac-nal; white		Nal-tel
Xmejen-nal (nal-tel x tuxpeño)	Kan-nal; yellow	2.0 months	Xtup-nal
	Sac-nal; white		Xtup-nal
	Kan-nal; yellow	2.5 months	Xmejen-nal
	Sac-nal; white		Xmejen-nal
Tsiit-bacal (dzit-bacal)	Kan-nal; yellow	3.5 months	Dzit-bacal
	Sac-nal; white		Dzit-bacal
	Sac-nal; white (colmillos) [‡]		Dzit-bacal; colmillos
Xnuc-nal (tuxpeño)	Kan-nal; yellow	4.0 months	Xnuc-nal
	Sac-nal; white		Xnuc-nal
	Pix-cristo; yellow-reddish		Pix-cristo
	Xhe-ub; purple-white		Xhe-ub
	Chac-chob; red-hot		Chac-chob
	Xgranada-nal; as pomegranate		Xgranada-nal
	Xwob-nal [§]		Not included

† Relation of maize varieties used to do the dendrogram and PCA.
‡ This material was included as a variant of Dzit-bacal. The principal characteristic is that the grains look like “a fang”.
§ This variety was not sown in the trial because there was not enough seed. The characteristic of this material is that in the farmer's field sometimes the ears have three or four branches.
Source: Arias *et al.* 2000.

Once there is a clear idea of what traits farmers use to name their varieties, a list of criteria for each named variety can be compiled. Some of these criteria may be **heritable**, i.e. they are inherited by the offspring, while others may be influenced by the environment where the landrace is grown. Therefore, when the landrace is grown in another environment, for example a different soil type, it may no longer express the same traits that a farmer uses to distinguish it.

agromorphological traits are normally measured in field evaluation, greenhouse and laboratory trials, which are discussed later in this chapter. These tests serve to quantify the differences between farmer-named varieties and show whether there is more diversity *between* than *within* varieties. If the between-varieties diversity is higher than within, we can look at these varieties as distinct units from a genetic point of view. If not, it will be necessary to get a better understanding of the traits farmers use to distinguish these varieties and explain why they do not correspond to empirical measurements. Gathering this information requires investigations and discussions with farmers at different stages of plant growth throughout the growing season. In this way the list of criteria is progressively refined.

Example: Morphological variability in barley within a single upland plot in Wujin County, Jiangsu Province, China.

In a field study of village ecology in China's rapidly developing Tai Lake Region (Ellis and Wang 1997; Ellis *et al.*), some farmers' varieties still show great genetic heterogeneity. These three barley stalks were taken from a single plot of less than 0.05 ha. Even though this region has been an early adopter of Green Revolution varieties, farmers still select their own seeds, especially for crops harvested for household use.

4.2.2 Differentiating named varieties

After farmer-named varieties are defined and deemed to be consistent units at some scale (the village or community), it is necessary to know the nature of differences among them. Do all varieties contain the same amount of diversity or do a few varieties represent the majority of the diversity within the community, or within the region? In Mexico it was found that the 15 maize varieties in the small community of Yaxcabá in the Yucatan peninsula contained most of the diversity for the whole Yucatan Peninsula, as measured by agromorphological traits (Arias *et al.* 2000; see example).

It may be that some of the *rare varieties* in a village or region are selections from some of the *common varieties* and that the common varieties contain all the diversity found in the rare varieties (discussed in Chapter 5). Analyzing this problem would entail examining a set of rare varieties and comparing them with common ones. These questions are necessary to understand the link between the farmer's recognized unit – his or her named variety – and the amount of genetic diversity within the system he or she manages.

4.3 Farmer choice of preferred or valued characteristics

Farmer's preferred or valued characteristics for a given variety may be distinct from those used to distinguish or name a variety. The characteristics farmers value in their varieties may relate to agronomy (e.g. yield, drought resistance), use (e.g. cooking or fodder quality) or aesthetics (e.g. colour, shape). Understanding how farmers in different situations value these characteristics will be important in creating strategies to support farmers in on-farm conservation. The traits valued by farmers in a particular variety may vary across a community or even within a household by gender or age. A method for studying the value to farmers of their varieties was discussed in Section 2.4.2. These preferred characteristics also may be the basis for farmers to direct change in variety populations over time, as farmers may practise selection to increase the prevalence of those desirable traits in the population.

Example: Men's and women's preferred maize characteristics in Oaxaca, Mexico

In the Central Valleys of Oaxaca, Mexico, both men and women in 240 survey households were asked to rate a set of 25 maize characteristics in terms of their importance (not important, somewhat important, very important). This table shows the percentage of men and women respondents who rated each maize characteristic as “very important.” For all respondents taken together, the most important five characteristics were, in decreasing order of importance: (1) drought tolerance, (2) resistance to insects in storage, (3) disaster avoidance (produce “something” even if a bad year), (4) yield by weight, and (5) the taste of tortillas. The relative importance of some characteristics differs between men and women, however. For example, grain yield is more important to men and the taste of tortillas is more important to women. Another step in the analysis, which is not shown here, was to ask men and women the extent to which they thought different maize types met these needs. The analysis revealed recognizable differences in the perceived performance of certain landraces and modern types by characteristic – with modern maize types particularly weak on consumption traits and superior for fodder and grain yield under favourable growing conditions.

Men and women’s perceptions of most important maize variety characteristics

		Percent of decision-makers rating characteristic as "very important"	
Characteristic		**Men**	**Women**
Agronomic			
grain weight (kg/almud)+		76.3	76.6
grain yield (kg/ha)		52.8	66.1
length of growing period		46.5	46.9
produces "something" even in bad years	*	63.8	89.8
drought tolerant		91.1	89.9
weed tolerant		26.7	39.8
disease resistant	*	31.5	61.4
resistant to insects in storage		79.7	75.5
Consumption-related			
taste of tortillas	*	50.8	78.4
good for atole	*	34	60.2
good for tamales	*	14.9	38.4
good for pozol	*	8.3	25.4
good for tlayudas		27.5	50.7
good for forage		30.9	51.4
good for feed		37.1	50
Management			
good for sale		32.4	53.6
produced with little labour		37.4	43.5
produced with few purchased inputs		48.2	57.5

* Chi-square test of homogeneity shows significant differences between men and women at the 0.1 level of significance

Source: Bellon *et al.*, Identifying maize landraces for participatory breeding: a case study from the central valleys of Oaxaca, Mexico. Unpublished manuscript. CIMMYT.

4.4 Farmer selection of agromorphological characters for the next generation

The characteristics used to distinguish a particular variety may differ from those characteristics that the farmer actively selects in the next generation of the plant population. By studying the criteria or management practices farmers use to select characteristics for the next generation, one can ascertain to what extent the selection of seeds for the next generation limits geneflow between varieties. Moreover, this selection process is one important force that will direct or maintain characteristics of the population over time.

When new genetic diversity becomes apparent in a population, whether from within a population (by hybridization, introgression or mutation) or outside a population (by migration as farmers introduce new seeds), farmers may select for or against the new characteristics, depending on their level of desirability. Farmer selection may be confounded with environment selection over time. Since plants with traits best adapted to the specific environment have better chance of survival, the seed for the next crop will contain a larger proportion of these adapted and preferred traits than the seed used for the previous crop.

4.4.1 Seed selection practices

In the process of selecting for varieties based on agromorphological characteristics, the practices farmers use may be a factor influencing the maintenance of genetic diversity on-farm. Practices associated with seed selection that may influence the genetic structure of varieties over time include: selection in the field versus in post-harvest storage, from a particular plot or designated area of a plot, if all or part of the grains taken from a cob, panicle or pod are used for seed. For maize in Mexico, for example, the grains on the ends of the cob generally are not used as seed. Cultivation techniques, such as high density in the seed-hole, elimination of unwanted plants during growth, or elimination of unwanted male flowering plants, may act as selecting forces. Farmers may select at the level of the ear or panicle or at the level of the seed. The time of selection may be done on the basis of reproductive organs or on vegetative characteristics, if these are considered important. There also may be ritual practices associated with selection of seeds or preparation of seed before planting.

These practices themselves may exert a selection force on the seed lot or crop population, influencing the survival of seeds for the next planting season, and thus affecting the genetic basis of the variety over time. As argued by Bellon and Brush (1994) in their study of maize in Chiapas, Louette and Smale (2000) show that the traditional seed selection practices of Mexican farmers conserve the integrity of the ear characteristics that define their varieties even in the presence of significant geneflows due to cross-pollination. Seed storage practices, discussed in Chapter 6, may further affect the genetic diversity maintained on-farm for these reasons. As with other farmer decisions and actions regarding on-farm conservation, these practices may vary with gender or other socioeconomic categories; information must thus be collected from different groups to understand who is involved in the processes maintaining genetic diversity over time.

Vietnamese farmer selecting rice seeds; storage containers are to her left.

4.4.2 Consensus of selection criteria and methods among farmers

In addition to consistency in variety names, it is important to find the level of consensus between farmers on selection criteria for the next generation. Are all farmers using the same selection criteria on the same landraces in the community, across communities?

4.5 Ranking of traits

In order to understand farmers' use of these characteristics, interviews with farmers should elicit their criteria for identification, valuation and selection of their varieties. The criteria in each of these categories can then be ranked by farmers in order of importance. Exercises in ranking traits by importance should be **disaggregated** by categories such as age, gender and socioeconomic status to highlight differences in how these groups identify, value and select their varieties.

Ranking agromorphological criteria should also yield insights regarding the basis by which farmers recognize new genetic diversity, whether from within a population (by hybridization or mutation) or outside a population (by migration as farmers introduce new seed). In either instance farmers are likely to categorize novel diversity using relevant agromorphological criteria; if the traits are considered valuable, the diversity will be encouraged. The toolbox of techniques often referred to as Participatory Rural Appraisal includes different methods of eliciting rankings from farmers (see Chapter 8).

4.6 Measuring agromorphological data

Researching the agronomic and morphological characteristics of crop varieties is central to on-farm conservation research in two ways. First, the systematic measurement and analysis of specific agromorphological traits are a common way to gauge plant genetic diversity. Second, farmers use agromorphological traits to identify and select crop varieties, making these traits a direct link between farmer behaviour and genetic diversity.

One agromorphological characteristic is phenotype, which results from the interaction between the genotype and the environment. As a result they can only be used as indirect measures of genetic diversity. Genetically homogenous local crop populations in slightly different agroecological niches could have very different phenotypic qualities, and some morphological characteristics will be affected by the environment more heavily than others (Newbury and Ford-Lloyd 1997). Likewise distinct local varieties may appear similar in different environments.

Measuring and analyzing agromorphological characters is also a way of arriving at empirical understandings of farmers' perceptions of the traits which are used to recognize and distinguish between crop varieties. This is important to understand how individual traits, and the groups of traits which are used to identify landraces, are selected and managed by farmers. This approach is of additional value because the agronomic and morphological characterization of crop varieties is of direct relevance to farmers as well as plant breeders in their use of germplasm. Although it can be time consuming, collecting and analyzing data on agromorphological traits is inexpensive and relatively simple in comparison with other ways of measuring genetic diversity.

4.7 Field measurements and trials

The procedures for collecting data on agromorphological traits are standard whether the data are used for measurements of genetic diversity or farmers' traits. It entails taking physical measurements of various aspects of a plant's morphology or agronomy under different experimental conditions or **treatments.** Plant morphological traits, such as seed size or colour, can be measured. Agronomic traits include characteristics that refer to a plant's growth and performance, such as time to flowering or yield.

From each crop variety, two different sets of agromorphological data are needed. First, agromorphological measurements need to be taken from crop varieties growing in farmers' fields. Second, seed samples of each variety should be taken from the farmers' field and grown out in test plots under controlled environmental conditions. The first set of samples allows measurements of the phenotypic characters that farmers use to select their crops, as these characters are influenced by environmental factors in farmers' fields. These are classified as farmer-managed trials, where the crop is grown and managed according to the farmers' usual practices. The second set of samples, from on-station trials, allows researchers to establish which agromorphological characters are due to environmental conditions and which represent actual genetic diversity. If farmer-recognized traits are due largely to environmental conditions, this has implications for the management of genetic diversity on-farm.

Example: On-farm and on-station characterization of barley landrace diversity in Morocco

Traits	Farmers' fields	Station experiments	Traits used by farmers
Plant growth and characteristics			
Growth habit (1: erect; 2: semi-erect; 3: semi-prostrate; 4: Heterogeneous)	X	X	
Plant vigour (1: very low; 2: low; 3: intermediate; 4: high; 5: very high)	X	X	
Plant height (1: <75 cm; 2: 75-95 cm; 3: 95-110 cm; 4: >110 cm)	X	X	X
Stem characteristics	X	X	
Leaf width: (1: Large; 2: intermediate; 3: narrow)	X	X	
Leaf colour (1: dark; 2: intermediate; 3: clear)	X	X	
Disease susceptibility: (Leaf rust; Barley Yellow Dwarf Virus (BYDV); Net Blotch; Powdery mildew)	X	X	X
Plant cycle			
Date of maturity	X	X	
Date of harvest	X	X	X
Seed yield and yield components			
Spike characteristics (Spike length; spike density; awn colour; awn length)	X	X	X
Number of seeds/ spike	X	X	X
1000-seed weight	X	X	X
Seed characteristics	x	X	X

Example: Means and variation ranges for several traits measured on 13 faba bean local varieties at Rabat, Morocco, 1998/99 season (Sadiki *et al.* 2000).

Traits	Mean	Minimum	Maximum
Plant height at flowering (cm)	44.00	30.00	50.00
Number of pods per plant	21.00	11.00	40.00
Number of seeds per plant	72.00	24.00	120.50
Average grain weight (g)	1.15	0.65	1.66
Number of grains per pods	5.47	2.20	6.51
Yield per plant (g)	80.00	44.00	130.00

On-station characterization of faba bean landraces in Morocco.

The characters to be analyzed in the trial are referred to as **variates**; they can vary widely from crop to crop. For example, in characterizing the agronomic qualities of a maize variety, tassel length may be important. This will obviously be inapplicable for rice, for which panicle size may be important. The range of possible characters which can be measured in agromorphological analysis is summarized in descriptor lists. These lists have been published for most major crop plants.

4.7.1 Measurements of agromorphological descriptors

Descriptor lists usually present all the potentially relevant agromorphological characters for a species, which may number well into the hundreds. Characterization descriptors describe plant traits that are highly heritable, easily seen by the eye and equally expressed in all environments in order to distinguish phenotypes. Evaluation descriptors describe plant characters, such as yield, agronomic performance, abiotic and biotic stress susceptibility, and biochemical and cytological traits, whose expression may be affected by environmental factors. Collecting this breadth of data is impossible for the purposes of on-farm conservation research. These traits may or may not be directly linked to meaningful genetic diversity, as morphological traits result from the interaction between genetic and environmental influences.

Farmers are likely to be the most useful guides in narrowing the range of agromorphological characters to be studied. The main traits that farmers use to identify and select landraces, both preferred and non-preferred, should be of particular interest.

Identification tests to understand the criteria farmers use to describe their varieties can be organized with farmers by sowing several rows of each variety in a plot without the farmers knowing which varieties were used. Farmers can be asked to identify the varieties at several stages of the growth cycle of the plants: young plants, flowering stage, maturity stage of the fruit/ear/spike on the plant, and maturity stage after harvesting (without the presence of the plant).

Example: Comparative value for farmers' descriptors for taro (*Colocasia* spp.)

As part of the Nepal component of the IPGRI on-farm conservation research project, researchers investigated farmers' descriptors for taro in Begnas ecosite. For 18 taro samples displayed, farmers most frequently (in nine cases) used longer cormel size as the descriptor; the least used descriptor was the corm sheath (in only two cases). Compared with men farmers, women farmers examined samples more closely, using their own descriptors. The most common descriptors used by female farmers included bud colour, number of buds, number of cormels, and corm and cormel sizes. The important descriptors for men farmers were number of buds, bud colour, number of cormels and corm shape.

Comparative value for farmers' descriptors by gender (n=24), Begnas, Nepal

		Women		Men	
Descriptor	**Character**	**times used**	**%**	**times used**	**%**
Corm	Round shape	8	23.9	8	18.2
	Large size	4	27.0	6	15.3
	Smaller size	8	12.5	7	15.4
	White bud colour	10	35.0	8	17.2
	Red bud colour	8	45.3	8	24.4
	Bud per corm	7	41.7	7	29.2
	Depressed buds	5	26.7	6	22.2
Cormel	More number	7	20.8	8	23.4
	Less number	6	31.9	8	13.0
	Large sized	6	29.2	5	15.3
	Longer	6	19.4	9	14.2
Sheath	Heavy or thick	2	12.5	2	16.8
Root growth	Cluster	3	19.4	3	26.4

Note: Above percent is calculated as total cumulative score obtained for each descriptor / × descriptor actually used across varieties × a potential response of total number of farmers (n=24) expressed in percent.

Characterization on-farm of rice landraces, Kaski, Nepal.

On-station characterization and evaluation of alfalfa landraces, with modern varieties used as a control, in the Errachidia oasis area, Morocco.

Additional evaluation criteria may be identified by the researchers based on local observations; potentially useful characters should be chosen according to crop specificity, heritability and the potential for high diversity within the trait (Brown 2000). The number of agromorphological characters to collect may be reduced through statistical methods such as ordination (see Chapter 3). In Mexico, principal component analysis (PCA) was used to determine that seven agromorphological characters accounted for 85% of the variability encountered in 15 varieties of maize (Sanchez *et al.* 1993; Arias *et al.* 2000). Depending on the variables (traits) to be measured, data are collected at the plant level, the plot level and the experimental level.

Eigenvalues and eigenvectors of first principal components with descriptive variables of 15 maize landraces (Arias *et al.* 2000)

	CP1	CP2	CP3
Eigenvalue			
Eigenvalues	3.450	1.725	0.775
Proportion of variance explained (%)	49.3	24.6	11.0
Proportion of variance cumulative (%)	49.3	73.9	85.0
Eigenvectors			
Ear length (cm)	0.365	–0.470	0.250
Ear diameter (cm)	0.200	0.415	0.762
Weight of corncob per plot (kg)	0.335	0.461	–0.443
Yield per experimental plot (kg)	0.452	0.056	–0.379
Plant height	0.476	–0.180	0.070
Ear height	0.477	–0.274	0.042
Weight of grain in the plot (kg)	0.235	0.532	0.096

4.7.2 On-station trials

In on-station trials, **treatment** factors are the only variables, while everything else is kept as uniform as possible. For example, in population comparison trials, all cultural techniques are standardized and uniformly applied to all varieties and replicates. The other growth-influencing factors (i.e. meteorological, pedological, hydrological factors) in the experimental fields are usually controlled by grouping the treatments in homogeneous blocks. The principle of controlled field trials is to keep the non-treatment factors as uniform as possible, thus allowing maximum expression of differences between treatments. This cannot be applied to the same extent in farmer-managed trials, where heterogeneity of soils within a field cannot be controlled.

Populations are normally evaluated under different **variants** of conditions in a **factorial** design. These variants are called **treatments**. The choice of treatments will depend on the question to be investigated. For example, an experiment evaluating 4 populations at 2 levels of spacing for 3 planting dates has 3 **factors** (the **populations**, the **levels of spacing** and the **planting dates**), giving a total of 24 **treatments** with a factorial design of 4 by 2 by 3. The treatments are chosen when the trial objective is formulated. Each treatment should be clearly defined, and its role in reaching the objectives of the experiment should be precisely known.

Trials often include **control** treatments used as checks (or references) for comparison of the treatments being evaluated. For example, **improved** varieties in local population yield trials can be used to compare the adaptive advantages of local varieties compared to improved varieties. Controls also are used for testing resistance of populations to diseases.

The choice of the site for conducting field trials may be crucial in some cases and should depend on the trial objectives. For example, site choice will be crucial to evaluate drought tolerance, and experiments may need to be repeated over a range of sites and years. In contrast, for some disease studies, the experiments may be best laid out in large pots, and the results may be relatively independent of the sites being used, as long as the presence of high and even disease pressure is ensured. GIS can be used to assist in determining both the most appropriate sites for field trials and the area over which the results of a given trial are likely to be applicable.

Trial components

Plot: the smallest experimental unit in the field trial
Treatment or variant: comprises all plots with the same treatment
Replication: establishment of two or more plots with the same treatment
Block: it is either a complete block (contains a replication of all treatments) or incomplete block (contains only some of the treatments)
Randomization: it is a random distribution of the plots with all the different treatments within one block. The randomization is essential to be able to compute the influence of the soil and the effects of adjacent treatments.
Factor: Any unidentified substance involved in, or the causal agent of, a specific reaction or process.

The results of the trials are affected not only by the action of the treatments but also by undesirable factors (differences in soil properties within the trial field). These extraneous variations are termed **experimental errors.** These effects can be reduced by grouping the treatments into uniform blocks. The purpose of blocking is to enable populations to be evaluated with high precision and accuracy in detecting differences between treatments. The precision required determines the **experimental design** used for laying out the field trial. The difficulty of laying out and implementing increases with the increasing exactness of the design adopted. The experimental design is concerned with how treatments are combined, how the treatments are assigned to the experimental units, and how many times treatments are replicated.

There is no defined number of treatments to be included in a trial. Most often there are choices of putting all the factors in one large trial or splitting them into smaller trials as it is often difficult to use a large homogeneous plot compared with a set of small homogeneous plots. Large trials are recommended if all the treatments need to be compared with each other. Large trials are more difficult to manage and collecting an enormous quantity of data may be beyond the capacity of the technical personnel.

4.7.3 On-farm trials

In **on-farm trials** the on-station practices of imposing uniformity and planting crops at a fixed time and prescribed density are not possible. Mutsaers *et al.* (1997) recommend that uniformity should be discarded and that the trial should be superimposed in a field chosen by the farmer, planted at a time the farmer would normally plant, and managed in his or her way. Non-treatment variables are not controlled but replaced by recording the farmer's actual practices. Different statistical approaches are needed to analyze this type of information, and a larger number of farmers is required to capture the entire range of variation in management practices (Mutsaers *et al.* 1997). An excellent guide for on-farm trials design and statistical analysis of uncontrolled variation in farmer-managed trials is Mutsaers *et al.* 1997, *A Field Guide for On-Farm Experimentation*, particularly Chapters 6 and 7, which we recommend as supplementary materials to this Training Guide.

Trial designs

Randomized complete block design (RCB)
In this design each block (one replication of all treatments) is complete, i.e. it contains all treatments once. The design is suitable for single-factor trials as well as multi-factor trials. The treatments are randomly distributed with each block, i.e. they are allocated randomly to experimental units within each replication. The number of replications often varies between 4 and 6 depending on soil heterogeneity. The RCB design has many advantages. It is the most accurate design for most types of experimental work. It offers flexibility in the number of treatments and number of replications. Control treatment may be introduced more than once. However, when there are more than 15 treatments, replications must be broken into partial series if the treatments do not need to be compared with each other. The statistical analysis of RCB design is simple and rapid. The principal disadvantage of this layout is when the trial should include a large number of treatments. This leads to large complete bocks which may be heterogeneous.

Latin square design (LS)
In this design treatments are allocated in two directions. The experimental area is divided into rows and columns and each treatment must appear once in a row and once in a column. Therefore treatments are randomized into row and column replicates. The number of replications is equal to the number of treatments. With the two-way stratification the LS design offer a good control of the field variation. It is suitable for single or multi-factor trials involving a small number of treatments (often less than 10).

Randomized incomplete block design (RICB)
The number of treatments to be tested together in single experiment is usually so large that it becomes difficult to find replicates that are homogeneous. The variation tends to increase as the replicate size increases inducing large experimental errors. Thus it is critical to maintain block size small. Therefore for large trials (with high number of treatments) only a portion of treatments may be included in a small block resulting in **incomplete block** layout. The whole replicate is divided into small incomplete blocks. The optimum size of each block depends upon the nature of experimental area and material. The variation between incomplete blocks is removed allowing for a smaller experimental error that if the trial was designed as RCB. Most often check treatments are included in each incomplete block. RICB offers a good flexibility for scientists in designing trials that are more suitable for their situation. This design is very used when analysing variability among local germplasm entries.

Lattice and alpha designs
Lattices are special cases of incomplete block designs. A great number of treatments can be included in the same trial with a smaller number of replicates but with the same degree of precision as RCB.
The number of treatments is always a perfect square (9, 16, 25, etc.). Replications (“lattices”) and blocks are not identical. The number of treatments in each incomplete block is equal to the square root of the total number of treatments. Any particular two treatments should not appear more than once in any one of the blocks. In order to evaluate all the treatment differences with the same degree of precision, the lattice should be balanced: every treatment is compared with every other treatment an equal number of times in the incomplete blocks.

Augmented design
Augmented designs are laid out in only one replicate. They are suitable for trials including a large number of populations and when the amount of seed is limited and is only enough for one replicate. Controls (or checks) are repeated systematically in the experiment to control the environmental heterogeneity. Examples of experiments using augmented design: screening plant entries for resistance to diseases, where checks consist of resistant and susceptible genotypes replicated in systematic pattern. The replicated checks measure the variation across the trial and the variables (traits) of the unreplicated entries are assessed against that of adjacent checks.

4.8 Laboratory experiments

In addition to field evaluations, laboratory and greenhouse evaluations may be necessary to distinguish different degrees of adaptive and quality traits that farmers may have identified. The elasticity of tortillas, cooking time of faba bean, etc. are traits that can be analyzed using laboratory techniques to quantify differences between farmer-named varieties. Some agronomic traits such as disease resistance and tolerance to abiotic stresses (water deficit, salinity, etc.) can be easily evaluated using precise laboratory or greenhouse screening techniques for better characterization of the genotype differences among landraces. The resistance of sorghum to post-harvest pests also can be tested (Teshome *et al.* 1999). The structure of the genetic variability between and within farmer-named varieties also may be described using biochemical molecular markers discussed in the next chapter.

Example: Confirming farmers' knowledge of sorghum landrace storability in Ethiopia

This study assessed farmers' knowledge of sorghum landraces' resistance in storage to insect pests. Farmers first categorized their landraces according to the level of resistance to rice weevil [*Sitophilus oryzae* (L.)] in storage. Resistance of the landraces was then measured by the researcher through standard susceptibility tests, which involved the introduction of 25 7-day-old weevils into 25 grams of each landrace, kept at constant temperature and relative humidity. After 7 days, the insects were removed but the eggs left to hatch. Beginning at the end of the fourth week after the original infestation, insect emergence was counted every other day for 3 weeks, enabling calculation of the Dobie Index. After the emergence count, the sorghum samples were weighed to determine the amount lost to the infestation. Dobie index, F_1 emergence, median development period, oviposition and weight loss for all sorghum samples were used as measures of susceptibility. The level of the landraces' susceptibility to rice weevil according to these measures correlated highly with farmers' categorization of the landraces' susceptibility.
Source: Teshome *et al.* 1999.

Nutrient content is another criterion that serves to distinguish varieties based on a potentially useful characteristic. A nutrient, or bromatological, analysis is a means to examine a food for the content of specific macronutrients (carbohydrates, proteins and fats) and/or micronutrients (vitamins and minerals). Nutrient analyses can serve to validate farmers' knowledge of the beneficial nutritional properties of specific varieties and to identify nutritional benefits unknown by farmers. This information can be taken into account in participatory crop improvement activities, as well as in adding-value actions through quality, depending on farmers' interests.

Example: Bromatological analysis of maize varieties
Bromatological analysis was used as one means of measuring the diversity of maize landraces from a village in the Yucatán, Mexico. The Instituto Tecnologico de Merida performed a nutritional analysis for 13 samples of maize after agromorphological and isozymic characterization. The analysis involved examining differences in humidity, fat, mineral and protein content among populations. According to the results of the analysis, nutrient content does not clearly correspond to racial type in these maize populations. Moreover, the differences in nutrient content between populations are not significant from a human nutritional perspective. A more detailed analysis of differences in amino acids, which may show greater variation than the other nutrients analyzed for maize, may be undertaken in the future. The average nutritional composition of the 13 landrace populations analyzed is presented below.

Population analyzed	Humidity (%)	Mineral (%)	Fat (%)	Protein (%)
Xhe ub	11.00	0.993	4.485	9.98
Tsiit bacal (yellow)	10.06	1.092	4.755	9.06
Xnux nal, chac chob (purple-yellow)	12.05	1.068	4.640	9.02
Chac Chob (red)	10.74	0.918	4.980	9.82
Xnuc nal (yellow)	9.28	0.979	4.950	10.56
Nal tel (white)	10.70	1.279	4.840	11.55
Pix cristo (yellow)	11.22	1.053	5.080	10.82
Xmejen nal (white)	11.35	1.278	4.745	12.08
Xmejen nal (yellow-red)	10.37	1.285	4.980	13.11
Nal tel (yellow)	10.22	1.411	4.985	10.89
Xtup nal (yellow)	11.46	1.409	3.529	11.31
Tsiit bacal (white)	11.27	1.173	4.506	11.13
Xnuc nal (white)	11.34	1.310	4.874	10.17

4.9 Measuring diversity using agromorphological data

The first step in analyzing agromorphological data usually involves compiling a data matrix. This is essentially a table in which data points (an entity, such as an individual, variety or population) are placed in rows, while the different categories of observations (i.e. the agromorphological traits) are placed in columns.

	Traits				
Samples					

Once data are in the form of a basic data matrix, **univariate** analysis can be used to describe different specific variables. More importantly, **bivariate** and **multivariate analysis** can be used to identify patterns and associations among variables within the data. Of interest to us are:

- Analysis of variation in each character.
- Analysis of relationship among characters.
- Partitioning of variation within and between populations, sites, sampling times.
- Analysis of relationships between results obtained from different sets of characters.
- Analysis of relationships among individuals, populations, sites, sampling times.

4.9.1 Univariate data analysis

Univariate data analysis is used to describe the total range and variation of a single agromorphological trait for a population as an **exploratory** step in the analysis. Traits may vary continuously (for example, quantitative traits, such as plant height, plant biomass, etc.) or discontinuously (such as colour or flowers, presence or absence of disease resistance). Most qualitative traits are discrete variables.

In univariate data analysis, common calculations are (1) **frequency distribution** – or the sorting of values according to the number of observations, (2) **mode** – the value which occurs most commonly in a frequency distribution, (3) arithmetic **mean** – the average of all values of the ***a*** variable, (4) **median** – the observation located halfway between the smallest and largest observations, (5) **range** – the difference between the highest and lowest values in the data set, and (6) **standard deviation** – the average difference between the arithmetic mean and the value of each observation in a data set. When univariate data have been collected from a set of local varieties grown in the same standard design experiment (4.8.2) **analysis of variance** is used to estimate genetic variance between entities (varieties, populations, regions, sites).

Diversity indices are measurements of diversity that include **richness**, the number of varieties or traits of a given variety, and **evenness,** the frequency of occurrence (e.g. observations distributed evenly among categories result in high diversity). Diversity indices can be used to allow comparisons within and between different populations. These indices can later be correlated with other factors. A large number of diversity indices exist. For quantitative (see above) agromorphological data, the **coefficient of variation** (CV) is commonly used. For qualitative or nominal scale agromorphological data the **Shannon Weaver Index** is common.

Examples of univariate analysis

Variation of plant height of durum wheat landrace can be described in a given environment using mean, median, mode, range, standard deviation.
Disease resistance to chocolate spot in faba bean may be described using the relative frequency of disease reaction class defined by a 0-5 scale visual score, namely: highly resistant (score 0), resistant (score 1), moderately resistant (score 2), moderately susceptible (score 3), susceptible (score 4), highly susceptible (score 5).

Qualitative and Quantitative descriptors

[Hd1] Qualitative descriptors

Qualitative descriptors are measured using nominal scales. This means that the different descriptor states represent different classes, but they cannot be ranked in any meaningful way (e.g. the ranking of white < red < green is not particularly meaningful).

Example: Qualitative descriptor scales
Cotyledon colour

1	Ivory (white group 155A)
2	Cream (yellow-white group 158B)
3	Yellow (yellow-orange group 20B)
4	Pink (red group 38B)
99	Other(s)

[Hd1] Quantitative descriptors

Quantitative descriptors are recorded using ordinal scales, meaning that their values can be compared to each other and ranked in a meaningful manner. The scale used may be continuous or discrete

[Hd2] Quantitative descriptors on a continuous scale

One way of recording quantitative descriptors is by actually scoring the measurement in exact units such as the Système International d'Unités (SI).

[Hd2] Quantitative descriptors on a discrete scale

Quantitative descriptors also can be scored on a discrete scale. In these cases a certain range of (continuous) values is grouped in discrete classes. These descriptor states representing discrete classes are sometimes a good measure to describe diversity within the crop or genepool.

For some descriptors the fact that they can be ordered from "very low", "intermediate" to "very high" without exactly defining the distances between the classes is sufficient. A common coding scheme for this type of scale where the descriptor state is scored on a 1 (weakest expression) to 9 (strongest expression) scale is provided below:

1	Very low	6	Intermediate to high
2	Very low to low	7	High
3	Low	8	High to very high
4	Low to intermediate	9	Very high
5	Intermediate		

Example: Quantitative descriptor using discrete classes

Female inflorescence	Fertility percentage
Low	(=< 40%)
Intermediate	(>40% and <80%)
High	(>=80%)

[Hd1] Descriptors using a binary scale

Both quantitative and qualitative descriptors can be scored on a binary scale (yes/no, absent/present). The following standard coding is used:

Example: Qualitative trait, binary scale
Leaf lamina appendage

0	Absent
1	Present

Example: Quantitative trait, binary scale
Occurrence of short plant (<25 cm)

0	Absent
1	Present

4.9.2 Bivariate data analysis

Bivariate analysis consists of tests for comparing two sets of data, for example comparing two varieties or two populations for disease resistance classes, or comparing observed phenotypic classes in one population with the expected series. The most common technique is the **Chi-Square** test, which is particularly useful for testing goodness of fit between observed frequencies and expected frequencies.

> **Example of bivariate data analysis**
>
> Comparison of a local population to a known established variety (check) for a qualitative trait distributed according to classes such as flower colour.

4.9.3 Multivariate data analysis: genetic distinctiveness and farmer-variety names

Multivariate analyses allow the use of all information available simultaneously (multitrait analysis). Techniques for multivariate analysis have been presented in Chapter 3. These techniques can give **similarity indices,** which measure the degree to which the populations of samples are alike, or **dissimilarity coefficients**, which measure the degree to which two populations or individuals are different in composition.

For agromorphological traits, these techniques may be used to:

- characterize the variation between and within crop varieties
- compare genetic variation with farmer variety names
- compare the variation of one site with another.

The first step in multivariate analysis is to derive from the basic data matrix either a matrix correlation among variables (e.g. PCA) or of similarities or distances among samples (e.g. PcoA). There are various ways of calculating similarities and distances, some of which are listed in the Box.

> **Example: Characterization of rice diversity with agromorphological traits in India**
>
> Multivariate analysis of agromorphological traits was used to characterize rice diversity in selected villages of Madhya Pradesh, India. Farmers' names for their varieties were found to reflect the general pattern of variation. The pattern of variation, differences between modern and traditional varieties, and differences within named varieties were examined with PCA. PCA revealed that three traits (days to 50% flowering, plant height, number of grains per panicle) explained 35.7% of the total variation. Grain width and shape explained another 17.2% of the variation, and grain weight and yield per plant explained a further 13.1% of the variation. PCA also showed a continuum of diversity rather than clear clusters.
> (Source: Motiramani *et al.* 2000)

Example: Analyzing the consistency and distinctiveness of farmer-named sorghum varieties in Ethiopia

Collected samples of sorghum landraces from North Shewa and South Welo, Ethiopia were analyzed for variation in selected morphological characteristics using cluster and multivariate analyses. Canonical Discriminant Analysis (CDA) and Modeclus cluster analysis were used to determine whether the samples could be grouped based on these morphological characteristics. CDA also was used to test farmers' consistency in naming landraces. These analyses confirmed that the sorghum landraces are variable populations that can be grouped into three categories and that farmers' names for landraces in the study areas are consistent and define phenotypically distinct units.
(Source: Teshome *et al.* 1997.)

Similarity measures for binary characters

Simple matching coefficients
Jaccard's coefficient

Other measures of similarity, dissimilarity and distance

Euclidean distances
Mahalanobis' generalized distance
Gower's similarity coefficient (useful measure of similarity when describing mixture of binary, qualitative characters with more than two states and quantitative characters)

Quantifying diversity using quantitative data

Coefficient of variation (CV)
Analysis of variance

(1) CV for only one category
The coefficient of variation (V) expresses sample variability relative to the mean of the sample – it is also called a measure of relative variability or relative dispersion.

V = s / X, or V = s / (100%)

where s = standard deviation, X= mean, and since s/X is generally a small quantity, it is frequently multiplied by 100% in order to express V as a percentage. Since s and X have identical units, V has no units at all, a fact emphasizing that it is a relative measure, divorced from the actual magnitude or units of measurement of the data.

(2) Shannon Weaver Index for more than one category
If a set of nominal scale data may be considered to be a random sample, then a quantitative expression appropriate as a measure of diversity is that of Shannon (1948):

$$H' = -\sum_{i=1}^{k} p_i \log p_i$$

where k is the number of categories and p_i is the proportion of the observations found in category i. Denoting n to be the sample size, and f_i to be the number of observations in category i, then $p_i = f_i/n$, thus eliminating the necessity of calculating the proportions. Unfortunately, H' is known to be an underestimate of the diversity in the sampled population (Bowman *et al.* 1971); however, this bias decreases with increasing sample size.

Quantifying diversity using qualitative data

Simpson's Index
Shannon-Weaver Information Index

4.10 References

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Chapter 5 Crop population genetics and breeding (mating) systems

(with the collaboration of A. Amri, J. Bajracharya, B.K. Baniya, A. Birouk, F. Castillo-Gonzalez, J.L. Chávez-Servia, N. Dudnik, N.N. Hue, S.P. Khatiwada, D. Louette, J.L. Pham, V. Ramanatha Rao, D.K. Rijal, A. Tan and J.-D. Zongo)[1]

[1] Photo credits: Pp. 73, 82: D. Jarvis; P. 80: A. Tan.

5.0 Objectives of this section

By the end of this module the reader should have an understanding of:

- The basic principles of population genetics that are useful for describing plant genetic diversity and its conservation
- The basic elements of plant reproductive biology and their relevance to on-farm conservation
- How farmer management affects crop population structure.

5.1 What is plant population genetics?

Plant population genetics is a branch of plant population biology with three aims. These are: (1) to describe the genetic diversity within and between the populations of a plant species, (2) to estimate the strength of evolutionary forces that shape these patterns of diversity, and (3) to develop theoretical models that predict the stability and change in these patterns. Thus population genetics is one of the basic disciplines underpinning the scientific basis of on-farm conservation, providing a framework and procedures for monitoring diversity.

A **population** can be defined as a group of crop plants from the same species that are grown together in a particular locality and share a common genepool. A population could be thought of in genetic terms, such as a particular landrace or a group of landraces comprising a species. In addition a population is the unit of management, fixed by the farmer. The procedures that the farmer uses to plant a field, to harvest the material, and to acquire or store the propagules for the next planting will define the effective shared genepool. Thus our working definition of a plant population for on-farm conservation is the unit of management of a farmer, normally a single landrace growing in a single field (Jarvis and Hodgkin 2000).

The genetic diversity of crop species is present on-farm at two basic levels: **within** each population or field of the species, and **between** different populations. This section focuses on a number of key characteristics or parameters of plant populations, and the processes that alter population genetic diversity and the way it is apportioned among populations, namely:

- population structure (size, maturity and connectedness)
- reproductive biology and dispersal patterns (mating, pollination, seed dispersal)
- selection, mutation, recombination and genetic drift.

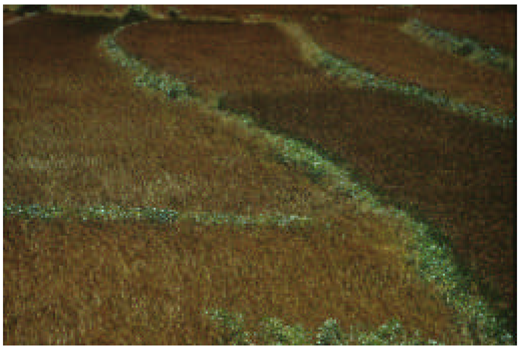
These are discussed along with their importance in on-farm conservation and the concept of minimum viable population size. Examples from on-farm conservation projects help to show how these principles operate in practice.

5.2 Population structure

Population structure refers to variation in size, maturity and connectedness among the various populations of a species in a region. Population structure takes into account the numbers and age range of individuals and their occurrence in the several populations over space and through time.

5.2.1 Size

The size of a population is the number of individuals of a species or variety present in a given area. The size of a landrace population could be measured within a field, or within a village or large unit if there is a consolidation of material at each generation. For example, if one farmer's field provides all the seed or tubers for planting the next generation for the whole village, then all the fields thus derived comprise one population. Not all members in a total population might exchange genetic material. Self-pollination may preclude intermating, some individuals may be sterile, or pollen dispersal systems may limit the number or range of individuals that can reproduce. In predominantly self-pollinated species, such as barley, the population genepool fragments into separate lineages that would be totally genetically isolated, except for the rare outcrosses. The population size may still be large genetically, if the seed for planting the next generation comes from all of a large number of adult plants.



Size and fragmentation of farmer fields, such as these rice plots in Nepal, may affect the population genetic structure of the crop.

The size of a population has particular implications for its genetic composition. Populations may shrink rapidly owing to stochastic or catastrophic events, a phenomenon known as the bottleneck effect. In the wild, small populations are likely to suffer particularly from genetic drift and inbreeding depression. Key questions are: what are the sizes of field and numbers of individuals in different populations? The key step is at the time of seed harvest and selection for the next generation. In alfalfa in Morocco, a small patch of a field is selected for seed and nearby plants removed. In this example seed sampling defines the effective population size genetically, and this may be far fewer than the number of plants planted locally to one variety.

Plant population geneticists have a number of measures of species or variety abundance. **Frequency** refers to the proportion of spatial units in an area – such as fields in a community – that contain a given species or variety. **Density** is the number of individuals per unit area, such as per field. For instance, if a particular variety of fruit tree occurs once in every home's fields in a community, the density of that species is likely to be very low, while its frequency will be quite high.

The genetically **effective size** of a plant population is usually smaller than its actual size and depends on the extent to which all individuals contribute offspring to the next generation.

5.2.2 Minimum viable population size

The size, maturity, connectedness and breeding systems of a population create the framework for the concept of a **minimum viable population** (Frankel *et al.* 1995). The minimum viable population is a population size needed to have a level of diversity that will ensure the persistence of the population for a specific time (Frankel 1974; Soule 1987; Nunney and Campell 1993).

5.2.3 Maturity

Do individuals in a field differ in maturity? The timing of pollen production in a sexually reproductive population can have a major impact on the dissemination of genetic diversity. For instance, two landraces of a species that flower during different seasons will be largely unable to cross without human assistance, rendering them genetically isolated. Differential flowering times is an important mode of isolation between different landrace populations in an open-pollinated species like maize.

5.2.4 Connectedness: fragmentation and the metapopulation concept

Connectedness refers to the spatial distribution within and between plant populations. It also includes both the concepts of **isolation** of plant populations and **migration** of seed or of pollen between and within populations.

Recently the term **metapopulation** was devised to describe the way in which many populations may be partially isolated from one another with each one likely to go extinct locally, but be founded again as a colony from one of the other member populations in the network. Brush has pointed out that this model is applicable to small populations of a landrace dotted among large areas devoted to improved or exotic genetically uniform varieties. The key parameters in the network that determine effective population size overall are patch sizes, frequencies of local **extinction** and dynamics of **recolonization**.

One aspect of spatial distribution which is thought to affect landrace diversity is the relative **isolation of crop populations**. Is the current crop of distinct population composed of a limited number of small isolated plots? In many parts of the world, changing patterns of land tenure have meant that for small-scale farmers, single-large agricultural spaces are being increasingly broken into smaller-multiple holdings. Meanwhile, the expansion of monocultures of HYVs (high-yielding varieties) has meant that coverage of traditional landraces has been reduced to smaller and scattered 'patches' of land. The effects of both these processes is to restrict landrace populations, making them more isolated from one another. Although this process of **fragmentation** is widely recognized, conservation scientists debate its potential impacts on crop genetic diversity.

In contrast to isolation that sets up barriers between populations, migration via pollen or seed movement (defined above) leads to geneflow between populations. The amount and frequency of migration is related to the reproductive biology of the population including the type of mating, pollination and seed dispersal systems.

5.3 Population genetic structure

So far we have been discussing concepts of population that refer to numbers of individuals, without reference to their genetic make-up. Population genetic structure is the parallel concept to population structure, referring to **genes** and **alleles** in these populations and their variation. **Genes** are sequences of DNA that control a discrete hereditary characteristic, usually corresponding to a single protein or RNA. **Alleles** are alternative forms of a genetic locus. A **locus** is merely the place on a chromosome where an allele resides. In a diploid organism such as barley, each chromosome will carry an allele of the same gene, occupying the same position (or locus) on each chromosome. If the two alleles at one locus are the same, the diploid individual is said to be **homozygous**. If the two alleles at the same locus are different, the individual is **heterozygous**. Within a population of plants, there can be several different alleles, or versions, of the gene. A genotype is the totality of the genetic constitution of an individual, referring either to the set of alleles at a particular limited number of loci, or to all the loci in the genome

At the level of the population or species, any particular allele at a locus occurs with a certain frequency. Multilocus genotypes in outbreeding organisms are notionally unique individuals, whereas in self-fertilizing or nonsexually reproducing species, genotypes may attain any frequency. Two key notions of diversity are **richness**, i.e. the total number of different alleles or genotypes present, and **equity** or **evenness** in the frequency of alleles (Frankel *et al.* 1995).

Alleles may be widespread (occurring in many populations) or locally distributed (occurring in only one or two populations). The frequency of a certain allele is the proportion of all the individual copies of a genetic locus that are the same allelic type. Thus alleles may be common and occur at reasonable frequencies in a population or species of more than 0.1, or rare and occur at frequencies of less than 0.05. A **polymorphic** gene is a gene whose most common allele has a frequency of less than 0.95. The amount of polymorphism within populations, the **allelic richness** (the total number of alleles in the population) the **gene diversity** or probability that two random copies of the gene will have dissimilar alleles, and the **heterozygosity** (the percentage of heterozygous genotypes in a population) are all measurements of genetic diversity within a population.

5.4 Key factors influencing diversity

Diversity is expressed as genetic differences between species, subspecies, varieties, populations or individuals. As discussed in Chapter 3, diversity may be measured at the morphological level (red versus white flowers), the physiological level (early versus late flowering time; diversity in a plant's resistance to pest and disease or in its degree of tolerance to drought). Diversity also can be measured in terms of differences in biochemical, protein and molecular (DNA) properties within and between plant populations. Genetic diversity is not randomly or uniformly distributed in space or time. The amount of genetic diversity differs between species and populations, or between regions and localities, and several key factors determine its distribution.

Selection is the primary force that shapes the levels and patterns of genetic diversity within and between populations on-farm. Selection happens when certain individuals in the population are more likely to survive to maturity and produce more offspring than other individuals. Selection often changes the frequency of genotypes or alleles during the course of one generation (e.g. in seeds compared with adults), but not necessarily. Also note that intense selection may sometimes be operative but not necessarily with any generational change in these frequencies. Selection arises both from the deliberate choices of the farmer (Chapter 3) and from the agricultural, biotic and abiotic environment (Chapter 4).

In addition to selection, other key forces that affect diversity are **mutation**, **recombination**, **migration** and **genetic drift**.

Mutation: is a heritable change in the nucleotide sequence of a chromosome. Mutation is the source of new genetic diversity. Natural rates of mutation are very low (about 10^{-5} per gene or 10^{-9} per nucleotide) and are usually minor and deleterious in effect. Their cumulative effects can take generations to develop into agromorphologically significant traits. However, humans have played an important role in selecting specific mutations that promoted domestication of crops and in turn their dependence on man for survival (e.g. the non-shattering gene complexes in most cereals). In some cases such as kernel colouration systems in maize, humans have probably selected (possibly as aids to landrace identification) for mutable systems with implications for an increased rate of evolution of the genome.

Recombination: is the process that at meiosis generates combinations of alleles at different loci that differ from the combinations found in the parents. Loci that are carried on different chromosomes are said to recombine freely, whereas those on the same chromosome recombine by crossing over between homologous chromosomes. Outbreeding promotes heterozygosity and the opportunity for recombination, whereas inbreeding, in depleting heterozygosity, acts to restrict such recombination.

Migration: is the movement of an organism or group of organisms from one location to another. In population genetics, the migration process usually refers to movement from one population and assimilation through sexual reproduction into another different population.

Genetic drift: is "the random fluctuations of gene frequencies in a population" (King and Stansfield 1997). While it occurs in all populations, genetic drift is more notable in small plant populations. Like mutation, genetic drift can lead to small changes that accumulate over time and give rise to genetic differentiation (Barrett and Kohn 1991).

The action of each of the key factors on populations of a crop species depends on how the species is managed by farmers, the **population structure** as discussed above, and the **reproductive biology** of the species or population, to which we now turn.

5.5 Reproductive biology

The reproductive biology of a plant refers to the various mechanisms that allow a plant to generate offspring. This topic is of relevance to on-farm conservation because it influences how genetic diversity is partitioned and spread within and between populations.

5.5.1 Breeding (mating) systems

The mating or breeding system is the means by which new individuals are produced for the next generation. It includes the time to maturity, the determinacy of flowering, the mode of pollination, the degree of relationship between parents, i.e. the levels of **self-fertilization, self-incompatibility**, and **asexual or vegetative reproduction**. The breeding systems of crop plants help determine how genetic diversity will be patterned within and between their populations, and also how new genetic diversity can arise in individual species.

Plants with high degrees of self fertilization are usually referred to as **inbreeders** or **autogamous**. Plants that are self-incompatible are predominantly **outbreeders** or **allogamous**. Asexually or vegetatively propagated plants are sometimes referred to as **clonal** species. In fact plant populations display a wide range of breeding systems. The systems are flexible and vary both among populations and over time.

An example of this comes from the tomato genepool (*Lycopersicon* spp.). The cultivated tomato (*L. esculentum*) and other species are autogamous, while other species are entirely self-incompatible and therefore allogamous (e.g. *L. chilense*). However, for some species the situation is more dynamic. Thus, *L. pinpinellifolium*, possibly an ancestor of the cultigen, is self-compatible, but 40% outcrossing at the centre of its elongated distribution, decreasing to 0% at its extremes. In contrast, there are mainly self-incompatible species (e.g. *L. hirsutum*), where central populations are self-incompatible and variable, marginal populations self-compatible and virtually monomorphic.

Given that sexual reproduction involves the exchange of genetic material, the mode of reproduction of a species is an important factor in understanding the profile of genetic diversity within a population. For example, a population of predominantly outcrossing plants is likely to have a higher degree of diversity within populations compared with a predominantly selfing population which is more likely to have greater differences in genetic diversity between populations. Hamrick and Godt (1997) summarize the effect of breeding system on variation within and among crop populations, based on an analysis of isozyme studies. Selfers showed twice as much population differentiation as outcrossers.

5.5.2 Pollination

Pollination is the movement of pollen grains from anther to style. While pollen relying solely on gravity for its dispersal is unlikely to travel more than a few metres (Hancock *et al.* 1996), wind-carried pollen can travel for much longer distances. In some instances, wind-carried pollen has been reported to travel for hundreds of kilometres (Ehrlich and Raven 1969). For some crops insects can be an important vector for pollen dispersal and have been reported carrying viable pollen up to a kilometre from its point of origin (Devlin and Ellstrand 1990).

Sexual vs. asexual reproduction

A basic distinction in plant reproductive biology is between sexual and asexual reproduction. Most plants can at some stage during their life cycle flower and set seed. However, many plants also can reproduce asexually. This usually happens via vegetative reproduction, in which one or more daughter plants is produced from specialised parts of a single mother. In addition, some plants can reproduce by setting seed without any exchange of genetic material (agamospermy). Plants that rely largely on asexual reproduction have very different patterns of genetic diversity than those which reproduce sexually, as parents and offspring are a single genotype (although mutations can give rise to new genetic diversity). Often, plants will reproduce both sexually and asexually during different periods. In some regions of the Andes, potato clones and true potato seeds are exploited by farmers and breeders. In the date palm, reproduction from suckers enables farmers to maintain specific desirable genotypes, whereas spontaneous germination from discarded sexual seed provides a constant input of new genotypes from which a farmer may select any new phenotype.

Genetic properties and breeding systems

There are several important elements of a description of the extent and distribution of genetic diversity that are related to the population's breeding system. The amount of polymorphism within populations, the allelic richness, the amount of heterozygosity, the number of distinct genotypes, the amount of recombination, differences in polymorphism, and migration rates. The table below displays the general effects of different breeding systems on aspects of genetic structure.

Genetic property	Outbreeders	Inbreeders	Clonal species
Polymorphism within populations	high	low	limited
Alellic richness	high	moderate	limited
Heterozygosity	high	low	high
Distinct genotypes	individuals are genetically unique	limited number of multilocus genotypes	few or single genotypes
Recombination	high	limited	none
Population differences in polymorphism	limited	high	small to extreme
Population divergence	limited	marked	small to extreme
Response to maternal selection	conservative, slow	purifying, fast	rigid, rapid
Migration	seed and pollen	multilocus structure	multilocus structure

While pollen may occasionally travel large distances, most fertilization takes place locally. The range of distances will depend in part on the breeding system of the crop in question. Research on the isolation distances necessary to produce pure seed lines can provide some insight into the outer limits of successful pollination for crops of different breeding systems (Hancock *et al.* 1996). Pollen movement in cross-breeding species is much more distant than in self-fertilizing ones. In cross-breeding crops, 1000 metres is considered a safe isolation distance (Ellstrand and Hoffman 1990; George 1985). In contrast, the safe isolation distances for most self-fertilizing species is usually around 200 metres (Levlin and Kerster 1974). In cereals, distances of 20 metres may well suffice.

The various mechanisms for pollen dispersal (gravity, insect, bird, wind) available to a plant can have an important impact on the potential distribution of genetic diversity within and between plant populations.

Example: Estimating the outcrossing rate in rice, a self-pollinated crop

This experiment was designed to estimate the outcrossing rate in a self-pollinated crop, cultivated rice (*Oryza sativa*). In farmers' fields, it is suspected that outcrossing can occur between plots when different varieties are planted side by side or within plots when varietal mixtures are planted.

Four planting designs were tested in a controlled experiment (Fig. 1). Five different pairs of varieties were used (« male »=pollinating, « female »=pollinated). A morphological marker was used to detect cross-pollination : hybrid seedlings showed a purple pigmentation.

Figure 2 shows the results. In no case did outcrossing exceed 1%. The three varieties that were the most subject to outcrossing were those with the longest and most exerted stigmas. The outcrossing rate was related to the proximity of male and female plants. The highest outcrossing rates were observed in design T_0 where panicles were clipped together. All female varieties showed cross-pollination in this design. The second highest frequency of hybrid seeds was observed in design T_1 where male and female plants were alternated. Very few hybrid seeds were observed in T_2 (alternate rows). No hybrid was observed in T_3 (side by side plots).

This experiment does not demonstrate that outcrossing cannot occur between adjacent plots, but it suggests that varietal or genotype mixtures within plots are the main reason for outcrossing in rice.

Source: Reaño and Pham 1998.

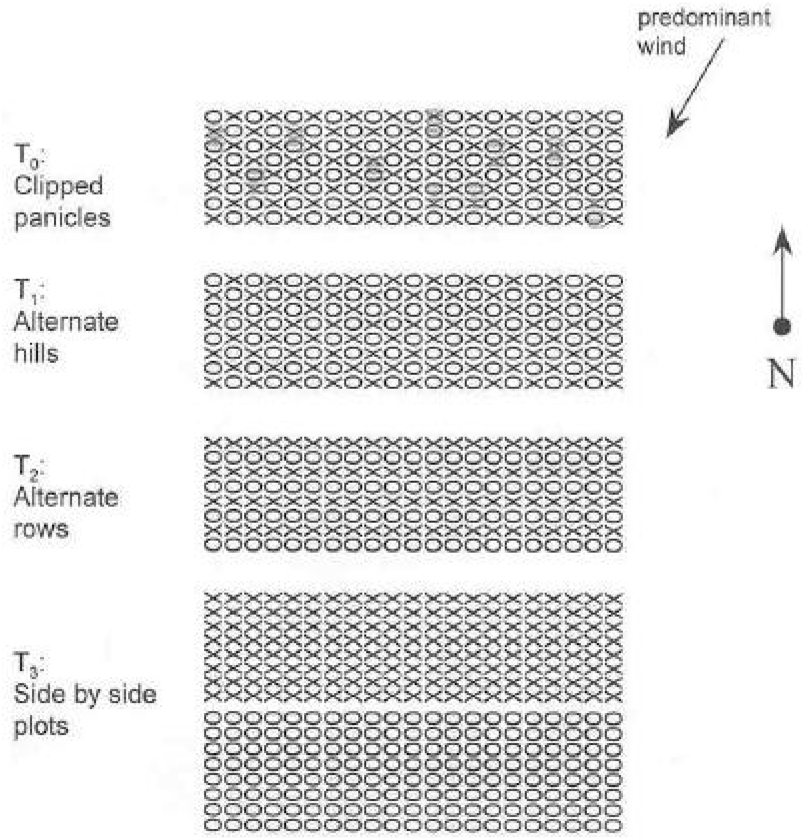


Fig. 1. Planting designs tested in the experiment (x: male plants, o: female plants).

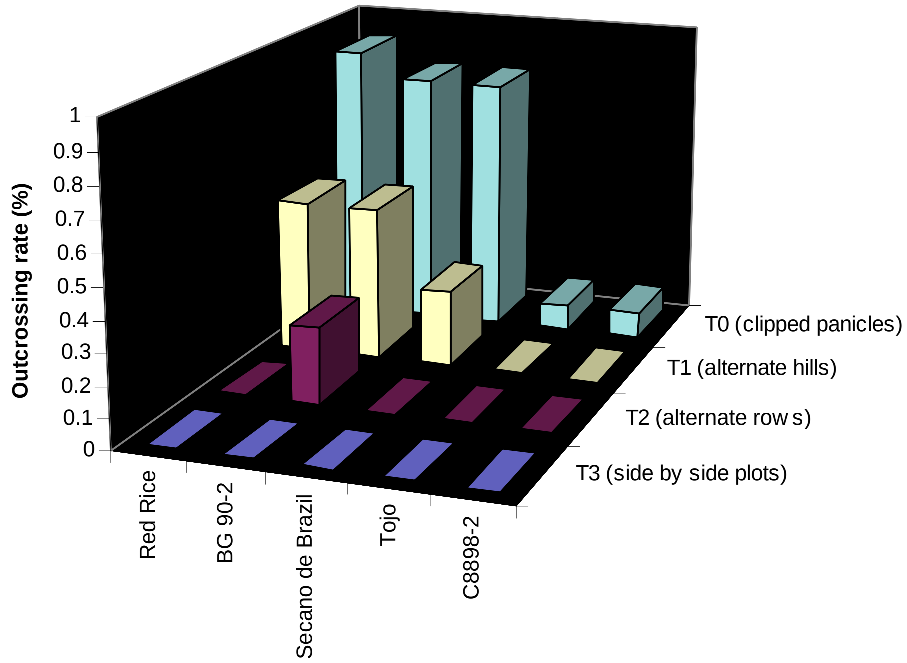


Fig. 2. Outcrossing rates (%) observed for the different variety x planting design combinations.

5.5.3 Seed dispersal

Among plants reproducing sexually, various mechanisms of seed dispersal can help to relocate seeds once seed has set. Possible agents of seed dispersal include gravity, wind, flood waters and various animals including humans. As some forms of seed dispersal can move seeds vast distances away from their origin, seed dispersal is particularly important in investigating the potential for migration and geneflow between populations.

For wild species, including the relatives of crop plants, the natural mechanisms for seed dispersal can have a major impact on individual migration and population genetics. As in the case of pollen, seed dispersal systems that rely solely on gravity are limited usually to the areas immediately surrounding the mother. On the other hand, species with explosive or plumose dispersal systems often rely on wind for a greater geographic mobility. Potentially the greatest seed mobility comes in different forms of animal dispersal, as seeds that attach to or are eaten by birds or mammals can travel hundreds of kilometres before they are deposited.

In most domesticated crop plants, particularly those in which seed is the principal useful part of the plant, natural forms of seed dispersal are not significant in comparison with human forms of seed dispersal. In fact the ability of seeds to break away easily from the cob or panicle, termed shattering, has in many instances been lost through farmer selection. This is largely because farmers act as the agents of seed removal (during harvesting) and eventual dispersal (during planting). Humans are the agents of seed dispersal for cultivated plants. Various forms of seed exchange often act as important dispersal mechanisms that allow individuals to migrate between farmers' fields. More specific information is given in Chapter 6 on seed flow systems.

5.6 Geneflow from wild or weedy relatives and other varieties

As we have seen from the principles of plant population genetics, the wild relatives of crop cultivars are potentially significant sources of new genetic diversity in landraces. This is especially the case in the various centres of crop evolution, where domesticated cultivars are likely to grow in close proximity to wild relatives. Cultivars can gain genetic material from their wild relatives through the processes of **hybridization** and **introgression**. Hybridization is the formation of derivative populations through crossing between two distinct taxa, e.g. barley and its wild progenitor *Hordeum vulgare* subsp. *spontaneum*. Introgression is the movement of genes of one species to another through repeated backcrossing of hybrids to one of their parental species (Anderson and Hubricht 1938; Heiser 1973).

The possibility of new diversity arising due to introgression is an essential part of the ongoing evolution of crop plants, and may be an important feature of an on-farm conservation programme in some systems. There are a number of documented cases of natural hybridization or introgression between crop plants and nearby wild relatives including: sorghum, rice, maize wheat, rye, oats, barley, pearl millet, foxtail millet, *Chenopodium*, potato, common bean, soyabean, squash, cowpea, carrot, tomato, radish, lettuce, peppers, beets, sunflower, *Brassica*, pears, raspberries and alfalfa. On the other hand, domestication is the process that generates the crop species and is one of direct farmer selection for desirable traits, such as non-shattering, that the untamed wild relative does not possess. Excessive geneflow from wild relatives would threaten the gains farmers have made, or as in the case of Johnson grass, generate troublesome weeds.

Example: Geneflow between wild and cultivated beets

In many areas of Turkey there is evidence of hybridization between cultivated beet landraces and wild maritime beets. Evaluation of beet collections from Turkey shows that various cultivated and wild maritime beet types formed distinct groups, but intermediate types between and within groups were observed (Tan 1992). A particularly high percentage of intermediate types occurred between *Beta maritima* and leaf beets. Some rare characters are common to both maritime and cultivated beet types, indicating their close relationship and genetic similarity (Ford-Lloyd and Williams 1975; Ford-Lloyd 1986; Tan 1992, 1993, 1994).

5.7 Farmer management of population structure

Farmers' decisions regarding the size and relative placement of their fields impact significantly on local crop diversity. Fields may be large or small, close together or widely separated. Depending on the reproductive biology of the crops in question, this structuring can have a range of effects on the genetic diversity of crops.

5.7.1 Size and distribution of farmers' fields

The **size and distribution of cultivated fields** combine to determine the size of a crop population as well as its degree of isolation from other populations. Populations far apart will be more genetically isolated than those nearby. It is logical that large fields are likely to contain more diverse populations, as diversity in farmer varieties is thought to be related to **population size** and **heterogeneous conditions** in the environment where they are grown. Within a field or plot, the frequency and distribution of a population will depend on the farming system employed by the farmers as well as the species in question. For example, stands involving numerous species (like agroforestry systems) are likely to have less dense species populations than cereal monocultures.

There will be differences in the way that **diversity is partitioned** depending on the biological characteristics of the crop. Differences between varieties could be less prominent in cross-pollinated crops than in self-pollinated ones. On the other hand, farmer-named varieties may be on a finer scale for inbreeders than for outbreeders. For the outbreeding alfalfa the generic name "landrace" might apply to the material grown in a whole village, whereas for sorghum, several named landraces may be grown in the same plot. Once outbreeding landraces such as maize are named, managed as separate units, distinguished by morphological heritable characters such as seed colour, and divergent in flowering time, they may evolve very significant genetic divergence between them.

These patterns broadly agree with those noted by Hamrick and Godt (1990) in their surveys of isozyme diversity. It is worth asking some specific questions for crops of different types managed by the same farmers in order to test how significant the biological factors may be at the farm or village level. One or two varieties or two or three selected samples of crops (self-, cross-pollinated and clonal) in different sites can provide enough preliminary information on this. This information will help managers determine how to maximize diversity maintained with either more varieties or more sites of the same variety.

> Qualset *et al.* (1997) suggested that small land holdings isolate landrace populations from one another, thus reducing the generation of new genetic material by natural recombination. In common with biogeography theory (MacArthur and Wilson 1967), they say that without human management, the genetic diversity in small 'patches' of crops would suffer genetic drift and inbreeding depression. They suggest that human inputs may offset these processes, as isolated populations can rely on seed exchange and farmer selection for the introduction of new genetic material (see Louette *et al.* 1997). However, if two populations are isolated, they will diversify genetically to a greater extent, and therefore interpopulation diversity will increase.

5.7.2 Common, rare, widespread and local

It is not known whether **common varieties** used throughout the village or region tend to be more variable than less common varieties. It could be that the differences are related much more to character differences (and possibly to the distribution of diversity) and all varieties have about the same allelic richness. Neither is it known whether increasing richness of farmer varieties or **number of farmer varieties** and increasing genetic diversity (**allele richness**) are positively correlated. It could be that the genetic diversity contained in a few varieties in some villages is similar to the amount of genetic diversity contained in villages with many varieties. To make rational conservation plans, it is important to test whether villages with a few varieties are conserving as much diversity as villages with many varieties.

Locally common varieties are those varieties that appear to be particularly important for farmers for certain specific objectives. One might expect them to have a high proportion of **locally common alleles** of adaptive significance and therefore to be particularly important for conservation and particularly interesting for users.

5.7.3 Farmer management of geneflow

Farmers recognize that new diversity may be introduced into their varieties through the processes of hybridization or introgression, and they may act to encourage or discourage these processes. Landraces may hybridize with their wild relatives, other farmers' varieties and modern varieties. Farmers may separate plots spatially, as discussed in Section 5.7.1. Farmer management of their crop populations according to flowering dates is another action with relevance for geneflow between varieties. Sufficient difference in flowering dates between varieties in adjacent plots may ensure reproductive isolation; farmers or communities may make management decisions, such as the dates to sow different varieties, to deliberately isolate (or not isolate) varieties in this manner.

When new genetic combinations arise through introgression, farmers select and maintain the new varieties in one of three instances. As discussed in Chapter 3, farmers may experiment with new crop varieties intentionally in their attempts to develop specific qualities in their landraces or accidentally. Farmers also may adopt new varieties out of necessity in times of war or famine, when diversity that would normally be discarded is valued (Jarvis and Hodgkin 1999). When crop plants and their wild relatives combine, the resulting new genetic combinations encounter the same forces of natural selection as other landraces. For on-farm conservation, the exact role of introgression between wild or weedy relatives and crop plants is not known. The question revolves around the idea that farmers introduce and maintain new characters into their varieties.

Farmers may or may not keep their own varieties separated from modern varieties. Introgression of new characters from modern varieties may be desirable for performance but may raise concerns for conservationists.

Geneflow from cultivated maize to teosinte (maize wild relative) in Mexico.

There is considerable evidence that farmers are likely to recognize, maintain and use the new genetic combinations that arise through introgression or natural hybridization, seen in cases from: Mexico (maize, squash, chilli); Burkina Faso (pearl millet); Uganda (sorghum); Andes (potato); Ethiopia (*Brassica*); Sierra Leone (rice). These examples can lead us to a number of important conclusions regarding new genetic diversity. These are of particular relevance in thinking about the setting and design of an on-farm conservation programme (from Jarvis and Hodgkin 1999).

1. Natural introgression is most likely to occur where local cultivars overlap with their wild or close weedy relatives.
2. Introgression is more common in outbreeding crops but does occur in self-pollinating crops.
3. Rare events over long periods (sometimes on an order of magnitude greater than the lifetime of a conservation initiative) may have substantial influences on crop evolution and adaptive characters.
4. In some crops the cultivated type has little genetic diversity when compared with its wild type.
5. The impact of the new type can be related to the size and genetic structure of the recipient population.
6. There can be strong natural and human selection pressures both for and against new genetic combinations.

5.8 Measuring population genetic structure

5.8.1 Measuring patterns of landrace occurrence

The simplest basis for measuring the population genetic structure in conservation *in situ* is the distinct landrace or farmer-managed unit of the species:

1. The number of different landraces in a particular sample or area or field.
2. The genotype diversity index (analogous to the Simpson Index or Nei index of gene diversity), being the probability that two randomly drawn individuals from the sample will belong to different landraces.

A further two measures of pattern of occurrence in the region apply to each specific landrace in the study:

3. The average population or field size of a specific landrace and hence the distribution of field sizes (mean and variance) within and between landraces.
4. The number of fields in the study region in which a landrace is grown.

These two measures classify each landrace according to whether or not it is **widespread** (occurs in more than a few fields) versus **localized** (restricted to a few fields), and secondly whether it is **common** (here defined as grown at least on some farms, in large numbers, in above-average field sizes) versus **rare** (in small fields only).

Example: Characterization of varietal dynamics of rice in Nepal

Research on the population genetic structure of rice landraces in the IPGRI Nepal on-farm conservation project began with the characterization of varietal dynamics based on average area and number of households growing each landrace. Rice landraces were categorized in groups of **large** and **small** (based on the average area) and **many** and **few** (based on number of households), for a total of four classifications (large and many; large and few; small and many; small and few).

Varietal dynamics based on average area and household growing the landrace (Khatiwada *et al.* 2000)

Category	Bara	Kaski	Jumla
Average area /landrace (ha)	1.62 (Bhaidaiya) 0.57 (Agahani)	1.17	0.91
Average no. households growing the landrace	7.5 (Bhadaiya) 3.19(Agahani)	10.9	9.76
Varietal classes:			
Large area and many HH	Sotwa, Maturi, Nakhi Saroo, Nakhi, Matmur, Jiri (Bhadaiya rice), Basmati, Lal farm, Madhumala (Agahani rice)	Ekle, Rato Anadi, Madhise, Kathe Gurdi, Mansara, Jethobudho, Thulogurdi, Panhele, Jhinwa Ghaiya	Kalo Marshi, Seto Marshi, Rato Marshi
Large area and few HH	None (Bhadaiya), Asahani, Mansara (Agahani)	Gurdi, Lahare Gurdi, Sano Madhise	None
Small area and many HH	Sathi (Bhaidaiya), Lajhi, Rato Basmati (Agahani)	Seto Anadi, Jerneli, Bayarni	Mahele, Rato and Seto
Small area and few HH	Rango, Dudhi Saroo, Guthani, Sokan, Saroo (Bhadaiya), Anga, Karma, Anadi, Gajagaul, Khera, LalTengar, Bhathi, Chhatraj, Mansari, Kataush, Batsar, Dudhraj, Ratrani, Lalka Katika (Agahani)	Anga, Tunde, Basmati, Thulo Madhise, Sano gurdi, Seto ghaiya, Rato Ghaiya, Bichare ghaiya, Gurdi Ghaiya, Ramani, kande Anadi, Naulo madhise, Ghaiya, Jire Ghaiya, Naltume, Dhabe Jerneli, kalo Jhinwa, kalo gurdi, Jhauri, Manamuri, Pakhe Jerneli, Biramphool, Jhinuwa,, Thapachini, Seto gurdi, gauriya, Kaude, Jhyali rato ghaiya, Mala, Kunchali Ghaiya, Lame, Kanajire Ghaiya, Katuse Ghaiya, Lahare Ghaiya, masino ghaiya, Masino Jhinwa, Seto Jhinwa, Tunde Jhinwa, Barmeli, Chobo,Jhinwa basmati, Kalo Bayarni, Kalo Tunde Jhinwa, Rate, Pakhe Ramani, Seto bayarni, Bayarni Jhinwa	Ratanpuri, Darime, Sijalaya, Seto Local, Marshi Jumli (1), Kalo dhan, Rato dhan, Rato and Kalo, Patle dhan, Majhule marshi, Jadan dhan, Dhan, Mahele dhan, Seto biu, Lahare (Rato),Pakhe

Example: Distribution of rice diversity in Central Vietnam

Research on rice diversity in 16 villages of Central Vietnam examined the distribution of rice varieties at regional and village levels. Ten farmers were surveyed per village. The distribution of varieties was shown to be structured by cropping season and agroecosystem. Modern varieties were more common in the inland agroecosystem and for the summer season, while farmers' varieties prevailed in the coastal agroecosystem and the winter cropping season. Most varieties in the study sites were distributed across a very limited area, with 27% of varieties grown by only one farmer, and 67% of varieties grown by 5 or fewer farmers. In addition, all widespread (grown in more than two regions) varieties were modern varieties. The researchers found the limited distribution of farmers' varieties to be a strong incentive for the use of an on-farm conservation strategy, as it would be unlikely that an *ex situ* programme would be able to collect all of the diversity contained within the study sites.
Source: Le Dinh Huong *et al.* 1999.

5.8.2 Genetic structure of populations

Genetic diversity is ideally measured by screening a sample of individuals for genetic differences (as different alleles) at marker loci. The more important variables are:

- the allelic richness or number of allelic variants per locus in the sample
- the frequencies of allelic variants
- the level of heterozygosity
- the number of multilocus genotypes. Multilocus genotypes can be assessed at several levels
- the degree of difference between populations (**distinctiveness**).

These data measure the **average diversity of a field,** the differences in **allele frequencies** among different populations, and the differences in **levels of polymorphism** among population.

Measuring the average diversity of a field

- Measurements of genetic diversity together with field size can determine whether diversity increases with field size and can be tested for different breeding systems.
- Collecting information on the number of varieties per household or village together with measurements of their genetic diversity can determine whether increased variety richness and increased genetic diversity are positively correlated.

Differences in allele frequencies and in levels of polymorphism among populations:

- Diversity analysis will provide information on the genetic distinctiveness of farmer-named varieties. Chapter 4 discussed the importance of determining this relationship.
- Measurements of diversity can determine whether rare varieties are selected from common ones and whether locally common varieties have the greatest number of locally common alleles for different breeding systems.
- Diversity analysis at different spatial scales will enable comparisons at community and regional levels, such as whether the crop population of one village represents all the genetic diversity in the region (see Box – scatter plot).
- Measuring the distance between fields along with the differences in flowering dates of the geneflow between fields.
- Diversity measurements of different crops grown together by farmers also can help indicate whether variation in different crops is correlated.

Different analyses of genetic diversity

- *Allelic richness at a single loci*: the total number (**A**) of distinct alleles at that locus in the population or sample.
- *Percentage of loci that were polymorphic:* The proportion of loci that are polymorphic is a relatively insensitive parameter which is determined largely by which genes are screened in the study
- *Coefficient of gene diversity* (**h**) (Nei 1973): the probability that two gametes randomly chosen from the population or sample will differ at a locus. This estimate involves two equations: **h = 1 - Sp²** where **p** are the allele frequencies at the locus in question. The gene diversity statistic (**h**) is high when the number of alleles (**A**) is large, but even more so when there is equality or low variance in their frequency
- The *observed level of heterozygosity*: measures the arrangements of alleles into genotypes (**H**)
- *Fixation index* (**F**): measures of the deviation of genotypic frequencies from panmictic expectations (of the Hardy-Weinberg disequilibrium) (**F**= 1-**H**/**h**)
- *Degree of linkage disequilibrium* (**D**): measures the arrangement of alleles at several linked loci as the deviation from random assortment of alleles in gametes or zygotes
- The *degree of population divergence*, **F(st)** or **G(st)**: measures the arrangement of alleles in populations, using variation in the frequency of each specific allele among the different populations [**G** = the proportion of total genetic diversity in excess of that found within the average population: **G(st)** = 1-**h(p)**/**h(s)**].

Example: Conserving allele richness

The contribution to the allele richness of 24 traditional and 47 modern varieties in the region of Huê, Central Vietnam was analyzed. The varieties were categorized into wet season (main cropping season) and dry season varieties. 111 accessions representing the 71 variety names collected in 16 villages were analyzed with 13 microsatellite primers.

Figure 1 shows that the dry season modern varieties are those that contribute the highest number of alleles (67) while the three other categories contribute about the same number of alleles. A simulation was made of what would happen in case of genetic erosion that would affect the less frequent varieties. We computed the number of alleles contributed by the 10 and 5 most frequent varieties in each category. In other words, is it worthwhile “protecting” the rarest and therefore less frequent varieties?

Figure 1 shows clearly that many alleles would be lost if the rarest winter season traditional varieties and dry season modern varieties came to disappear (Pham *et al.* 1999).

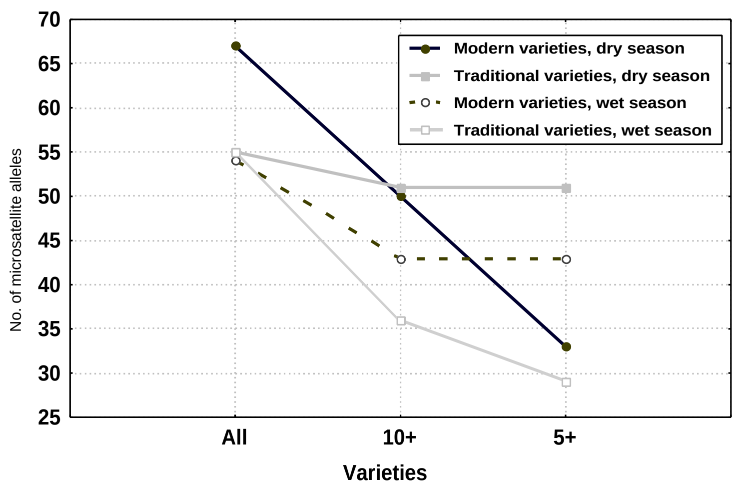
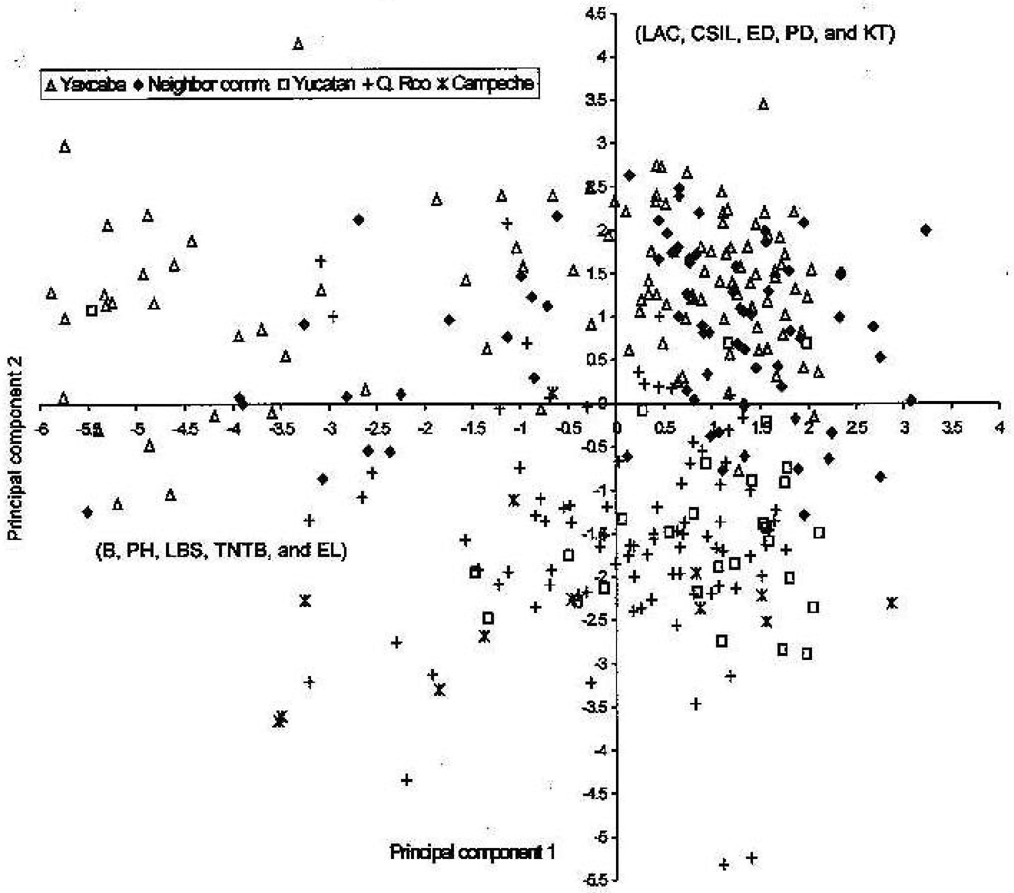


Fig. 1. Number of microsatellite alleles contributed by four categories of varieties in three situations: all varieties considered, ten most frequent (10+) and five most frequent (5+) varieties considered.



Scatter plot of the first two principal components showing the dispersion of 314 maize populations from Yucatán Peninsula. Yaxcabá is the target community of research, Neighbour communities refer to those communities in the same district as Yaxcabá, Yucatán refers to other communities in the Yucatán State other than the Yaxcabá region and Quintana Roo and Campeche are the two other states that together with the state of Yucatán make up the Yucatán Peninsula.

314 maize populations were collected in the three states of the Yucatán peninsula: Yucatán State, Quintana Roo State and Campeche State in 1999. 182 of these populations were collected in the village of Yaxcabá and its neighbouring communities, which are located in the geographic and cultural heart of the Yucatán peninsula. The populations were characterized for 34 morphological and phenological traits.

Axis 1 (Principal Component 1) was determined basically by the blossom (B), plant high (PH), length of branching space (LBS), total number of tassel branches (TNTB) and ear length (EL). Similarly in the Axis 2 (Principal Component 2) according with its eigenvectors it was determined by leaves above the cob (LAC), central spike internode length (CSIL), ear diameter (ED), pith diameter (PD), and kernel texture (KT).

The main morphological characters which describing the difference between maize populations of Peninsula Yucatán are related with reproductive traits such as tassel (length, branches, and internodes), ear (shape, length, diameters and pith), and kernels (thickness and texture). As the graph shows, the maize populations from Yaxcabá and its neighbouring communities cover almost the entire spread of morphological diversity along the second Principal Component Axis, which was determine by leaves above the cob (LAC), central spike internode length (CSIL), ear diameter (ED), pith diameter (PD), and kernel texture (KT). The blossom (B), plant high (PH), length of branching space (LBS), total number of tassel branches (TNTB) and ear length (EL) in the first Principal Component Axis established the differences between Quintana Roo and Campeche State landraces, and Yucatán State landraces.

Source: J.-L. Chavez-Servia, C. Camacho and L.A. Burgos-May, unpublished data.

5.8.3 Biochemical and molecular markers

Biochemical and molecular markers can be used to reflect genetic differences between plants. These differences are measured in the form of differences in amino acid sequences of proteins and by differences in nucleotide base sequences in DNA. By looking directly at such variation, molecular markers allow us to avoid the complications of environmental effects acting upon characters that are problematic when studying morphological characters discussed in Chapter 4.

Using molecular markers, it is possible to make direct and accurate measurements of:

- Gene diversity (Nei 1973) and allelic richness
- Population subdivision (Wright 1951)
- Heterozygosity, effective population size and allele frequency
- Similarity and distance (genetic distance) within individuals and populations
- Genetic maps for use in selecting germplasm within breeding programmes.

Again, one starts with a basic data matrix (see Chapter 4), where the columns are different genetic markers rather than agromorphological traits. As with agromorphological traits, however, it is still possible to calculate diversity and distances and similarities among samples (Chapter 4).

No molecular marker is perfect. Instead, different processes have different strengths and weaknesses. The usefulness of a marker will be determined by how well it fits a particular situation. To work well, molecular markers should possess some of the following criteria:

- They must be *polymorphic* (but the exact level of polymorphism can vary)
- *Co-dominant inheritance* allows the discrimination of homozygotes and heterozygotes
- *Selectively neutral behaviour* eliminates the problems associated with pleiotropy
- Markers should be evenly distributed throughout the genome
- Results and analysis should be reproducible within laboratories
- Market technology should be reasonably simple and require a short analysis time
- Costs should be manageable.

Important terms for molecular markers

DNA: The molecular basis of heredity. Formed of two strands of nitrogen bases (A, T, C, G) which pair and bind to each other by means of complementarity (A with T, C with G). The size of a DNA molecule is measured in base pairs (bp).

Protein: A macromolecule composed of one or more chains of amino acids. Proteins are of diverse function and include enzymes that catalyze chemical reaction, structural and seed storage proteins.

Electrophoresis: The separation of a mixture of DNA, RNA or protein fragments using an electric field to move the fragments through a gel matrix. This results in separating the fragments by size.

DNA Probe: A short fragment of single-stranded DNA which can bind to a complementary sequence within a longer DNA molecule. A probe is tagged biochemically or radioactively for detection and isolation of the molecule it has bound.

Primer: A short fragment of single-stranded DNA used in PCR. It binds to a site on a larger DNA molecule and initiates synthesis of a new DNA strand copied from that template.

Allele: one type in a series of different forms of a particular genetic locus

Polymorphism: The existence of two or more genetically different classes in the same interbreeding populations (King and Stansfield 1997). At the molecular level, polymorphisms consist of changes in the structure or sequence of macromolecules – DNA or protein.

Homozygote: An individual having identical alleles in the corresponding loci in homologous chromosomes (King and Stansfield 1997).

Heterozygote: An individual which has inherited different alleles in the corresponding loci in homologous chromosomes.

Different types of protein-based markers

Seed storage proteins: Seed storage proteins of many species can be studied using conventional gel electrophoresis, or for greater resolution, isoelectric focusing. Detection of bands after electrophoresis is done by using a general protein stain (e.g. Coomassie Blue). Storage proteins can provide useful genetic profiles for the identification of genotypes of varieties, and in some cases for more practical characters. In wheat, for instance, they can provide useful markers for breadmaking qualities. Because several to many bands can be identified at one storage protein genetic locus, which probably results from the tightly linked duplication of genes, storage proteins cannot supply the range of genetic markers provided by enzyme polymorphism.

Enzymes: Allozymes (also referred to as isozymes) are different alleles of the same enzyme at the same locus. Allozyme electrophoresis can reveal genetic polymorphism allowing the direct study of genetic variation. Active enzymes can be separated into discrete bands by placing tissue extracts (e.g. from young leaves) onto starch or polyacrylamide electrophoresis gels. After electrophoresis, the positions of these bands are made visible by allowing them to act on an enzyme-specific substrate which gives a coloured product. Isozymes are usually controlled by co-dominant alleles and inherited in monogenic, Mendelian ratios. The number of bands seen on a gel will depend upon the number of loci, the number of alleles per locus and the quaternary structure of the enzyme. Isozyme polymorphism has been used for characterizing and identifying genotypes and varieties of crop plants, for studying population genetics and for examining geographical patterns of variation. There is a limit to the number of enzymes available for study (because of the requirements for detection), and therefore a limit to the proportion of any plant genome which can be accessed.

Non-PCR, Hybridization-based techniques

Restriction Fragment Length Polymorphism (RFLP): The RFLP technique detects mutations which alter the pattern produced by cutting a genome with a particular restriction enzyme. Such mutations can be base-pair changes, abolishing an existing restriction site or inserting one where none had existed, or they can be insertions/deletions which alter the size of the fragments produced in a digest. Any alterations in the fragments which bind the probe will appear as a change in band size on the gel or as the appearance or disappearance of a band. These markers are co-dominant, segregate in populations, and can be mapped and linked to genes or traits of interest. However, only one locus can be studied at a time.

Variable Number Tandem Repeats (VNTR): This technique, also called DNA fingerprinting, uses basically the same methods as RFLP. The two differ in the types of sequences being analyzed and thus the origin of the probes used and the kind of data produced. The VNTR assay uses a core ‘motif’ of about 10 to 60 bases, a multilocus probe which gives rise to complex banding patterns. RFLP probes, on the other hand, are normally locus-specific and give rise to easily identified co-dominant marker bands. DNA fingerprinting may use probes which are not species-specific, whereas RFLP probes are normally species-specific.

The underlying basis of RFLP and VNTR protocols:

- Genomic DNA is digested with one or a combination of restriction enzymes which splice the DNA at specific sites to generate a complex mixture of fragments.
- The digested DNA is separated by agarose gel electrophoresis.
- The DNA is transferred from the gel to a membrane (Southern blotting) and then incubated with a radioactively labelled probe from a specific locus. The probe hybridizes to any complementary fragments on the membrane which are detected by exposure to X-ray film (autoradiography).

PCR-based DNA markers

Polymerase Chain Reaction (PCR) is a procedure to amplify a specific sequence of DNA. A pair of primers designed to be complementary to sequences flanking the DNA region of interest are annealed to a DNA template and the normal extension function of DNA polymerase is exploited to extend the primers, copying the sequence of the template strand. The reaction products can be separated by gel electrophoresis, and since they can often be detected by direct staining, the use of radioactivity and autoradiography is usually avoided.

Random Amplified Polymorphic DNA (RAPD): This technique observes the variation in non-specific regions throughout the genome. A single short (10 bp) primer of randomly chosen sequence is used which can potentially hybridize to hundreds of sites throughout the target DNA. When the primer anneals at two sites on opposite strands within 2 kilobases of each other, the intervening sequence is amplified. Sequence mutations, insertions and deletions all lead to polymorphisms in the resulting pattern of amplified fragments. Generally between 1 and 20 bands are detected by RAPD.

There are variations of the technique in which different lengths and concentrations of primers are used, and certain other protocol steps are modified. A cloned RAPD fragment can be used to design longer primers which, when used in PCR, amplify specific single loci called SCARS (Sequence-Characterized Amplified Regions). Because the primers used are longer, the system is far more robust than RAPD.

Microsatellites and Sequence-tagged microsatellites (STMS): Microsatellites or simple sequence repeats (SSRs) are tandemly repeated units of 2-10 base-pairs which are dispersed throughout eukaryotic genomes. Polymorphism in microsatellites arises when the number of sequence repeats in tandem increases or decreases. When a microsatellite locus is cloned and sequenced, the unique sequences flanking the SSR can be used to design PCR primers. These are then used to amplify specific SSR loci – sequence-tagged microsatellites, or STMSs.

Amplified Fragment Length Polymorphism (AFLP): The principle behind this technique is the PCR amplification of a selected subset of all fragments produced by restriction digest of genomic DNA. Genomic DNA is digested with a restriction enzyme, and linked to adapter molecules. PCR primers consisting of a core sequence (part of the adapter), a restriction enzyme specific sequence and 1-3 selective nucleotides amplify only those fragments with fully complementary sequences. This generates fragments from many genomic sites (usually 50-100 fragments per reaction) that are separated by gel electrophoresis and generally scored as a dominant marker.

DNA sequencing information

DNA sequencing is most commonly used for studying phylogenetic relationships, where certain regions of the genome are focused upon. The precise determination of nucleotide sequence of a defined genomic region provides the most direct means of studying DNA polymorphism. A modification of the PCR using one primer and terminating nucleotides is used. This technique can be highly reproducible and informative; however, it is expensive and can be difficult and time-consuming without automated sequencing machines.

5.9 The time dimension

Evidence of the nature, pace and causation of genetic change in the short term is important to an understanding of on-farm conservation. Is the genetic diversity of the populations changing over time? If so, how rapidly do allele frequencies changes? Are alleles or genotypes being lost? Or at a larger scale, do whole populations go extinct? Is there a marked change in heterozygosity, or degree of inbreeding? Is there a change in the number of combinations of genes, or in the mating system?

Most of these questions are comparative. They require more than one sample in time and use the same measures of genetic diversity based on the same marker loci for strict comparability. With such measures, per-generation rates of change can be computed and used as indicators of genetic erosion. **Time series analysis** (also discussed in Chapter 9) can be used to predict future patterns, based on data that is classified temporally (e.g. by year, season, etc.).

Populations of farmer varieties also may be susceptible to random events as discussed in Chapter 3. These events have the potential to cause the loss of diversity at different scales, from household to village and even regional levels. It is important to have long-term information of the frequency and intensity of events such as droughts, floods, volcanic eruptions and even war, and to know from what sources farmers have replaced their varieties after these events, in order to examine their effects on crop genetic diversity over time.

5.10 Maintaining sufficiently large populations for effective conservation of varieties

The size of the effective genepool is a key concern in understanding and managing the population structure of a particular crop. Population structures and dynamics are relatively simple to consider when limited to a single field, or to a group of fields maintained within one community. But given the potential for migration and introductions with seed exchange, the effective genepool of a crop may span an entire region. Probably a single farmer does not maintain a sufficiently large population for effective conservation over time. At what scale are sufficiently large populations maintained to ensure their continued ability to adapt and evolve with their environment? Is it the level of the village, the community, the region? If seeds are lost from one farmer or one village or one community, do farmers have access to other populations to renew their source of seeds? Chapter 6 on seed systems discusses these issues in more detail.

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Chapter 6 Seed systems

(with the collaboration of D. Balma, B.K. Baniya, P. Bramel-Cox, N.N. De, M. Djimadoum, E. Ellis, N.P. Ha, T. Hodgkin, D. Louette, H. Mellas, F. Nassif, J. Ndung'u-Skilton, R. Ortega-Paczka, R.B. Rana, M. Sawasogo, R. Tripp and R. Valdivia-F.)[1]

[1] Photo credits: Pp. 96, 102: D. Jarvis; P. 99: E. Ellis; P. 101: M. Djimadoum.

6.0 Objectives of this section

By the end of this module, participants should:

- Understand the seed system through which new germplasm enters a household's and a community's crop populations
- Understand the dynamics of seed supply, storage and exchange systems, and how they may impact crop genetic diversity.

6.1 Seed flows

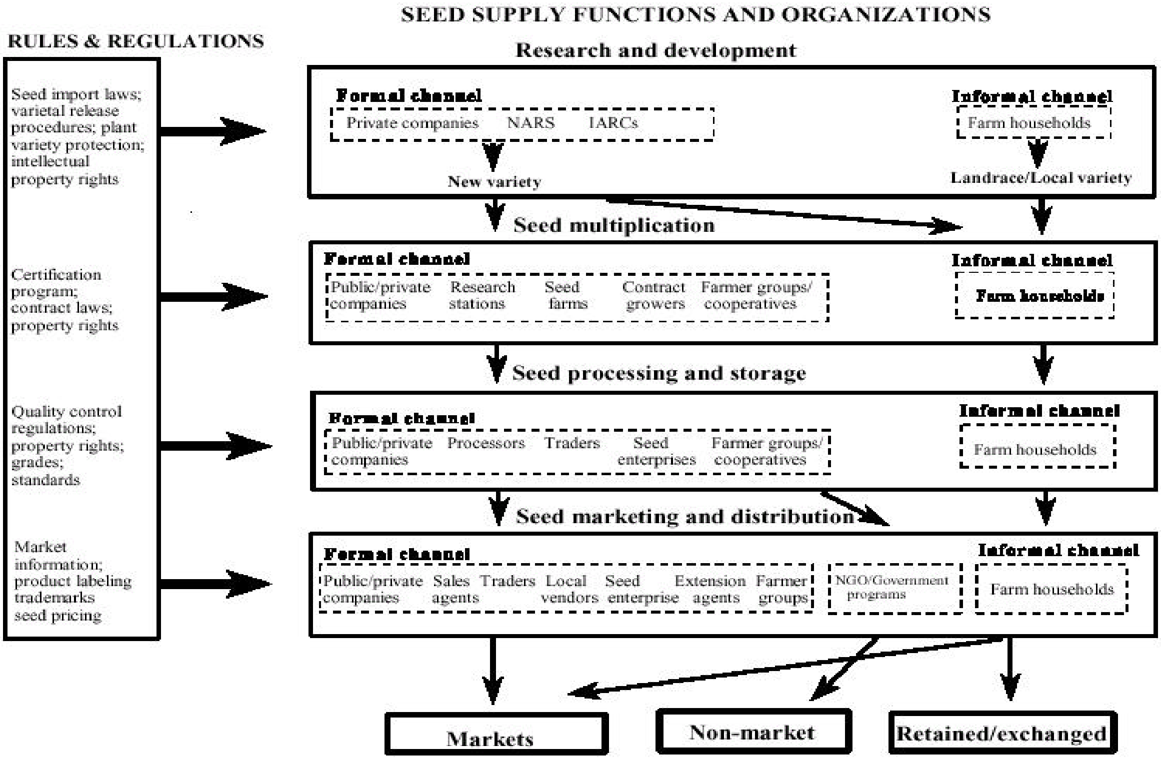
Each year the farmers decide how much seed to plant and where that seed comes from. In addition to the seed selected and stored from their own crop, the farmers may obtain new seed from markets or other farmers. By planting seeds from sources beyond their own fields, the farmers make a conscious decision to introduce new germplasm into the agroecosystem. These practices, by which the farmer affects the level of genetic diversity in a crop population, are termed seed flows (Bellon *et al.* 1997). Seed flows describe "the process by which farmers obtain the physical unit of seed for a given variety. The seed a farmer plants may have been selected from his or her own crop in the preceding season, exchanged or pur-chased from other farmers or institutions, or mixed from a combination of sources" (Bellon and Smale 1998: 3). The seed lot is defined as the physical unit of seed for a given variety that is selected by a farmer and sown during a cropping season in order to reproduce that variety (Louette *et al.* 1997). Studying seed flows will enable a better understanding of the processes by which seed is stored and exchanged and the associated impact on the distribution of genetic diversity.

The **seed system** is composed of organizations, individuals and institutions involved in the development, multiplication, processing, storage, distribution and marketing of seeds (Maredia and Howard 1998). At the farm level, the use of the word "seed system" may be flawed; there is no one systematic way in which farmers acquire and manage seed – rather, there are a number of techniques and opportunities that farmers use under different circumstances to access and save seed. For the purposes of this training guide, a "seed system" refers to the different ways that farmers access seed at the farm level.

Farmer-saved faba bean seeds in Morocco.

6.2 Key components of a seed system

The seed system by which farmers acquire new seed can be loosely categorized into informal (or traditional) and formal seed supply systems. Informal seed supply systems refer to those in which seed originates from and is disseminated by small-scale farmers, while formal seed supply systems typically supply modern varieties developed by plant breeders and distributed by non-local institutions like national research and extension programmes, seed companies, international organizations and NGOs. These categories should not be thought of in strict terms, as common practices fall between the two extremes, such as seed acquisition from grain markets and local farmers who specialize in producing grain suitable for seed.



(Source: Maredia and Howard 1998)

6.2.1 Farmer demand for off-farm seed

Farmer demand for off-farm seed can be categorized into four types, although these may not be strictly separate in practice:

- emergency, which refers to seed shortage due to a disaster situation
- poverty, meaning seed shortage due to low yields and / or consumption or sale of seed stocks
- seed quality, which may refer to the ability to store seed on-farm, market demands for grain quality, or the use of hybrid seed
- variety change, when a farmer seeks to plant a new variety (Tripp 2000).

Formal sector emergency relief programmes typically respond to emergency seed demand, and formal sector supply of modern varieties may partially supply small-scale farmers' seed quality and variety change demand.

The level of off-farm seed demand every year in a given community depends on the crop (e.g. storability) and certain socioeconomic and agroecological conditions (e.g. drought or poverty leading to consumption of seed stocks) (Tripp 2000). Farmers routinely introduce seed from outside sources in order to test new varieties and evaluate (using various agromorphological criteria) whether they are successful. Acquisition of off-farm seed may be a last-minute response to the arrival of the planting rains, causing farmers to use the seed that is most convenient (Tripp 2000). In other instances, farmers introduce new seed because they have lost a particular landrace, or an individual trait within their landraces.

> Seed stocks are vulnerable to natural disasters, poor harvests and the life-cycle changes of farmers. In some parts of West Africa, for instance, rural farmers have lost many of their traditional rice varieties when they abandoned their farms because of protracted armed conflicts. When they returned to farming, these farmers depended upon MVs (Modern Varieties) introduced by relief agencies for seed stock (Richards and Ruivenkamp 1997). Rice *et al.* (1998) graphed "seed lifecycles" to depict the high frequency of experimentation, exchange, loss and replacement of seed that occurred for the same varieties (both traditional and modern) in the Sierra de Santa Marta, state of Veracruz, Mexico. Tripp (2000) estimates that at least 20-25% of seed is acquired from off-farm sources in sub-Saharan Africa, and significantly more when seed stocks have been lost during the year.

6.2.2 Informal (traditional) seed supply systems

Informal seed systems are composed largely of individual farm households, each carrying out most seed system functions – the development, multiplication, processing, storage, distribution and marketing of seeds – on their own with little or no specialization (Maredia and Howard 1998). They include all the methods, apart from buying seed from formal sector organizations, by which farmers can obtain their seed requirements (Cromwell 1996). Most small-scale farmers obtain seed of new varieties from informal seed sources, primarily from within their own communities. Studies on farmers' seed acquisition of sorghum, cowpea, groundnut and pigeon pea in Malawi, Kenya, Zimbabwe and Zambia demonstrate that farmers obtain the majority of their off-farm seed from other farmers, most often relatives, rather than markets and shops, extension and research, NGOs or formal mechanisms (Tripp 2000). In Milpa farming systems of the Yucatan, Mexico, over 90% of maize seed requirements are met by on-farm and informal seed supply sources, despite the existence of government programmes promoting the use of modern varieties (Ortega-Paczka *et al.* 2000). Informal seed supply systems fall into two subgroups.

6.2.2.1 Seed retained on-farm from previous harvest

In developing countries, farmer-saved seeds account for most of the seed used (Cromwell *et al.* 1992). The seeds are mainly local landraces but could also be modern varieties. The latter are normally maintained on the farm and will eventually be mixed up and modified by local seed selection and thus evolve into new landraces.

6.2.2.2 The community seed supply system

This is the next most important means of sourcing seed for small farmers. It includes farmer-to-farmer exchange of seed based on barter, social obligations, etc. (Cromwell 1996). This system is used primarily when farmers are unable to supply their own seed needs because their previous harvest has been inadequate. Even with a reasonable harvest, these households may have difficulty in storing enough seed until the next season and may have to dispose of their remaining stocks for cash or consume them as food (Tripp 2000).

Cultural traditions play an important role in mediating such acquisitions, such as kinship networks and gender responsibilities for particular crops (Tripp 2000). The reasons behind seed acquisition may include farmer experimentation and the perception of value in moving seed between fields. The term "**seed exchange**" refers to a reciprocal relationship in which a farmer acquires seed by giving seed to another farmer. A farmer also may obtain seed through other means, such as gifts or payment in cash, grain, or another non-seed commodity or purchase of grain that is utilized as seed. Human migration, marriage outside the community, and outside job opportunities can play important roles in disseminating seeds over larger distances and across geographical or cultural barriers.

Example: Rice seed selection by a household farmer in Wujin County, Jiangsu Province, China

In a field study of village ecology in China’s Tai Lake Region (Ellis and Wang 1997; Ellis *et al.* 2000), in press), it was demonstrated that some “expert farmers’, like the woman pictured below, select seed of modern varieties and trade them locally in exchange for greater amounts of unselected rice or other barter items. Original Green Revolution varieties have been bred locally for several years, yielding local landraces, though these may ultimately be replaced by newer Green Revolution varieties that also will be selected locally. Local seed selection is practised because it cuts seed costs, while improving the local adaptation of the introduced varieties. This shows that even though a region may adopt Green Revolution varieties, some farmers still choose to select their own seeds.

6.2.3 Formal seed supply systems

The formal seed system is composed of public and private organizations with specialized roles in supplying mainly new varieties. The structure, coordination and performance of formal seed systems is controlled by various rules and regulations that influence the type, quality and quantity of seed that is supplied through formal channels. Materials developed and distributed by the formal seed supply system are often characterized by homogeneity and thus may not be appropriate for diverse, marginal agroecosystems. Farmers' access to these materials may differ with the community's proximity to a market centre or the household's wealth status. Biases exist in the way that varieties are developed and released by the formal sector, such that resource-poor farmers are less likely to benefit from the products. Seed certification and distribution regulations often hinder farmers' access to potentially beneficial varieties. Only 10% of seed requirements from developing countries are met by the formal sector, while the remaining 90% of seed demand is supplied by informal and on-farm sources.

6.2.3.1 Seeds and modern varieties

The introduction of modern varieties into farmer systems through the formal sector has led to the replacement of landraces on a large scale in some instances, drastically reducing the level of genetic diversity maintained on-farm. National breeding and extension programmes may promote a few high-yielding varieties at the expense of diverse local landraces.

The introduction of modern varieties does not, however, necessarily lead to the complete replacement of landraces. In parts of Mexico, farmers experiment with new maize seed, including modern varieties, to determine its performance under local conditions. Farmers may then incorporate the new germplasm into their portfolio of varieties, increasing the possibility of introgression and hybridization (Bellon and Brush 1994). Instead of reducing crop diversity, this practice may in the short term enhance the overall genetic diversity within an agroecosystem.

6.3 Seed systems and diversity

Besides **selection**, **mutation** and **recombination** discussed in Chapter 5, **seed flow**, which is a form of **migration** of germplasm (**genes**) into a locality, is one of the primary mechanisms through which new diversity enters farming systems. Local and other seed dissemination mechanisms that contribute to seed diffusion and seed flow, as discussed above, include:

- Neighbours, friends, relatives
- Local seed-producing farmers
- Community seed banks
- Local and other markets (grain markets, formal seed sector)
- Development projects
- Retail outlets from the formal seed sector.

These mechanisms introduce new germplasm into farmers' crop populations from different spatial scales (from next door to national and even international levels) and with different frequencies over time. It is important to examine the spatial range encompassing a farmer's or village's seed supply system to understand the effective genepool of the crop diversity maintained by the farmer or village.

It is also important to account for the genetic change that may occur within varieties as a result of the selection and use of seed on-farm ("seed recycling"), depending on the breeding system of the crop. Morris *et al.* (1999) examined the considerable effects on varieties of maize, an open-pollinating crop. The genetic structure of maize varieties altered over time on-farm owing to farmers' intentional seed selection processes, as well as to the effects of unintentional seed mixing, contamination, genetic drift, mutation, natural selection and segregation.

In the Cuzalapa valley of Mexico, farmers constantly exchange small lots of maize seed, both within the region and further afield. Although small in scope, these exchanges have become an integral part of local maize cultivation because they can provide seed for planting at any time of the year and because they help to introduce new diversity into an existing landrace (Louette *et al.* 1997). Farmers' practice of exchanging seed lots for the same named varieties in order to "renew" seed has been noted there and in a number of other studies (Almekinders *et al.* 1994; Sperling *et al.* 1996; Wood and Lenné 1997). In light of this practice, the structure of genetic diversity in landrace populations is very different when considered in one field, a village or across an entire region.

6.3.1 On-farm seed storage

Seed storage devices and methods may determine the vulnerability of seed to pests, diseases and physiological deterioration, affecting seed quantity and quality for the next planting season. Thus, the conditions under which seed is stored may act as a selecting force on the seed lot, as seed better adapted to the conditions will be more likely to survive until the next planting season, with potential effects for the genetic diversity of the crop population over time. When addressing issues of seed selection and storage practices, it also is important to know who is responsible for what tasks.

Example: Farm seed storage system in Kaïn, northern Yatenga, Burkina Faso

Ears of sorghum, millet and corn are stored in granaries. Local plants are used to protect the grain from pests in storage, including *Cissus quadrangularis, Sansevieria senegambica, Hyptis spicigera* and *Cassia migricans*. The plant is freshly ground, mixed with water, and spread in the granary before storage. Shea almond residue is also used for protection against pests. Grain is also blended with ash and stored in jars. This process is carried out in the early morning or the evening without natural light. Pregnant and menstruating women do not participate in the process.

The images below illustrate these seed storage systems: granary with clay roof (photo 1); granary with straw roof and seeds hung outside (photo 2); granary with shea almond residue visible on the wall (photo 30; 40-50 year old "dogon" jar that will store 50 kg grain (photo 4); storage jar containing peanut seeds (photo 5); three different jars for seed storage; the small calabash contains ash (photo 6).
(Contributed by Madibaye Djimadoum)

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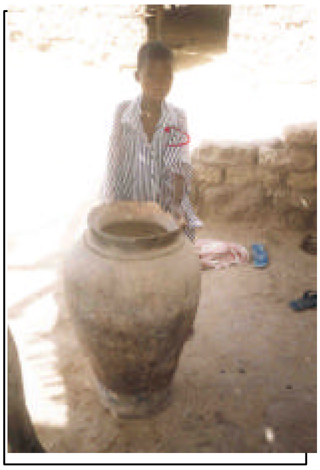

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Modern containers such as bottles also may be used with traditional methods, as the storage of different types with ash to guard against pests, as pictured in Vietnam.

6.4 Measurements to link seed systems to other factors

In Chapter 2 we discussed relationships between social, economic and cultural factors and the maintenance of diversity on-farm. Household characteristics such as wealth status, labour availability, land size, education, gender or ethnicity also can play a role in farmers' decisions regarding whether to use their own seeds or to borrow, exchange or buy seeds. It is important that at the same time household data are collected, information on the seed system (shown in Box) is also collected.

Information to be collected on seed system(s)

Seed source
Own seed (%)
Acquired in the village (%)
Introduced from outside the village (%) and location if known

Seed exchange
Within an extended family
Between farmers within the community
With farmers from other communities

Seed selection for next cultivation cycle (Chapter 4)
By whom (male/female/age/other)
Special plot only for seed production
Extracted from a sown area as a whole
Extracted from a specific part of the field

Level of Selection (Chapter 4)
Ear/Panicle
Grain

Time of seed selection (Chapter 4)
Prior to harvest, considering also vegetative characters
After harvest, on the basis of reproductive organs

Example: Wealth status and rice seed supply systems in a Nepalese village

Research on seed supply systems from the IPGRI on-farm conservation project in Nepal revealed that rice seed supply systems differed significantly between farm households of different wealth status. While most farmers change seed lots or cultivars regularly, rich households have access to improved varieties from formal channels as well as from relatives. Poor farmers, on the other hand, must rely on acquisitions from neighbours to meet their off-farm seed demand. Farmers of the rich, medium and poor wealth classes may also differ in their means of acquiring seed, whether by exchanging rice seed for other rice seed, trading rice grain for rice seed, or giving or receiving rice seed as a gift. (Source: Baniya *et al.* 2000)

Comparative estimate of rice seed supply (in kg) within household level, Begnas, 1999

	Wealth class			**Total**	
Seed source	**Rich**	**Medium**	**Poor**	**Quantity**	**%**
Own landraces	215	173	184	572	68
Neighbour's landraces	–	–	10	10	1
Own improved variety	142	91	12	246	29
Neighbour's improved variety	–	–	5	5	1
Relative's improved variety	10	–	–	10	1
Other improved variety	1	–	–	1	–
Total	368	264	211	843	100

6.4.1 Seed system and partial membership data sets

In some cases classical statistical techniques such as multiple regression (see Chapter 2) or ordination (see Chapter 3) may be useful in elucidating correlations between seed systems and other factors. However, often seed system data may be imprecise, or families may only have partial ownership to a particular type of seed source or seed exchange system. An organized analysis method for dealing with imprecise data sets – such as % seed source – that allows partial ownership is "**fuzzy logic",** where partial or imprecise groups are called ***fuzzy sets*** (Baldwin 1981). This method deals with data that may not wholly belong to one group or another. Different groups can be assigned different percentages of membership, ranging from full membership (e.g. always using one's own seed) to partial membership (e.g. 30% of the time using one's own seed) to no membership (e.g. never using one's own seed).

Fuzzy logic internet sites
Tutorials, references and software for using fuzzy logic and software can be found at the following internet sites:
http://www.austinlinks.com/Fuzzy/tutorial.html
http://www.eng.rpi.edu/dept/env-energy-eng/WWW/FUZZY/title.html.
http://www.geocities.com/SiliconValley/Lakes/6007/Fuzzy.htm
http://www.realtime-info.be/encyc/techno/terms/80/36.htm

6.5 Seed systems and effective population size

Seed systems give us an indication of how many plants, over what spatial and temporal scales, have been involved genetically in the composition of a farmers variety. The effective population size (N_e) is a measure of the number of plants of the preceding generation that have provided the seeds in this generation. To obtain a clear picture of N_e and of the origin of the parent plants, information will be needed on crop variety management from harvest to sowing. For example, are separate plants selected to provide the next season's seed? Are seed lots from different fields, farmers or localities combined before sowing?

The genetic constitution of a variety and its effective population size will also be influenced by seed exchange between farmers, villages or regions, and by the extent to which farmers mix exchanged seeds – or their progeny – either deliberately or accidentally. Seed and seedling survival ensuring storage, germination and emergence also will have significant effects on the genetic constitution of the next generation. Differences between seed parents in respect of their contribution to the farmers' variety can be measured as differences in fitness (Chapter 5).

In order to gain a better understanding of the genetic characteristics or composition of a variety, it may be desirable to combine a number of analyses of individual populations or components. This involves **meta-population** analyses which are described by Hanski and Gilpin (1996) and used by Louette (2000). This approach assumes that "populations are spatially structured into assemblages of local breeding populations and that migration among the local populations has some effect on local dynamics, including the possibility of population reestablishment following extinction (Hanski and Simberloff 1997:6)."

Knowing the effective size of the populations through an understanding of the extent of the seed supply system and the diversity it represents will be key for managers who are deciding the spatial scale of management. This will be further discussed in Chapter 9 under using information for action plans.

6.6 Seed supply system and policy initiatives

Strong seed supply systems enable farmers to maintain a high level of biodiversity over time, despite losses of seed stock, bottlenecks, and other regular or unanticipated losses of crop genetic diversity. Strengthening the informal seed supply system could serve to promote on-farm conservation of local varieties and to supply a majority of farmer seed demands caused by poverty, seed quality and variety change. Strong seed supply systems can foster increased use of diversity while fulfilling certain types of farmer seed demand. Linking the formal and informal seed sectors also can serve to increase farmers' access to new crop diversity. Chapter 10 discusses policy and other initiatives that could help support seed systems that maintain or increase crop diversity. A number of key questions need to be answered at national and local levels to help a national programme propose policy recommendations that support seed systems that maintain diversity (IPGRI 1999).

Key questions for decision-makers

National level:
- What kind of domestic seed industry exists?
- What kind of public breeding sector exists?
- How does national legislation affect the seed supply system?

Local level:
- What are the local seed sources and diffusion mechanisms?
- What are the speed and effectiveness of these mechanisms?
- What is the frequency with which seed is acquired and the reasons for acquisition?
- To what extent do farmers use seed saved on-farm, acquired through informal sources, and acquired through formal sources?
- Does farmer experimentation encourage the use and diffusion of new and diverse varieties?
- Do farmers have adequate access to appropriate varieties of seed to replace losses from disasters or crop failures?
- Do seed-producing farmers or villages exist that supply community and regional demand?
- How do cultural differences affect use of and access to seeds?
- How do differences in social mobility (e.g. exchange between tribes) affect farmer use of and access to seeds?
- How do differing economic conditions and market access affect farmers' access to seeds?

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Chapter 7 Building an on-farm conservation initiative

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[1] Photo credits: Pp. 109, 114: D. Jarvis; P. 112: N.P. Ha.

7.0 Objectives of this chapter

By the end of this chapter, the reader should have an understanding of:

- The partners that need to be involved in national on-farm conservation programmes and their potential roles and importance
- How effective linkages can be formed and maintained between partners at various levels
- How training and equity can strengthen national capacity for on-farm conservation.

7.1 Institutional frameworks for the implementation of on-farm conservation

Although much of this guide is concerned with highly technical topics, developing and carrying out an on-farm conservation programme requires more than resources and the expertise to collect and assimilate research data. It also requires partnerships among many individuals and institutions. Although they may be easily overlooked, these collaborative aspects are a fundamental element of a successful on-farm conservation initiative. This chapter focuses on the range of partners involved, the types of relationships that are necessary, and the ways in which responsibilities and benefits can be shared.

7.2 Who is involved?

Different types of institutions will be involved in an on-farm conservation effort at different levels. This **institutional diversity** is necessary in part because each type of organization has a unique set of capacities, and only through combining these abilities is it possible to address the complexities of on-farm conservation. These include:

- **Farmers:** As farmers are the implementers of on-farm conservation, their participation is the foundation of a successful conservation programme.
- **Farmers' Organizations:** Farmers' organizations will be important actors in on-farm conservation where they exist to represent farmers' interests.
- **Community-Based Organizations (CBOs):** CBOs can provide local support to a conservation initiative by representing and mobilizing local communities outside of farmers. The capacity of CBOs can be strengthened to implement activities related to public awareness, market networks and holding information on PGR matters.
- **Non-Governmental Organizations (NGOs):** NGOs can help to represent local, regional or national interests. They vary greatly in their aims and abilities—some are almost technical organizations, while others act as advocates for community rights or environmental conservation.
- **National research institutes**: These can be private, parastatal or public, and may be focused on conservation or development. National Plant Genetic Resources Centres (NPGRCs), which oversee PGR conservation efforts, are likely to be the national-level focal points for conservation programmes.
- **Government Ministries:** Beyond NPGRCs, other institutions working within national Ministries or Departments of Agriculture or Ministries of the Environment can make important contributions to an on-farm conservation team.
- **International Institutes**: International institutes can provide technical guidance and policy support for a particular on-farm conservation initiative. They also may be of value as global bodies which can identify and coordinate various initiatives.

Beyond their technical contributions, involving a range of institutions has the added effect of balancing the needs of various stakeholders. For example, a project dominated by conservationists may fail to priorize farmers' livelihoods, while a project dominated by agricultural development workers may not place enough emphasis on conservation. By incorporating multiple perspectives into an initiative, it is possible to begin to balance objectives and address the needs of all the parties involved.

Farmers meeting with multidisciplinary, multi-institutional team of development workers, natural and social scientists, and national policy advisors in Azilal region, Morocco.

A successful on-farm conservation initiative will bring together a range of partners with diverse objectives. By balancing the perspectives of the various partners, the disparate needs of conservationists, environmentalists and economic and development social workers can be addressed simultaneously:

- For the conservationist and breeder, the objective may be maintaining or enhancing the genetic value of the material to ensure adequate diversity for future breeding efforts toward increased yields, stressful environments, changes in adaptation to new pests and diseases, and intensified agriculture from increased population density and changing environmental systems (Frankel *et al.* 1995; Gollin and Smale 1999).
- For the ecologist, *in situ* conservation on-farm is important as a way to maintain local crop management systems for the sustainability of ecosystem services and the health of the agroecosystem in terms of moderating greenhouse gases, ensuring soil formation processes, reducing groundwater pollution and other waste emissions, and restricting the spread of plant diseases (Goodland 1995; Vandermeer 1995; Costanza *et al.* 1997; Finckh and Wolfe 1997).
- For the development worker, community-based organization and farmer, the objective may be to increase the economic value to ensure local food security, increase income and to develop and enhance social organizations for empowerment of farmers and local communities (Mushita 1993; Tanedo and Haugen 1993; Bellon 1996; Vazzana 1996; van Oosterhout 1996).
- Likewise, a national government may be interested in *in situ* conservation on-farm as a method to preserve a national heritage for national use and access or as a way to ensure social stability (Goodland 1995; Balma 1997; Maheswari 1997).

(Adapted from Jarvis and Hodgkin 1998)

The IPGRI *In Situ* Conservation On-farm Projects

The IPGRI *in situ* projects are being managed and administered by the National Plant Genetic Resources Programmes within each country. The within-country management and administrative structure of a project that involves multiple institutes, disciplines and stakeholders is inherently complex. In the countries participating in the IPGRI-supported project, the first step has been the formation of multidisciplinary and multi-institutional National Advisory Committees, headed by a national project coordinator and bringing together members from formal sector institutions and NGOs and other informal sector actors. The National Advisory Committee serves as the lead institution in coordinating and monitoring project activities within the country, providing technical backstopping, assuring the integration of the project into national programmes, and approving plans and reports for the regional and global project management levels. In addition, technical working groups under the National Advisory Committee are established in biological and social sciences as well as in extension and training. These provide technical backstopping to the project, and supervise and monitor project activities. The working groups are particularly conscious of the importance of gender, both in ensuring the representation of women and men on research and management teams and in collecting disaggregated data from women and men farmers. The technical working groups are also supported by a global project Technical Advisory Panel.

7.3 Institutional linking

Such a range of institutions will only be able to carry out an on-farm conservation project if they can work together. These institutional linkages are what makes on-farm conservation, like any complex task, function effectively. The most important features of such relationships are collaboration in multidisciplinary teams, effective communication and the ability to negotiate adversity.

Such a management framework should be in place at global, national and grassroots levels. Because on-farm conservation teams are multi-institutional and multidisciplinary, a participatory planning process should be institutionalized on thematic issues to enhance and strengthen team dynamics. The outcome of successful linking will include linked biological and social science programmes in institutes and universities, improved links between formal and informal institutions and farmers, and strengthened community institutions for biodiversity management.

7.3.1 Collaboration: working together in multidisciplinary teams

A strong sense of collaboration is necessary between the members of a multidisciplinary team to ensure that each partner makes appropriate contributions to the group effort. Collaboration can be thought of as teamwork, in which all partners understand the overall aims of the team (effective on-farm conservation) as well as the role each individual or institution plays (making a specific contribution to research, community participation, etc.). In some instances, a good sense of teamwork may exist among partners from the start of a project. More often, effective collaboration within a group must be built. This can happen in part by providing each partner with enough respect and autonomy to give them a clear stake in a project's development and outcomes.

7.3.2 Coordination: effective communication and networking

Within a diverse team, effective coordination is vital to ensure that each institution and individual shares progress and hurdles with the rest of the group. A common means of ensuring coordination is through the establishment of systematic paths of communication, or **networks**. Networks may function through Email, but can use almost any communication medium, and can operate either directly between each institution involved (a decentralized network) or by channeling all communications through a central ‘secretary’ (a centralized network). Networks are a useful way to share experiences and questions, advance a multidisciplinary group’s aims, and use limited resources efficiently (Starkey 1997).

7.3.3 Potential hurdles in collaboration

Given the complexities involved in on-farm conservation, setbacks are inevitable. The emergence of problems – whether in the form of delays or disagreements between partners – can test the collaborative spirit of a multidisciplinary group as well as its capacity to communicate effectively. The ability to resolve potential conflicts, however minor or major, in a timely and agreeable manner is one sign that a group is functioning as it should. In fact, overcoming such hurdles may often help to bring a collaborative team closer together and allow them to communicate even more effectively.

7.4 Establish collaborative project frameworks

Not all institutions are used to working in a multi-institutional, multidisciplinary way, and at many times the framework for this type of collaboration is non-existent. In these instances, time and energy must be set aside to develop collaborative project frameworks. The hierarchy and administrative bureaucracy involved in this process can be cumbersome and time-consuming. Conscious effort may be needed to garner political support and goodwill for such a project through a series of high-level meetings with policy-makers. Activities related to gaining this support must be assigned as much time initially as other project activities, so that the result leaves all formal and non-formal institutes satisfied in terms of their scientific, administrative and financial responsibilities and benefits.

7.4.1 Memorandum of Understanding

To achieve a collaborative management framework, the partner institutes may need to formalize partnerships with other national and international institutions through a Memorandum of Understanding (MoU). Memoranda of Understanding, though they can be time-consuming to develop and require widespread approval, are useful tools in formalizing cooperative agreements. MoUs are developed by the institutions involved and are signed at very high levels, and they stipulate the framework under which the collaboration will take place. A MoU may be signed by two or more institutes within a country, or it may be signed by an international agency and a national institute, stipulating that the national institute agrees to enter into a collaboration with other national institutes. MoUs are particularly important in countries where upper-level administrators are frequently moved from one post to another, to provide continuity and commitment from an institute rather than an individual administrator.

7.4.2 Building collaboration with farming communities

A collaborative framework involves increasing the linkages between farmers and genebanks, the central institution of most NPGRCs. This is a two-way connection, in which each side (genebanks and local farmers) can provide valuable resources for the other. Farmers participating in an on-farm programme have the capacity to conserve far more genetic material than most genebanks. And by providing germplasm from their fields, including the products of participatory breeding exercises as well as hybrids with wild or weedy relatives, farmers can give *ex situ* collectors access to new material. Farmers also may be of assistance in the characterization and evaluation of genetic material and providing local knowledge on the management and use of particular varieties. Community sensitization is an integral step in the process of implementing an on-farm conservation programme, further discussed in Chapter 8. In addition, participatory research techniques (also discussed in Chapter 8) should ensure that farmers' interests are addressed by the research objectives.

Example: The processes used in Nepal to build collaboration with farming communities.

In situ crop conservation project - Nepal

Process	Activities	Roles
Develop strategy for on-farm conservation	1. Sharing of results with participants through FGD 2. Explore various options 3. Adding benefits through PPB, seed networks, market and policy incentives 4. Continue diversity fair and monitoring through CBR	Local team (LMDG)
Community Biodiversity Register	1. Monitoring genetic erosion using CBR 2. Categorization of diversity: abundant, occasional, rare 3. Preference matrix ranking - preferred traits analysis/ values	LMDG
Diversity fair	1. Locating diversity and custodians 2. Understanding reasons for cultivation 3. Understand process of on-farm conservation (seed retention, selection, exchange, etc.) 4. Farmer network analysis - identify hub of germplasm and knowledge exchange	Local team (LMDG)
Community sensitization	1. Village workshop, field visit, meeting, exchange visit, etc. 2. Diversity fairs, indigenous food fairs, diversity blocks, diversity kits, etc. 3. Rural poetry journey, street drama, song/ painting/ essay competition, etc.	Local team (LMDG)
Participatory planning	1. Explore existing farmer groups to create institutional framework at grassroots 2. Create a national framework linking local and national levels 3. Develop participatory working procedures 4. Identify roles and responsibilities	NMDG
Locating ecosystem and community	1. Discussion on criteria of macro site selection 2. Rapid biodiversity assessment - FGD, transect walk, etc. 3. Situation analysis - capacity of local institutions, interest, sustainability, diversity, etc. 4. Joint decision for site selection	NMDG

LMDG= Local Multidisciplinary group; NMDG= National Multidisciplinary group

Example: Establishing collaborative project frameworks
Participatory meeting in Hanoi for the Vietnam *in situ* conservation on-farm team where members from the participating villages, district extensionists and national research programmes are meeting to discuss project progress and future direction.

7.4.3 Taking time to develop frameworks

Setting up the management and administrative structure of such complex projects is a time-consuming task, and in the rush to secure funding for projects, time may be a limited resource. Projects are often developed by a few persons, representing only a few of the total stakeholders, who hope that once the funding is secured the project will be 'explained' and accepted by the other stakeholders. The stage of explaining the project's purpose and value to team members is often not given adequate time. As a result some stakeholders may feel no ownership in the work they have been asked to perform. Often the project sponsors and designers are under tremendous pressure to get a project underway and meet project deadlines, but it is important to spend time consulting with stakeholders and allow them time to fully understand their roles in the project and make informed commitments. They have to be accorded time to fully understand the commitments they are being asked to make and time to judge their abilities individually and collectively to fulfil it. The absence of this informed commitment prior to the start of a project is sure to hinder implementation.

Taking time to develop partnerships: Using the ZOPP method

One approach to overcoming problems in stakeholders' differing objectives and needs is to hold a series of consultative meetings among all partners prior to the start of a project. These meetings help to provide a forum to establish the purpose of the project as well as each partner's responsibilities and commitments. Any outstanding concerns or issues can be addressed during these meetings, helping to avoid confusion and strife later. One approach to project planning and management which can be effective in stakeholder meetings is called **ZOPP**, a German term meaning Objectives-Oriented Project Planning. It is used to help encourage participatory planning and analysis throughout a project cycle, but is especially effective in project planning. The purpose of ZOPP is to undertake participatory, objectives-oriented planning that spans the life of the project or policy work to build team commitment and capacity. The ZOPP method is easily adapted to on-farm conservation planning, and helps to allow the production of a project plan in which each stakeholder is committed to the activities of a project. The technique ideally requires stakeholders to come together in a series of workshops to set priorities and plan for implementation and monitoring. The main output of a ZOPP session is a project-planning matrix, which stakeholders build together, and commit themselves to specific activities within the project plan over the life of the project. For more on ZOPP and project matrices, see:
http://www/worldbank.org/html/edi/sourcebook/sba102.htm.

7.5 Strengthening national frameworks for on-farm conservation through training and equity

The first step in the establishment of a national framework for on-farm conservation is the identification of partners and the creation of linkages between them – including diverse disciplines, institutions, and formal and informal sector organizations – as discussed above. Other important aspects of creating a national framework for long-term, sustainable research and implementation of on-farm conservation include training and equity.

7.5.1 Training

Training may be an important means to increase national capacity for the interdisciplinary research involved in on-farm conservation. Enhancing national expertise through training male and female personnel in plant population biology, ecology, biogeography, conservation biology, economics, sociology and anthropology will create a foundation for sustainable research and conservation programmes. Training should target both farmers and project personnel and when possible should serve to strengthen the collaboration between them, such as training on participatory approaches to research and participatory plant breeding.

7.5.2 Equity in participation and decision-making

On-farm conservation initiatives also should promote equity at all project levels, from farmer participation to research to project management and decision-making. Gender awareness is one important facet of national on-farm conservation projects, not only in the collection of gender-disaggregated data and the participation of women farmers in the project, but also in the involvement of women and men as members of research and management teams. Increased participation of women, minorities and farmers in decision-making is essential to ensure that diverse perspectives are incorporated into project objectives and that all stakeholders feel ownership in the project.

Involvement of women in decision-making to ensure that diverse perspectives are incorporated into the management of local crop diversity in Nepal.

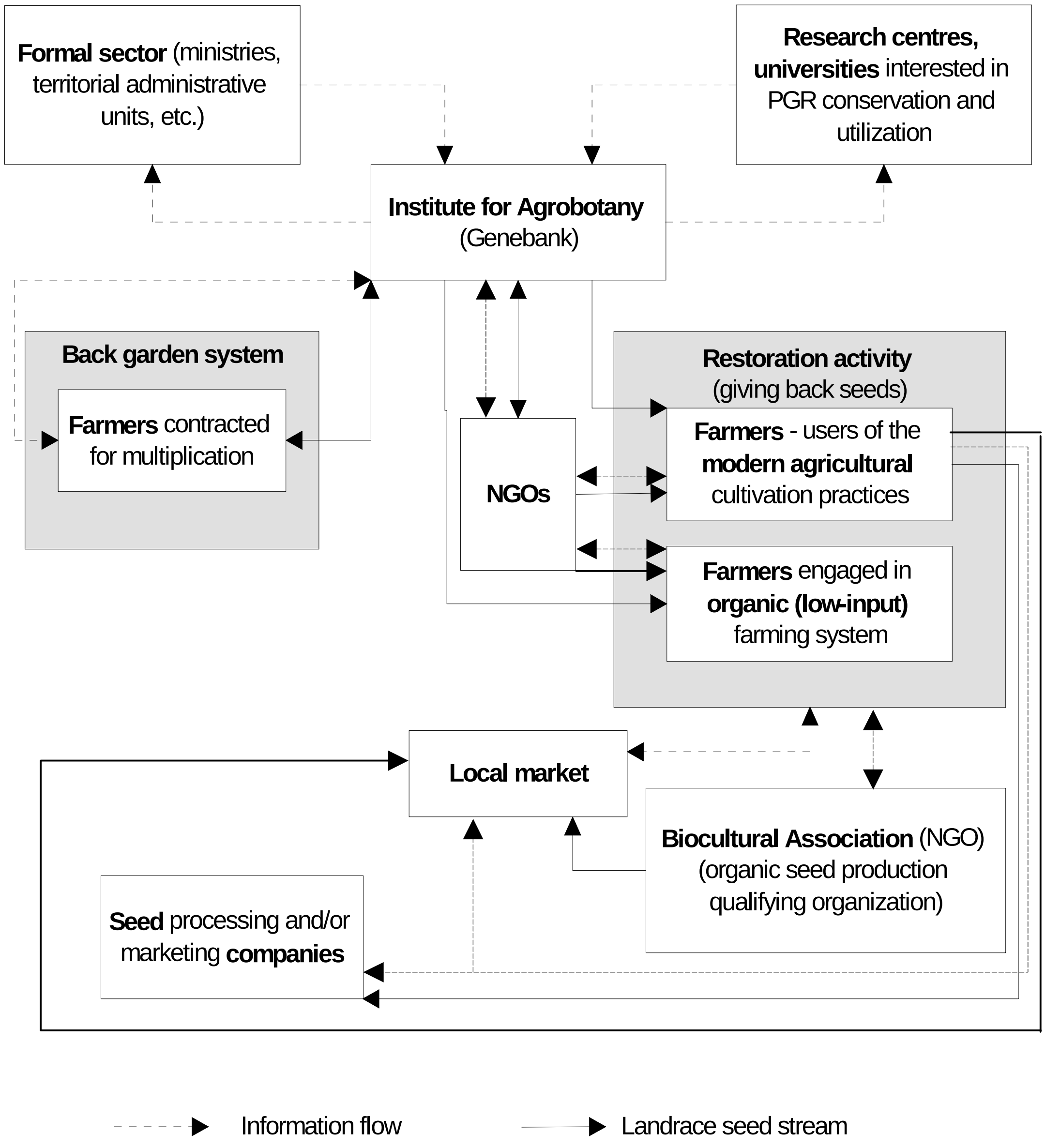
Example: Linking farmers and genebanks in Vietnam

In 1995, Can Tho University, with the support from IRRI and Community Biodiversity Development and Conservation Project (CBDC), initiated activities to create mutually beneficial links between farmers and the national genebank in the Mekong Delta region of Vietnam. Studies were carried out in rice, cassava, sweet potato, taro and yam. Activities include documentation of indigenous knowledge on PGR and locating and assessing genetic diversity and genetic erosion using isozyme and agromorphological traits. Soil survey maps and meteorological data are linked to local CGR (crop genetic resources) diversity to identify site-specific crop diversity. Participatory Plant Breeding and Participatory Variety Selection are used to develop varieties with farmers according to their preferences but with access to germplasm and technologies from the genebank. In this process, the formal plant breeding sector acknowledges the farmer's role in plant breeding and PGR management. On-farm trials have been of benefit to breeders for assessing their work in real farm conditions, and benefit farmers through increasing their access to new crop diversity. Farmers have received training in breeding and new technologies. These activities have enabled farmers, breeders, technicians and extension workers to work together for crop improvement in local farming systems. Such partnerships can provide the basis for research and implementation of on-farm conservation; indeed, Can Tho University has been one of the lead institutes implementing on-farm conservation research in Vietnam.

Source: Nguyen Ngoc De 2000

Example: A national framework for implementing on-farm conservation in Hungary

The existing national PGR conservation structure in Hungary, centred at the Institute for Agrobotany's national genebank, is implementing on-farm conservation by involving new partners like farmers and NGOs. The Institute for Agrobotany, which holds the mandate for PGR conservation in Hungary, first involved farmers in its conservation activities in 1959 with the "Back Garden" programme. The Back Garden programme incorporates farmers into national conservation activities by contracting the multiplication of *ex situ* accessions to farmers in the appropriate agroecosystems for the target crop varieties. Beginning in 1997, new partners were involved to expand the existing programme into on-farm conservation. Regional NGOs are linking farmers interested in long-term reintroduction and cultivation of landraces with the Institute of Agrobotany, while universities and research centres are investigating the socioeconomic, agroecological and genetic implications of reintroduction. The formal sector (Ministry of Agriculture and Rural Development and Ministry of Environmental and Territorial Development) supports this framework.
Source: Mar 2000.



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Chapter 8 Getting started: preparation, site selection and participatory approaches

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[1] Photo credits: Pp. 123, 125: D. Jarvis; P. 128: A. Tan

8.0 Objectives

By the end of this chapter, the reader should be familiar with:

- The preliminary steps to implement of on-farm conservation research
- A range of information sources to consult to begin on-farm conservation research
- Potential criteria for the identification of appropriate study sites
- A range of techniques that can be used to carry out participatory research.

This chapter outlines the preliminary steps required to develop and implement an on-farm conservation programme. These steps are not part of a concrete model, and the process will need to be adapted to fit the contexts and constraints of any particular on-farm setting. The steps in the process of on-farm conservation described here presuppose that a multi-institutional, multidisciplinary framework at national and local levels is in place, as discussed in Chapter 7.

1. Identification of key crops for conservation
2. Review of existing information sources
3. Training local research teams in participatory methods
4. Defining criteria for site selection
5. Diagnostic survey to generate information for site selection
6. Site selection
7. Community sensitization
8. Selecting a sampling regime for data collection.

8.1 Identification of target crops

Target species for on-farm conservation should be identified as national conservation objectives (e.g. conserving the processes of crop evolution and adaptation, farmer livelihood improvement, etc., as discussed in Chapter 1) are developed. Key crops selected for conservation by a national programme should fulfil one or more of the following criteria:

- Important for local livelihoods
- Important for national breeding programmes
- Important for future food security
- Important for national consumption or sale
- High, useful, or important diversity contained in the country
- Rare or endangered.

In addition, the objective of conserving diversity at all levels, which entails an ecosystem approach to conservation, might lead to the identification of a complement of target species that are typically cultivated together within an agroecosystem. The review of existing data and diagnostic survey, discussed below, may be used to refine the list of species and to determine which species should be targeted for conservation in which regions or sites of the country, based on local and national needs.

8.2 Review of existing data

Data collection begins with a **review of secondary data** (such as census reports) and previous research (such as anthropologists' case studies). Other information resources useful for consultation include:

- **Descriptor lists**, which describe the important types of phenotypic variation found in the crop.
- **Databases of ex *situ* germplasm collections** may identify where potentially relevant accessions of the crop species are held. Each accession's passport data may supply

information on phenotypic variation, local names and uses, geographic range, agroecological information (including altitude, slope, aspect, etc.), and agronomic information. Both national and international databases may be important.

- **Herbarium collections** may have information on the habitats, distribution and genetic diversity of species, particularly crop wild relatives, and the records of specimen collectors can provide useful ethnobotanical insights.
- **Published literature in the natural and social sciences**, which can be accessed through bibliographic database systems, such as those produced by FAO (AGRIS), USDA (AGRICOLA) and IPGRI/CAB International (Plant Genetic Resources Abstracts), in addition to libraries.
- **Grey literature**, such as the reports produced by government and development agencies, may provide information on local crops and farming systems. These may come from Ministries of Agriculture, Environment, or Development and Planning but rarely reach publications or bibliographic databases. They are probably best searched in national agricultural libraries and documentation centres or through experts in particular departments.
- **Personal knowledge of experts**, including personnel from NGOs, CBOs, and extension services.

(Dearing and Guarino 1995; Maxted *et al.* 1995; Thormann *et al.* 1999)

8.3 Define criteria for site selection

The **criteria defined for site and farmer selection** should relate to the factors that are hypothesized to be associated with significant variation in crop genetic diversity, which may be socioeconomic or cultural (such as ethnic diversity, fragmentation of land holdings, population density, and integration into input, product and labour markets) and agroecological (such as the presence of diverse niche environments). Variation must exist between study sites and between farmers within the sites in order to test these different relationships. In addition, the criteria for site selection should account for particular ecological or geographic factors that define the region of interest for on-farm conservation. For example, in Nepal, the watershed was identified as a key geographical unit for selecting target areas because of the strong linkages between land and water biodiversity. Once key watersheds were selected, a list of potential villages for on-farm conservation was generated.

8.4 Diagnostic survey

The review of existing data should be combined with a diagnostic survey, using Rapid Rural Appraisal (RRA), Participatory Rural Appraisal (PRA), or a similar approach. This **rapid participatory diagnostic exercise** will provide further information to characterize sites in the target regions by their socioeconomic and agroecological situations, diversity in the target crops, and the feasibility for research. Diversity within the target crops can be measured by the number of farmer-named varieties for the purposes of a diagnostic survey, which can be validated with morphological and genetic analysis later. The levels of various factors should be recorded, such as: population density, road surface and transport, access to different types of markets, percent of irrigated and rain-fed area, variation in altitude and soils, the importance of crop production and other sources of income in community livelihoods, recent perceptions of change in the genetic resources base, and other criteria of national or regional interest. The interest of the community in the project, and other logistical considerations like accessibility, also should be gauged. Before a PRA can be successfully employed, local research teams must be **trained in participatory approaches** for gathering data in rural communities. Specific techniques that can be used in a participatory diagnostic survey are discussed in Section 8.7 on Participatory Techniques.

8.5 Site selection

One purpose of these activities is to **identify appropriate study sites**. Selection of the households, plots and varieties to be studied in the project should be determined by the sampling strategies of the disciplines involved, which are further discussed in Chapter 9. A summary of potential criteria to be used for on-farm conservation site selection follows (Poudyal *et al.* 1998; Rijal *et al.* 1998; Sherchand *et al.* 1998).

Ecosystems

- General magnitude of diversity at agroecosystem, species and variety levels
- Local diversity in specific agroecological variables (soil, altitude, precipitation, etc.)

Crops

- Richness of intraspecific diversity within target species
- Presence and diversity of wild or weedy relatives, and possibility of introgression / hybridization
- Likely presence of specific adaptations
- Genetic erosion and presence of landraces under threat in target species

Farmers and communities

- Sociocultural and economic diversity
- Diversity of livelihoods, and importance of target crops for various ways of life
- Farmers' knowledge and skills in seed selection
- Market opportunities

Partners

- Community interest and cooperation
- Previous conservation interventions (if any)
- Presence and capacity of local institutions, especially for research

Logistics

- Site accessibility throughout the year
- Availability of resources.

8.6 Community sensitization

Although community interest in the project should be assessed during the diagnostic survey, activities to involve the farmers in the project before data collection begins are crucial for generating enthusiasm for research activities. To ensure that farmers, who are the actual implementers of on-farm conservation, are stakeholders in the project, a dialogue must be well established so that their interests can be voiced to researchers and included in research activities. A **community sensitization** activity may be the initial foundation for a collaboration between a farming community and a national plant genetic resources programme that will be the basis of a sustainable on-farm conservation programme, including research and long-term monitoring.

Community sensitization activities for an on-farm conservation project may focus on educating farmers about the value of local crop diversity and building on local pride in the cultural heritage of their landraces. Activities chosen will depend on the specific community context. Examples include informal village meetings and workshops or Diversity Fairs (which are discussed in Section 10.4.5), or they may build on participatory research techniques that facilitate the process of farmers asking their own questions and taking action regarding their community (discussed in Section 8.7). Community sensitization will help to identify and involve a network of households to carry out multidisciplinary research work. CBOs and farmer organizations may be important partners in coordinating large numbers of households for different types of work.

Women farmers' group in Burkina Faso.

8.7 Participatory approach

Research for on-farm conservation should be implemented with a participatory approach at all stages of the process. Participatory research refers to techniques that emphasize researchers and participants learning together, rather than the extraction of information by researchers from participants. The use of participatory methods can serve to include farmers in the research process and to incorporate their knowledge on local socioeconomic and agroecological conditions, their crop and seed management practices, and the characteristics and origins of their varieties into project data. An exploratory approach – one which is not based on preliminary hypotheses – is initially useful because it does not presuppose or assume the different categories or reasons underlying farmers' knowledge and enables farmers to employ their own values and standards of measurement. Techniques can be structured to allow for the collection of quantitative data, or semi- or unstructured to elicit qualitative data. Qualitative data do not fit a rigid or standard format for collection or analysis, whereas quantitative methods use standardized scales of measurement.

Participatory research differs from more traditional research approaches in several aspects, including the following.

- **Focus**: Participatory methods are best applied with a focused perspective limiting research data to the needs of on-farm conservation. Collecting contextual data can be important to understanding local situations but collecting extraneous or unnecessary information can waste time and confuse the purpose of research.
- **Flexibility**: The ability to adapt to changing local conditions as well as unanticipated setbacks is an important quality. This applies to overall study design as well as the process of developing specific research techniques and applying them in conjunction with participants.
- **Overlapping techniques**: Participatory methods are most effective when different techniques collect at least some of the same data from different participants. This is important in gaining a wide variety of perspectives and also to cross-check research results.
- **Cooperation**: In preparing for and carrying out research, gaining the full support of local communities can make research more productive and less problematic. This can be part of every stage of research, from gaining permission for research from local authorities, to developing a sense of learning between researchers and participants.
- **Sharing**: Researchers should be prepared to incorporate the research needs of local communities into the design of a project, and in turn must be willing to communicate the results of the research back to communities.

As a part of a locally held body of indigenous knowledge (IK), farmers' knowledge is characterized by unique features determining how it should be researched. These characteristics include how local knowledge is patterned within communities, how it can change through time, and the ethical responsibilities involved in such research. These characteristics drive the need for a unique set of techniques for the collection of data on farmer knowledge.

Indigenous or local knowledge may be characterized as:
- unevenly distributed within and between communities
- dynamic and often fragile
- possibly difficult to access, especially for outsiders
- commonly linked to local environmental factors
- unique to particular regions and locales

Rather than extracting data from local settings, techniques that allow farmers to participate in the research process are better suited to study the spatial and temporal dynamics of local knowledge and create a foundation for maintaining local control of indigenous crop diversity. These participatory approaches are the focus of Section 8.7. First, some ethical issues in researching indigenous knowledge are raised.

8.7.1 Research ethics

A basic tenet of ethically sound field research is the principle of informed consent, which holds that all participants should fully understand the purpose and process of the research before agreeing to participate. It is the responsibility of researchers to ensure that participants understand the possibilities for positive or negative repercussions of their participation in research. In addition, researchers must be able to guarantee some degree of privacy to informants. This may take the form of a guarantee of anonymity (in which all participants' names are removed from data) or confidentiality (in which researchers must retain farmers' names for research purposes, but data linked to individuals or households will not be revealed publicly). However, future on-farm conservation activities may require farmers or households to be linked to data on local crop diversity.

In addition, before starting any research to document farmers' knowledge and perceptions of crop genetic diversity, researchers must think carefully about the implications of their work for local Intellectual Property Rights (IPR). In the case of plant genetic resources, intellectual property refers to the knowledge associated with a particular landrace or allele that may be an economic resource. Researchers must be aware that in researching local IK, they are inevitably accessing local intellectual property. Their research may serve as an important record of local IK, which should be documented and respected accordingly.

8.8 Participatory techniques

A number of techniques that will be useful for participatory research for on-farm conservation were developed through Participatory Rural Appraisal (PRA) and Rapid Rural Appraisal (RRA). These will be particularly valuable methods for use in the informal diagnostic surveys (discussed in Section 8.2). PRA and RRA both describe an approach and range of methods emphasizing farmers' knowledge and ability to participate in research. They share many innovative methods but differ in that the focus of RRA is learning by outsiders, while the objective of PRA is analysis and action by insiders (Chambers 1994). There is a wide range of participatory research techniques, and researchers commonly blend existing techniques or invent new ones to suit particular settings. We discuss here only a handful of these:

- Key informant interviews
- Focus group discussions
- Spatial mapping
- Correlation exercises (including matrix ranking)
- Calendars and temporal mapping
- Transects.

8.8.1 Key informant interviews

Key informant interviews, sometimes referred to as in-depth interviews or free-flow interviews, are usually conducted by a single researcher with only one informant at a time. These interviews are aimed at exploring the knowledge of an individual through a conversation between researcher and informant. The key informant should be an individual with special knowledge of specific fields of interest.

The most important feature of a key informant interview is highly detailed data collection. Although the researcher may use a question guide to avoid missing key topics, these interviews are traditionally unstructured, and the conversation is left to flow naturally (even if it drifts from the subject at hand). The most obvious participants are farmers but others such as elders or members of a community may be especially knowledgeable in particular areas. Because only one participant is interviewed at a time, the discussion may contain information which would not normally be discussed in a group setting and will be useful for topics that are sensitive or individualistic. Well-prepared interview guidelines can help to produce fruitful results.

A key informant interview may become semi-structured by using a checklist of discussion topics, or even a handful of preliminary standardized questions. This will help to improve the comparability of interview data while still allowing individuals to present unique perspectives. Another possibility is to integrate other participatory research methods (such as mapping, calendars or transects) into the interview. A disadvantage of the technique is its time-consuming nature; it is unlikely that many such interviews will be possible with limited time and resources.

This Hungarian farmer is one of the few in his region cultivating old maize varieties.

8.8.2 Focus group discussions

A focus group discussion, or a group interview, involves a number of people meeting with a facilitator in an unstructured discussion about a specific topic. These will usually be pre-arranged meetings, but also can be effective in informal groups. As in the case of key informant interviews, focus group discussions should emphasize the free flow of conversation. The composition of the focus group may vary depending on the situation and the preferences of the facilitators: 4-10 people at a time and 1 or 2 facilitators. Focus groups can be used to generate a large amount of data in a short span of time. It is possible to cover more ground than in an individual interview and gain multiple perspectives on the topics discussed. With an experienced moderator working in the local language, these can be the most productive techniques for generating general data. The role of the facilitator is crucial here to encourage discussion, steer the flow of conversation, and probe particular issues in detail.

Whom to include in a group discussion is debatable. Some researchers prefer to include individuals from a variety of socioeconomic backgrounds to observe group dynamics and the discussion of opposing views. Others opt for more homogenous groups to explore seemingly uniform opinions in great detail. Because of the group nature of the exercise, it can be difficult to separate individual responses and disaggregate data by socioeconomic or demographic variables. Recording data during a focus group discussion can be difficult. In addition, different perspectives may be overshadowed if the discussion is dominated by a few individuals.

8.8.3 Spatial mapping

Spatial mapping involves participants drawing maps of any kind of spatial relationship. This may be performed alone or with the assistance of a researcher. Maps are used to gather data on participants' perceptions of the spatial distribution of elements in their agroecosystems and communities. These include:

- the layout of households and their fields within a village
- how social networks, such as farmers' groups or families, are distributed in a region
- where particular agricultural activities take place
- the location of different landraces among fields or across a community
- the distribution of resources (e.g. soil types).

Mapping usually involves either generating a map (on a blank piece of paper) or working on a standardized base map (either a professional map or one developed by researchers). The use of standard base maps is advantageous because it allows participants to work from the same basic set of geographic reference points, thus partially standardizing data collection. Meanwhile generating maps 'from scratch' allows participants to define significant reference points in their own terms.

Although spatial mapping does not necessarily demand literacy, participants must be able to conceptualize mapping and spatial relationships. Youths and elders may find this difficult. Mapping allows participants to express their knowledge in a non-verbal format, which has the potential to uncover relationships and patterns that interviews cannot. However, for participants who do not grasp spatial relationships well, mapping can be an intimidating task, and group mapping exercises may become chaotic.

The results of participatory mapping may be incorporated into a GIS also containing data from more formal sources, such as published maps and remote sensing.

8.8.4 Correlation exercises

Correlation exercises refer to the categorization of a series of items, according to their relative preference (ranking), their absolute preference (rating) or their degree of similarity (sorting, triads). These can be applied to any element within farming systems that can be ranked or compared. Variety choice and seed selection criteria are obvious categories, but ranking of agroecological niches also may be possible.

Almost any member of the community can express preferences and thus participate in these exercises with varying degrees of assistance from researchers. If well-designed,

Steps for Matrix Ranking of Farmer Selection Criteria

Sometimes it is difficult to elicit from farmers what criteria they are interested in selecting for their different varieties. By asking the farmer to compare or rank his or her different crop varieties, the interviewer can bring out many traits that the agronomist might not have considered. Here we describe an approach to creating a matrix ranking of farmer selection criteria.

1. Start by asking the farmer to list his or her landraces by name (do this one crop at a time).
2. Write down the names in a table with several columns.
3. First have the farmer rank the varieties in terms of area share (the amount of area allocated to each variety). Label column 1 "Area share."
4. Ask the farmer which variety is planted in the largest area. Put a number "1" in this variety's row under "Area share."
5. Ask the farmer which variety is planted in the second largest area, and put a "2" in that row.
6. Ask the farmer which variety is planted in the third largest area, and put a "3" in that row.
7. Then ask the farmer which variety is planted in the smallest area, and put a "6" (or however many named varieties there are; in this case, there are 6) in that row.
8. Ask the farmer which variety is planted in the second smallest area, and put a "5" in that row.
9. In the remaining row, put a "4."
10. Ask the farmer why Variety C is planted in the largest area share. Perhaps he or she will answer because of yield. So label column 2 "Yield."
11. Verify with the farmer that Variety C has that highest yield of all the varieties; if so, put a "1" in Variety C's row under "Yield."

Names	1. Area share	2. Yield	3.	4.			
Variety A	**3**						
Variety B	**4**						
Variety C	**1**	**1**					
Variety D	**5**						
Variety E	**2**						
Variety F	**6**						

12. Have the farmer rank the rest of the varieties in terms of yield according to the procedure outlined above in steps 5-9.
13. Look again at column 1 ("Area share") and ask the farmer why Variety F is planted in the smallest area. Perhaps he or she will answer that birds eat it, but it has a good taste for tortillas. So label column 3 "Bird resistant" and column 4 "Tortilla quality."
14. Verify that Variety F has the worst bird resistance of all the varieties; if so, put a "6" in Variety F's row under "Bird resistant."
15. Have the farmer rank all the varieties in terms of bird resistance.
16. Move on to column 4. Verify that Variety F is the best variety for tortillas; if so, put a "1" in Variety F's row under "Tortilla quality."
17. Have the farmer rank all of the varieties in terms of tortilla quality.
18. Look again at the area share and yield rankings. Note that Variety E is planted in the second smallest area and has low yield. Ask the farmer why he or she plants it. Perhaps he or she will say that it is drought resistant. Label column 5 "Drought resistant."
19. Verify that Variety E has the best drought resistance of all the varieties; if so, put a "1" in Variety E's row under "Drought resistant."

Names	1. Area share	2. Yield	3. Bird resistant	4. Good tortillas	5. Drought resistant		
Variety A	**3**	**4**	**5**	**1**			
Variety B	**4**	**2**	**2**	**2**			
Variety C	**1**	**1**	**3**	**3**			
Variety D	**5**	**6**	**4**	**6**	**1**		
Variety E	**2**	**3**	**1**	**5**			
Variety F	**6**	**5**	**6**	**1**			

20. Have the farmer rank all of the varieties in terms of drought resistance.
21. Continue the exercise by asking the farmer why particular varieties are planted to large or small areas, etc. until he or she has listed and ranked all varieties by all of the criteria used for choosing a variety and determining its area share.

Example: Research at all stages of cultivation and use and with all household members, Turkey
Conducting research at different stages of the agricultural calendar and with different members of the farm household is essential to collect information about their landraces, as well as to understand who is responsible for the maintenance of crop diversity and the processes that support this maintenance. Pictured below are several stages in the processes of cultivating, processing and marketing local crops in Turkey.


1. Harvesting a wheat landrace crop on a small farm near Bolkar Mountain.


2. Threshing a wheat landrace crop with traditional methods in Pusan.


3. Threshing a chickpea landrace crop with the traditional methods used for wheat threshing in Kilis.


4. Grinding wheat grain for bulgur (a skill shared by women and men farmers).


5. Processing hemp landrace plants to separate the fibre from the stalk (a skill of women farmers) in Kútahya.


6. Farmer's wife preparing bread as she discusses the quality of the wheat, Toros Mountains, Korkuteli Antalya.


7. Vegetables from a home garden being sold at market.


8. Wild medicinal and aromatic plants (*Sideritas* spp.) from natural habitats being transported to markets (usually collected by women or children), Toros Mountains.

standardized and conducted extensively, correlation exercises produce extremely valuable data on preferences and perceived categories. Moreover, results from individuals and groups can be aggregated and compared, presenting a way of translating qualitative information into quantitative form (cf. King 1999). To be effective, these require some degree of advanced planning. It is important to remember that if results are to be aggregated and/or compared, the exercises must be standard for all participants.

8.8.5 Calendars

Calendars are a way of expressing temporal variables in a visual or spatial format. They can be used to document any variable linked to changes through time, such as when different crop varieties flower during a season, when pests occur during a year, or when extreme environmental conditions (such as a drought) have taken place over the previous decade. Calendars may be especially useful in documenting the labour patterns of different members of the community (referred to as labour calendars). As in the case of spatial mapping, these do not necessarily demand literacy but participants must be able to conceptualize calendars and temporal relationships. Again, these exercises allow participants to express their knowledge in a non-verbal format which has the potential to uncover relationships and patterns which interviews can not.

Researchers can choose either to develop entire calendars ‘from scratch’ with participants (thus allowing participants to use their own temporal units), or to use a standard ‘base calendar’ (with uniform temporal units – whether days, months, years, or local units). Again, the use of base calendars helps to standardize data collection and facilitates comparisons, while developing entire calendars with participants allows them to identify and express significant events in their own terms.

8.8.6 Participatory walks

Participatory walks incorporate aspects of interviews and spatial mapping exercises to explore variations in land use and local agroecology across an area. They can be undertaken with one or several participants at a time. These walks may be informal and impromptu, or they may cover a predetermined path. This latter type of walk is called a **transect**, and involves walking with participants along a predetermined route, usually a relatively straight line, which crosses through different ecological niches within the agroecosystem. Along the way, researchers and participants use direct observations and immediate examples to explore particular issues related to the environment, including:

- soils and vegetation
- terrain and slopes
- water availability
- crops and crop diversity
- land tenure and use (adapted from FAO 1997).

The output of a transect will probably be a cross-sectional map cutting through various agroecological niches and recording participants’ comments on the different niches and variations encountered. By conducting a single transect several times, each with a different participant, it is possible to illustrate differing perceptions of the same agroecological area. These exercises can link spatial data directly with individual perceptions of the agroecosystem.

Selecting the right transect is essential. Time and local knowledge are needed to select a potentially productive transect. Collecting data on transects can be difficult (walking, asking questions, listening and taking notes at once). Group transects can be chaotic.

In addition to these formal data collection techniques, a tremendous amount can be learned simply by informal **direct observation** while spending time in a community. There is nothing like seeing something first-hand. During a rapid appraisal, it is important to look carefully at the places, people, resources and conditions described by the participants. Direct observations help to support and cross-check the findings from other methods, and can reveal new details and raise new questions. In addition, through participant observation, researchers actually take part in activities in the village. For every observation made, remember to write down two things: (1) what was observed, and (2) your interpretation of what it means. It is important to cross-check your interpretations with the findings from other methods and with other participants (FAO 1998:43).

When to finish participatory research: The law of diminishing returns

The efficiency of our data collection is governed by the law of diminishing returns – we gain a decreasing amount of new information from each interview or plant collection that we make. We may learn much from the first person to whom we talk. The second interview will give us some new information, but some of what the first informant told us will probably be repeated. The third respondent will probably give us even less original data. Eventually, we will find that each new person we talk with tells us things that we have already heard from others. Hearing the same thing several times helps us to confirm our data, and noting disagreement between informants allows us to gauge cultural variation in the community. But at some point, it simply becomes inefficient and uninteresting to keep asking the same questions over and over again (Martin 1995:23).

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Chapter 9 Sampling, structuring, documenting and presenting information for action plans

(with the collaboration of D. Louette, P. Mathur, P. Quek and I. Thormann)[1]

[1] Photo credits: P. 137: D. Jarvis; Pp. 140-141: N.P. Ha.

9.0 Objectives

By the end of this module, readers should have an understanding of how to:

- Carry out representative sampling over space and time
- Structure information to answer key questions related to *in situ* conservation on-farm
- Document *in situ* conservation efforts and return information to the community
- Present information for conservation and development action plans.

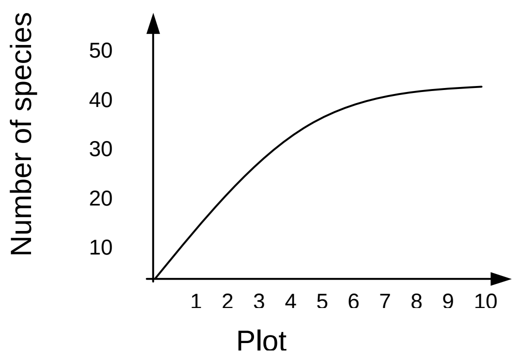
9.1 Obtaining a representative sample

Appropriate sampling is important to ensure that adequate representation of the situation or site is reflected in the information collected. Regardless of the approach chosen, some part of the diversity in human, environmental and genetic diversity factors will not be sampled. Sampling strategies must consider resource constraints along with scientific needs.

9.1.1 Choosing a representative sampling size

How many subsamples of households, plots, and plants are necessary to have a representative sample of the site or population in question? The objective is to determine the smallest number of samples to adequately characterize the region in question. Sampling size will depend on the amount of variation among samples. A larger sample size will give more information on the variation between samples than will a smaller sample. Thus, the more homogenous the population, be it in terms of household characteristics, field soil types or variety populations, the less the need will be for larger sample sets. This concept or trend in the decrease in new information as more and more, or larger and larger, samples are included is often used by plant ecologists in a technique called the **species-area curve** to determine the minimum size and number of samples that will be representative of a population. A more general form of the relationship is known as the law of diminishing returns.

A species-area curve is created by sampling the area in a system of nested plots (larger and larger plots arranged on the ground such that each successive plot encompasses all of the previous plot) (Barbour *et al*. 1987). After a certain point, very few new species are found in each successive plot.



Besides this nested method of determining sampling sizes, decisions are often made through consulting existing information (e.g. scientific literature) regarding the population. For example, social scientists commonly sample 5–10% of the households in a village when manner (Causton 1988). In random sampling every point in the field site has an equal chance to be sampled. In systematic sampling, transects or grids are used to take samples at regular intervals. This has the advantage of avoiding the over-sampling of “uninteresting” areas at the expense of “interesting” ones. However, consideration is required when selecting a sampling approach, because sampling can have a profound impact on study results; poor sampling choices can lead to results that may be considered invalid. Potential biases, particularly when choosing non-random samples, require special attention.

The primary purpose of random sampling is to detect and assess correlation between distributions of one factor in relation to another factor. One might want to know how the distribution of genetic diversity relates to certain social, economic, biological, environmental and other factors in the community. Does wealth status relate to any level of genetic diversity in the community? Do farmers with more fragmented land contain more diversity? These questions require a random sample of households across the landscape. Random samples of farmers' fields throughout the site also may be appropriate for gaining an idea of the range and diversity of the main abiotic and biotic factors affecting crop diversity.

Although it is the most statistically robust method, the placement of random samples is particularly time consuming. Regular or systematic placement of samples is the simplest method to carry out, but may be less appropriate for statistical analysis. A compromise method is **stratified random sampling**. In this method, the area to be sampled is first systematically subdivided into relatively homogenous sections, and then randomly placed samples are taken in each subsection (see Barbour *et al.* 1987; Kershaw and Looney 1985; Gauch 1982; Greig-Smith 1983). Stratified random sampling is often used once an area has already been stratified into different areas. Criteria are used to divide the study site/population into various strata, from each of which a certain number of samples are drawn randomly; criteria for stratification may be socioeconomic, agronomic or environmental in nature.

9.1.3 Structuring multidisciplinary information for sampling – the number problem

Stratifying to structure date becomes extremely important when more than one discipline is involved in a sampling procedure. For example: a community or village containing 1000 households is selected as a study site. Ten percent or 100 households of the village are sampled for social and economic variables. In each household, a farmer grows four target crops. For each crop, the farmer manages an average of three varieties grown in a particular field with certain soil and topographical characteristics. For each variety a minimum of 30 samples will be needed for an adequate study of the population. Thus, in order to compare household characteristics, plot characteristics and varieties, we end up collecting 30 samples × 3 varieties × 4 crops × 100 households or 36 000 samples for analysis. Of course this number of samples is unreasonable given time and resource constraints. How is this problem solved? One method is to return once again to the key questions that the study is trying to answer – what is the amount and distribution of genetic diversity maintained on-farm, by what processes is this diversity being maintained, by whom and why – to structure the data collection.

What has been useful in ongoing on-farm work is to first carry out a random sample of the households in a village to have an idea of the range of social, economic, cultural and farming management practices. At the same time, it will enable a preliminary idea of the total range of abiotic and biotic factors in the sites and the total range of genetic variation within the village. Where topography is an important factor, it may be useful to run a transect across north- and south-facing slopes and randomly sample households along this transect to have an idea of the entire range of agroecological factors for the site. Likewise, it may be useful to collect samples of all the landraces in the village for preliminary characterization to have an idea of the total range of variety diversity.

Once the range of (1) household and village social, economic and cultural characteristics (Chapter 2), farming management practices (Chapter 3), abiotic and biotic factors (Chapter 3), and genetic diversity of target crops (Chapters 4 and 5) is known, this information must be **structured**, or **stratified** to make comparisons among groups of different data types.

9.1.4 Sampling over time

On-farm conservation of crop diversity is influenced by agroecological, socioeconomic and genetic processes with different directions and rates of change over time. Some factors are stable, meaning that they do not change over time, at least in the short term, such as the soil, parent rock or climate. Rainfall may fluctuate annually, and market infrastructure may develop rapidly or gradually. It will be crucial for on-farm conservation efforts to study how changes in these factors over time might affect crop genetic diversity. For annual or biennial plants, sampling over time may be feasible within the lifetime of one research project, but this may not be possible for perennial species. For such long-lived species, spatial proxies for time will need to be used to understand how these different factors may influence genetic diversity over time.

When data are collected at different times, **time-series analysis** methods can be used to examine relationships between variables over time (Kendall and Ord 1990). Time-series analysis is based on the idea that measurable variables that are observed continuously may be regarded as information signals. Sampling this signal at different intervals produces a discrete signal, or time series (1996-2000 Finney: http://www.chaos.engr.utk.edu/CTSA.html). 1985). An **autocorrelation coefficient** is determined as a measure of the similarities of measurements that are separated by a particular time interval, while a **cross-correlation** coefficient is used for detecting patterns of variation between variables over time. For comparing frequencies of events over time, a common statistical tool is **power-spectral analysis**. Power-spectral analysis is used to determine periodicities within the data by giving an indication of the different frequencies over time of variation, which account for most of the variability in the data. All these tools usually require numerous data points or sampling occasions. In some cases, it may be interesting to calculate transition probabilities among classes (e.g. identify land-use types in different aerial photographs of the study area and then use Markov modelling to simulate changes over time).

9.2 Collecting and structuring information to support *in situ* conservation on-farm

In Chapters 2 through 6, we saw how different categories of information are needed to answer key questions important to *in situ* conservation on-farm. In Chapters 7 and 8 we discussed creating a framework, selecting sites and sensitizing the community. Once these aspects are in place, partners in an on-farm conservation programme are in a position to collect and structure information that will support *in situ* conservation on-farm under the four major topics discussed throughout this guide:

1. The amount and distribution of genetic diversity being maintained on-farm.
2. The processes being used to maintain this diversity.
3. The social, economic, cultural and environmental factors influencing farmers to maintain diversity on-farm.
4. The people maintaining this diversity in terms of gender, age, ethnic and social or economic status in the community.

The information to study these topics comes from different levels and disciplines. The different sources and levels of information, i.e. the **variety**, the **crop**, the **parcel or plot**, the **household**, the **village** or **community**, the **landscape** or **region** are summarized in the diagram below. Information from one aspect may be useful to answer more than one question. **What is important is that the information collected at the level of the household or farmer's plot may not be the appropriate scale for analysis or for crop diversity conservation.**

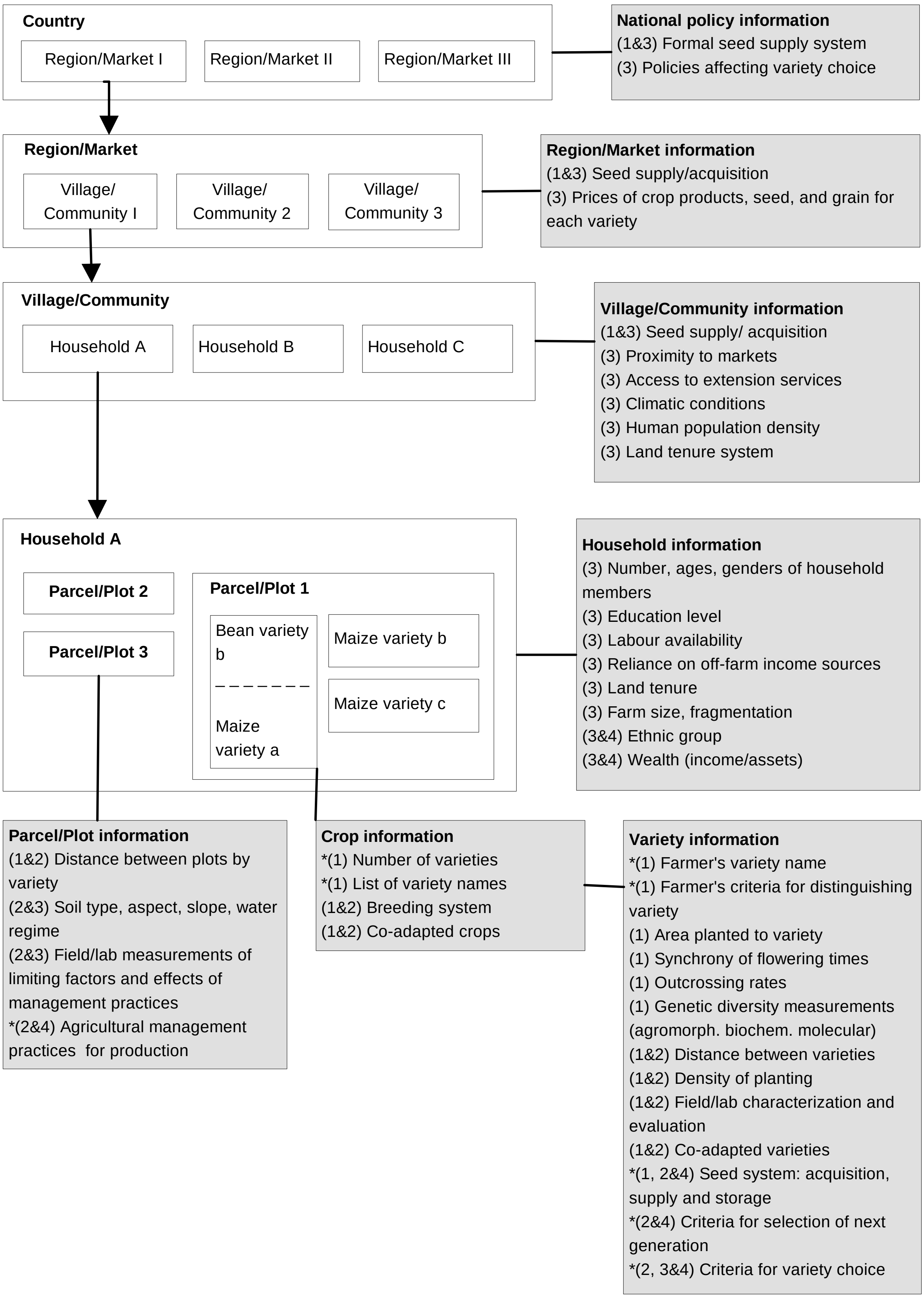
Barley stored on the rooftops in Jumla, Nepal. Single families have their own populations of barley, but it may be that the village is the appropriate scale for conservation.

As noted in earlier chapters it is probable that one single farmer does not maintain a sufficiently large population for effective conservation over time. More likely it will be the village or a network of villages or even a region that will be the appropriate level for understanding the maintenance of crop genetic diversity on-farm. In other cases, it may be that one village is representative or contains the entire range of diversity for a region, and therefore should be given particular attention (see Example, section 5.8.2). The collection and analysis of this information gives conservation managers and development workers the tools to develop conservation plans and make interventions as noted below after the steps.

The experience of ongoing work in *in situ* conservation on-farm suggests that the steps described below may be appropriate to follow to answer some key questions once a site has been selected for on-farm conservation as described in Chapter 8.

The collection and analysis of this information gives conservation managers and development workers the tools to prescribe conservation plans and make interventions as noted below after the steps. The information is also needed formulate interventions that will improve the value of local crop diversity for farmers discussed in Chapter 11.

(1) Information needed to determine the amount and distribution of genetic diversity maintained on-farm
(2) Information needed to understand the processes used for maintaining diversity
(3) Information needed to understand the factors that influence farmers to maintain diversity
(4) Information needed to understand who maintains diversity
*** Information collected, disaggregated by gender / age / other**



9.2.1 Determining the amount and distribution of genetic diversity maintained on-farm

Documenting the amount and distribution of genetic diversity on-farm requires information on the genetic identity of farmer-named varieties (see Chapter 4.2), the genetic structure of populations, the pattern of farmer-named variety occurrence (see Chapter 5), and the seed supply system (see Chapter 6). The plant's breeding system (see Chapter 5) is important, and initial data have shown that inbreeding crops such as rice, barley and durum wheat will have different patterns of distribution than outcrossing crops such as maize.

The information collected through these steps allows the determination of the extent and distribution of genetic diversity on-farm so that a conservationist can make decisions to prioritize the conservation of certain areas and target populations.

Steps:

1. Using participatory methods discussed in Chapter 8 and direct observation in fields and granaries and markets, compile a list of farmer-named varieties for the village / site, and note the exact name of the variety as given by the farmer without modifying it (Chapter 4), or encourage farmers to do this through a Community Biodiversity Register (Section 10.4.1).
2. Repeat this procedure during several cultivation cycles, preferably with the same farmers (male and female) to make sure that all cultivated varieties have been recorded and to observe changes in the relative importance of certain varieties over time.
3. Determine together with farmers which criteria they use to describe, recognize and name their varieties using participatory methods (Chapter 8) and identification tests at different stages of the growth cycle of the plant (Chapter 4).
4. Determine whether farmers are consistent in naming and describing varieties by comparing information from farmer households and different groups (gender, ethnic, wealth) (Chapters 2 and 4)
5. Have the farmer rank varieties in terms of importance (according to his or her different criteria) and area covered (Chapter 4).
6. Obtain measurements of the size and distribution of cultivated field / plots for each variety, the density of planting and the distance between varieties along the farmers' fields, and the flowering time of varieties (Chapter 5).
7. Using the methods discussed in Chapter 6 determine the source of seeds, whether self, from within the family, between farmers in the communities, with farmers from other communities, from local or distant markets.
8. Conduct field trials (Chapter 4) to characterize local varieties together with modern varieties according to both farmer criteria and key agronomic criteria.
9. Conduct biochemical and molecular characterization on a subset of varieties and calculate diversity indices (Chapters 4 and 5).
10. Statistically compare farmer-named varieties with measurements of genetic identity (agromorphological, biochemical, molecular) to determine whether and / or at what level farmer-named varieties are genetically distinct (Chapters 4 and 5).
11. Examine the extent of farmer-named varieties and determine whether they are the same genetically throughout the village (Chapter 4).
12. Calculate the average diversity of a field, the population divergence of genes and of levels of genetic variation, the spatial divergences of genes and levels of variation (Chapter 5).
13. Determine whether diversity increases with field size (Chapter 5).
14. Determine whether rare varieties are selected from common ones for different breeding systems (Chapter 5).
15. Determine whether locally common varieties have the greatest locally common alleles (Chapter 5).

16. Determine whether increased variety richness and increased genetic diversity are positively correlated (Chapters 4 and 5).
17. Determine whether the amount of variation in different crops is correlated (Chapter 5).

Identification of distinguishing agromorphological characters for rice in Vietnam.

9.2.2 Studying the processes used for maintaining and managing diversity

What are the key agricultural management practices including planting methods and distances, weeding, harvesting, storage and seed selection (Chapters 3 to 6) that ensure the maintenance of diversity? These practices may relate to a particular farmer-named variety, a crop in general, or a land or soil type. This information can be used by breeders for the improvement of local varieties, by farming system managers for improved management of abiotic and biotic limiting factors. It also can be used to identify methods to introduce new diversity into the farming system and to determine the vulnerability of the present seed supply system and its effectiveness for conservation under normal and abnormal (e.g. random events) conditions. This information will be important in designing strategies that support farming systems in continuing to maintain crop diversity over time.

Steps:

1. Using participatory methods, determine what are the agromorphological characters that farmers are trying to maintain because preferred and the characters that farmers are selecting against (Chapter 4).
2. Through participatory methods, have farmers identify varieties with particular adaptive traits to environmental conditions including soil types, post-harvest storage disease resistance, etc. (Chapters 3 and 4).
3. Through participatory methods, identify varieties with particular quality characteristics (short cooking time for beans, tenacity of tortillas, spiciness of chilli peppers) (Chapter 4).
4. Evaluate landrace samples for these characters using field and lab trials (Chapter 4).
5. Using participatory methods, elicit from the farmer what he or she thinks are the environmental factors limiting to crop production (water regime, soil type, topography, disease and temperature).
6. Using the methods discussed in Chapter 3, characterize these “limiting factors” for the site and where possible map agroecological factors using GIS (Chapter 10).
7. At the village or site level, compile a list of agricultural, seed management and/or land management practices described by farmers at both the (1) farmer variety level and (2) parcel level or for particular soils or topography, to overcome limiting factors or to improve production.
8. Through field and lab experiments test to see the effectiveness of practices identified by farmers as being key in the continued maintenance of diversity on-farm.
9. Collect historical information on whether farmers' varieties are susceptible to random events that have resulted in the loss of varieties at the household, village or regional level.

10. Through participatory methods determine whether farmers are introducing and maintaining new characters into their varieties and / or in the system through seed flows.
11. Using the information above and the information collected under 9.2.1 and methods from Chapter 6 on seed source, determine whether farmer / village / seed networks maintain sufficiently large populations for effective conservation over time.

Use of irrigation, as in this date palm and alfalfa cropping system in Morocco's oasis area, may be one of the processes shaping the genetic diversity of these crops.

9.2.3 Determining the factors that influence farmers to maintain diversity

One of the reasons for collecting socioeconomic data at the household level is to provide a basic understanding of the human contexts that characterize local farming systems. Household characteristics, market development, agricultural intensification, agroecology and government policy may be important determinants of how many and which varieties farmers plant, as discussed in Chapter 2. Aggregated to the village level, such variables will provide a basic understanding of how households are structured. Taken at the individual level, bivariate analysis can illustrate how particular subgroups of the population may be situated, such as men and women or young and old. In addition, simple bivariate tables can show social and economic correlations that may underlie agricultural practices. For instance, household size or wealth may have significant associations with the fragmentation of land holdings, with potential consequences for farmers' maintenance of genetic diversity.

Identifying which of these factors affect farmers' maintenance of diversity, accounting for the potential effects of environmental, economic and cultural change over time, will be important in allowing us to predict which farmers and communities will continue to cultivate genetically diverse populations over time. This knowledge can foster the design of appropriate on-farm conservation programmes that support farming systems associated with high genetic diversity.

Steps:

1. Using the methods in Chapters 2 and 8, collect information on household characteristics, stratified by agricultural intensification, agroecology, and market development.
2. Test the relationship of these factors to some measure of variety choice with multiple regression analysis (Chapter 2)
3. Relate the farmer variety choice analysis to actual crop genetic diversity (agromorphological, genetic measurements) (Chapter 4 and 5).
4. Using participatory methods from Chapter 8 and surveys from Chapter 2, collect information on farmers' preferences for varieties and traits, along with costs of

production, to estimate their "value" to farmers
5. Collect information on markets for grain and other crop products and the market valuation of specific variety traits (Chapter 2)
6. Conduct hedonic analysis of variety traits based on market prices (Chapter 2)
7. Relate market valuation of variety traits to genetic diversity

9.2.4 Determining who maintains diversity

Knowing who (gender, age, ethnic, social, wealth, etc. group) is responsible for variety maintenance, selection and agricultural management practices including planting, weeding, harvesting, storage and seed selection is important when producing action plans for supporting *in situ* conservation on-farm. Disaggregation of data is needed before conclusions can be drawn on who is responsible for maintaining and managing genetic diversity on-farm (see Chapter 8).

Steps

1. Ensure that collection of information from the farmer household is disaggregated by gender and where necessary by age on (1) criteria for distinguishing varieties, (2) criteria for selection of the next generation of a variety, (3) decision-making process of crop choice, e.g. what seed should be planted in which plot, and (4) crop and seed management practices (Chapters 2-6).
2. Investigate whether all plots are managed as a household unit or whether some are managed only by specific gender or age groups (Chapter 2).
3. Determine from structuring the household surveys above whether any particular groups, ethnic, social status, wealth, educated, labour-abundant, etc. maintain more diversity than others (Chapters 2).

Local and regional marketing opportunities may be one factor affecting farmers' decisions to maintain crop diversity, as shown here in Burkina Faso.

9.3 Documentation for *in situ* conservation on-farm

On-farm conservation teams must ensure that their work is well recorded throughout the process of research to ensure that research can be replicated in other contexts to build a global data set. Documentation of the research process will also provide a useful basis for a longer-term system of documentation on the crop populations and communities targeted for conservation. This is often an afterthought in many types of PGR research, although a few simple steps can be taken to help ensure effective documentation.

Effective documentation requires a system for the storage and management of information that meets the particular needs of on-farm conservation research (Hulden 1999). For instance, several categories of data will be recorded at various times, making an easily accessible documentation system – one that can be added to as time goes by – of great importance. A good documentation system will also be flexible, capable of handling different types of data. Other features of a good documentation system include the ability to maintain data integrity, fast information retrieval, user-friendly operation, and clear organization (Painting *et al.* 1995). A good documentation system will combine these features in a manner that is suited to local needs and abilities.

Documentation for on-farm conservation may be particularly effective when it involves farming communities. For example, the IPGRI Nepal on-farm conservation project initiated a Community Biodiversity Register to record information on PGR by the community itself and find ways to interpret and use the information to benefit the farming community and PGR professionals.

9.3.1 Data recording and verification

The information learned from participants must be recorded so that it is accessible and durable. While some participatory techniques involve the creation of physical products, such as drawing maps or calendars, others require different forms of documentation. Two options are generally available to field researchers: written records (field notes, preset forms and transcriptions) and visual records (photographs and videos).

9.3.2 Written records

Field notes can be taken both during and after collecting data with participants. A common approach is to note major points while conducting research and later fill in details from memory along with particular observations and questions arising from the discussion (Scrimshaw and Hurtado 1990). The main disadvantage of field notes is that they rely largely on memory, and inevitably data are lost in the process of interviewing and writing field notes.

Standardized data collection forms, which entail designing the forms for recording data before going to the field, may simplify data collection (a common example of these are structured survey questionnaires, discussed in Section 2.3). They allow researchers to record data immediately and are simple and unlikely to distract a participant. The use of any standardized form for recording data requires that decisions be made before the information is collected. As a result, preset forms are largely inappropriate for most participatory techniques. The exception to these are correlation exercises (ranking, sorting, rating) which may be simplified by developing basic forms for recording participants' responses.

It is also possible to make an audio recording of an interview or exercise and later transcribe the recording to writing. The main advantage of this approach is that it allows every word of an interview to be recorded. This is especially useful for focus group discussions, in which many people may be speaking at once, as well as interviews containing numerous languages or dialects that may be difficult to discern. The drawback of transcriptions is their resource requirements – in terms of money (audio recorders and cassettes must be bought) and time (making a written transcription can take much longer than the actual interview).

Written data records can be sorted and coded for basic quantitative analysis. For interview data on a specific topic, a researcher can categorize different types of responses. By coding each category of response, it is possible to calculate basic quantitative statistics using qualitative interviews. In this way, qualitative interview data may be directly linked to other forms of participatory data (such as results of correlation exercises) or to measured biological data.

9.3.3 Visual records

Visual records can be useful for specific types of data. Photographs and videos can help to document particular aspects of farmer knowledge with a level of detail to which written text can not compare. Photographs can be used by researchers to document physical characteristics, of either an agroecosystem (soil conditions, etc.) or a landrace (morphological traits, etc.), in the format in which farmers see them. Video recordings are even better suited to the documentation of processes, such as seed selection in the field or food preparation.

9.3.4 Triangulation

Checking the accuracy of the data which have been collected during qualitative research is an important step toward producing effective results. One approach is triangulation, or cross-checking the findings from data collected with one technique using data collected with other techniques (FAO 1998). This is made possible by the overlapping data collection techniques which are a feature of participatory social research. If results are confirmed using triangulation, then they are more likely to be reliable. If results conflict during triangulation, the data may need re-examination. Seemingly incongruent data can be the result of poor-quality data from participants, but can also reflect significant differences in the knowledge of participants from different demographic, social or economic backgrounds.

9.4 Returning information to the community

Part of participatory research involves making sure that data are of some use to the communities from which they are being elicited and returning these data in a user-friendly format. Data collected through on-farm research, such as compilations of variety names, could be useful to communities for use in Community Biodiversity Registers and other local knowledge documentation systems. Posters or displays in vernacular languages can present written information. Cultural knowledge such as recipes or folk songs highlighting the importance of local crop diversity can be published and disseminated to communities in vernacular languages. The other public awareness strategies mentioned above, such as Diversity Fairs and Diversity Theater, can be utilized to share information with a wide audience and have the advantage of reaching beyond the literate population. As always with participatory work, community members must be involved in deciding the most useful strategies for sharing the information generated through such collaborative research.

9.4.1 Community information systems

Community information systems may include community-based registers or records, kept in a paper or electronic format by community members, of all landraces in a community, including information on their custodians, passport data (e.g. agromorphological characteristics), agroecological characteristics, and cultural or use significance. The collection and documentation of farmers' knowledge for their and others' future use is termed "memory banking" by Nazarea (1998; Nazarea-Sandoval 1990), in an analogy to the storage and documentation of germplasm in a genebank. Memory banking serves to capture the cultural dimensions of plant biodiversity – including local names, indigenous technologies and uses associated with different plants and varieties – for access and control by communities. The mechanism described by Nazarea involves integrating this type of knowledge into genebank documentation systems or associating it with an *in situ* conservation initiative. An example of a community information system maintained at the local level by farmers is the Community Biodiversity Register, discussed in Section 10.4.1.

9.5 Using information for action plans for on-farm conservation

With a knowledge of the extent and distribution of diversity, the processes that maintain this diversity, the reasons the diversity is being maintained, and by whom, a national programme can begin to formulate plans to support ongoing processes, which may include targeted interventions.

Conservation goals, which may concern the species and/or ecosystem levels, should necessarily shape the action plan for on-farm conservation. The decision to conserve a given crop population should be made based on factors such as the amount of diversity, the uniqueness of diversity, the usefulness of diversity, the threat faced by the diversity, and other national priorities. The needs of the community will also factor into this decision.

If the amount and quality of genetic diversity in the target crops is found to be sufficient for the purposes of national conservation goals and for local uses, and the processes maintaining diversity and factors influencing farmer decision-making are constant over time, the only action taken in an on-farm conservation programme may be a community-based monitoring system, linking to the central PGR institute, to ensure that local and national needs continue to be met. If not, interventions to support farmers' decisions and the processes that maintain diversity can be targeted effectively with the knowledge of the spatial distribution of genetic diversity and of who is maintaining diversity. For example, knowledge regarding whether rare varieties are derivatives of common varieties would assist PRG managers in prioritizing varieties to be conserved. If diversity is found to increase with field size, then larger field sizes should be targeted for support. If resource-poor farmers maintain important crop genetic resources adapted to marginal, niche agroecosystems, the conservation strategy may target this group. Likewise if the seed supply is the limiting factor for farmers' maintenance of diversity, support may be targeted to local seed suppliers. All interventions must be designed and implemented through collaboration between the community and the national PGR system. Potential options to "add value" to local crop resources to support farming systems maintaining high crop diversity are the subject of Chapter 10.

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Chapter 10 Enhancing the benefits for farmers from local crop diversity

(with the collaboration of A. Amri, L.M. Arias-Reyes, D. Balma, A. Birouk, F. Castillo-Gonzalez, S. Ceccarelli, J.L. Chávez-Servia, N.N. De, P. Eyzaguirre, D. Fanissi, D. Gauchan, L. Holly, K.D. Joshi, O. Kabore, I. Mar, F. Marquez-Sanchez, F. Nassif, R. Ortega-Paczka, D.K. Rijal, K. Riley, A. Subedi, A. Tan and L.N. Trinh)[1]

[1] Photo credits: Pp. 149, 153, 155, 156: D. Jarvis; P. 150: J.L. Chávez-Servia.

10.0 Objectives

By the end of this module, participants should have an understanding of:

- A range of options available to enhance the benefits for farmers of maintaining on-farm diversity
- The need to assess various "adding value" initiatives.

10.1 Increasing crop genetic diversity's competitiveness for farmers

When on-farm conservation research has identified genetically important crop populations and farming systems that are priorities for conservation, it may be appropriate to assess different options for "adding value" to these populations, or in other words, increasing the benefits that farmers get from cultivating diverse local crop resources in a given social, economic and ecological context. When we refer to "enhancing the benefits" for farmers of local crop diversity, we mean the **net** benefits (benefits minus costs), as there also could be costs to farmers associated with participation in these options. In order to design appropriate strategies, it is first important to document how the crop populations targeted for conservation are valued – either by the farmers who produce and consume them or by the consumers who purchase them on the market, as discussed in Chapter 2. By understanding the incentives farmers have to continue cultivating local crop diversity, on-farm conservation programmes then can act to increase those incentives. An important component of on-farm research will be to investigate which strategies can be used to add benefits to landrace production and support farming systems associated with high genetic diversity.

We list some potential methods for "adding benefits" for farmers below, but note that it remains to be tested which, if any, of these methods is associated with the maintenance of high genetic diversity over time. A mandate of future on-farm conservation research will be to test these relationships. The methods listed below are discussed in three separate categories for convenience, although they may overlap and do not encompass all possible strategies. General means of enhancing the benefits of landrace cultivation for farmers include improving the landrace material and production system, increasing farmers' access to a diversity of varieties, and increasing consumer demand for products using a diversity of varieties.

10.2 Improving the material itself

Improving diverse crop populations or the production systems in which they are grown is one possible means of increasing benefits to the farmers who grow them. Plant breeding strategies have been developed to improve varieties locally and according to farmers' interests, like Participatory Plant Breeding and seed-cleaning treatments. In addition, seed storage practices could be strengthened to prevent losses due to diseases, pests and deterioration. Particular agroecological management practices may also serve to support production of crop diversity. Low chemical input or organic farming with local varieties can serve to promote agroecosystem stability and health. Such improvement strategies must necessarily be local in order to be used for a diversity of landrace materials.

10.2.1 Participatory Plant Breeding

The field of Participatory Plant Breeding (PPB), a collaboration between scientists and farming communities in breeding activities, presents an ideal opportunity for farmers to use the germplasm conserved in their fields as part of a crop improvement initiative (Eyzaguirre and Iwanaga 1996). Landraces may be improved in this way by preserving traits which are preferred by farmers, or by adding additional traits to a preferred landrace. Traits for improvement may refer to yield, pest and disease resistance, palatability for fodder, taste, nutrition, marketability or other requirements. Landraces have been selected over time by farmers for particular traits or their adaptations to local conditions with better yield stability. This local selection will continue to take place in an on-farm conservation setting. Although the precise methodologies involved may vary, PPB may build on farmers' plant breeding practices by introducing new germplasm for farmers to mix with existing landraces and select preferred traits or specific adaptations. For example, a landrace is chosen as a parent to give genes for local adaptation (such as drought resistance), and a modern cultivar is chosen to give genes for other preferred traits (such as high yield potential or disease resistance). When landrace and modern cultivar are crossed, farmers can select from the hybrid offspring as they grow under local agroecological conditions.

PPB emphasizes farmers' ability to participate in research. PPB is one way of building the capacity of farmers by transferring plant breeding skills, such as crossing, selection and seed production. Over the long term, these skills could become the basis for supporting on-farm conservation, farmers' empowerment, and increased control over their livelihoods. Skill development based on PPB can employ farmers' existing knowledge of selection and teach farmers scientific approaches to crop breeding.

The effectiveness of PPB as a strategy to maintain crop diversity on-farm still needs to be assessed. Questions to be answered include, can farmer cultivars *per se* be conserved *in situ*? Can PPB contribute to the enhancement and conservation of landrace diversity *in situ* and provide benefits to the communities? Can genetic improvement be achieved without loss of genetic diversity?

As shown in this field trial in Nepal, participatory plant breeding with local varieties was more successful at producing well-adapted varieties than was formal breeding. A local Jumla rice variety, crossed with other Nepalese varieties (on the right) outperforms modern, cold-tolerant rice varieties (on the left).

10.2.2 Strengthening farmers' seed management

On-farm conservation potentially could be supported through strengthening farmers' skills and knowledge regarding seed cleaning, production, maintenance and storage. Seed training seldom focuses on enhancing the capacity of farmers to ensure that desired characteristics are retained in their landraces. Rather, training often focuses on making landraces more uniform, distinct and stable, which can result in the loss of valuable adaptive traits unique to local varieties.

10.2.3 Agroecosystem health

Cultivation of local varieties linked with low-input, or organic, farming can support farming systems through improving agroecosystem health and stability. Use of landraces adapted to local environmental conditions can improve soil structure and allow for decreased use of chemical inputs like fertilizers, pesticides and herbicides relative to widely adapted modern varieties. In addition, cultivation of diverse varieties decreases agroecosystem vulnerability to pests and other environmental stresses. For an in-depth discussion of the role of crop genetic diversity in agroecosystems, refer to Chapter 4.

Example: Mass selection of maize in Yaxcabá, Mexico

Mass selection is the selection and use for the next generation of planting of seed from individual plants based on preferred or non-preferred phenotypic characteristics. The Mexico component of the IPGRI *in situ* conservation on-farm project is working with farmers in Yaxcabá, Yucatán to enhance local landrace productivity by improving their mass selection techniques. Just before and during flowering (rather than in post-harvest storage, as is the farmers' traditional practice), plants with desirable characteristics were chosen and at harvest time were reselected for the healthiest and most productive plants, using a selection pressure of 20% to avoid genetic drift and according to the farmers' preference. This process will be repeated five times, and the mass selected populations will be evaluated agronomically each year, assessing grain yield and plant quality. Reports on expected gains from mass selection are in the order of 2% per cycle. In the Mexican central plateau, overall gains for three cycles of selection and over five populations were in the order of 20%. Considering the huge variability in farmers' populations and the potential for removing the worst part of the population, these gains may be feasible in the earlier generations of selection.

Mass selection of maize varieties in Yucatán, Mexico.

Example: An indigenous organic agriculture movement: *Nayakrishi Andolon* in Bangladesh

Farmers in Bangladesh developed the *Nayakrishi Andolon* (New Agricultural Movement) to promote ecological agriculture in response to the negative repercussions of widespread chemical-based agriculture, particularly the loss of production and income for households and communities. At least 50 000 farmers practise *Nayakrishi* throughout Bangladesh. The principles of Nayakrishi include:

- No use of pesticides or chemical fertilizers, but an emphasis on improved soil fertility through the use of 'green manure'
- Mixed cropping regimes are emphasized, especially those employing nitrogen-fixing species, in order to reduce plant and pest competition
- Conservation, management, and use of local crop resources.

(Mazhar 1996)

10.3 Improved farmers' access to genetic materials

Increasing farmers' access to diverse crop genetic resources, as well as information about these resources, could serve to broaden farmers' options regarding variety choice while fostering diversity conservation. Access to new and diverse varieties can be improved through community genebanks and community biodiversity registers, strengthened seed exchange networks, and the incorporation of landraces into national extension programmes, while information regarding these resources can be disseminated through community-level public awareness activities like Diversity Theater and Diversity Fairs.

10.3.1 Community Biodiversity Registers and genebanks

The limited supply of good-quality seed for local varieties can be an obstacle to farmers' continued maintenance of genetic diversity. One potential means for overcoming this limitation is the establishment of community biodiversity registers or community genebanks. These are small-scale institutions, serving individual communities or several communities in a region, which store local seed on a short-term basis. These genebanks are inexpensive, usually employing simple storage technologies.

The greatest feature of community genebanks is their accessibility for farmers as a storage point and a source of new and local seed. These genebanks give farmers the ability to store small amounts of seed in a secure environment over the short term, in order to test new varieties or to help negotiate environmental risks. In addition, farmers can access the genebank to identify new seed stocks to incorporate into their fields. Some community genebanks invite local farmers to evaluate landraces when germplasm is grown out.

Community genebanks may provide a way for farmers to store valuable landrace germplasm in a community-based *ex situ* setting. This approach may further enhance benefits when integrated with a seed exchange network, helping to improve farmers' control over their genetic material.

There are some drawbacks to this approach, however, as community genebanks are typically small in size and thus can only maintain a limited number of accessions and replicates. In addition, community members may prefer to store seeds on an individual basis but have access to knowledge on the location of other seeds in the villages. In this regard, **Community Biodiversity Registers** (CBR) may be an alternate approach. A CBR is a record of landraces cultivated in a community that is maintained by community members and may contain such information as the agromorphological and agronomic characteristics, agroecological adaptation, special uses, place of origin and cultivators of the landrace. Managers of CBRs not only keep track of households who store the seed, but also address the problem of seed management at community level and encourage farmer-to-farmer informal seed and information exchange. CBRs affirm the value of indigenous knowledge of crop genetic resources and encourage their continued use and conservation. It will be a future challenge for PGR conservationists to support communities in the creation of CBRs, to foster the implementation of sustainable systems that do not require outside support.

10.3.2 Seed exchange networks

Another way of enhancing the maintenance of local germplasm is through the strengthening or establishment of local seed networks. These can increase the supply of and facilitate access to locally adapted crop germplasm, thus overcoming the supply bottlenecks which may lead farmers to adopt readily available modern varieties.

In many communities, seed exchange networks have a long history and do not need facilitation or development. Such networks may already be in place to re-introduce common landraces into areas where they have been lost or fallen into disuse, or to disseminate new germplasm from wild or weedy hybridization or formal sector breeders. Such networks can be based on family ties, social relationships or local market systems.

These types of local networks are equally important for disseminating knowledge and germplasm. For seeds to be exchanged and used effectively, they must be accompanied by local knowledge regarding that variety's useful traits, as well as its shortcomings. In this way, germplasm and accompanying knowledge can be kept in circulation, and thus conserved, across a community or a region.

To function on a sustainable basis, seed exchange networks may require support from other types of on-farm conservation initiatives. For example, coupling a seed exchange network with a community genebank, a diversity fair or informal research and development

(IRD)[2] will help to provide additional benefits for participating farmers. In addition, seed exchange networks could be important links for integrating farmers into a national plant genetic resources programmes and seed supply systems (see below).

10.3.3 Linking farmers' seed supply systems to the formal sector

Coordination between informal and formal seed supply systems could foster conservation of landraces at risk of extinction while increasing farmers' access to new varieties. Regional and district-level institutions in particular could support on-farm conservation at the local level, linking with community genebanks and biodiversity registers to ensure that rare varieties are conserved for future use by farmers.

> The Ethiopian Plant Genetic Resources Centre, now the Biodiversity Institute (BDI) holds some 50 000 accessions of over 100 crop species. Since 1987 it concentrated on local germplasm rescue and sustainable use through programmes assisting farmers in conservation and the improvement of landraces. A Seed Reserve Programme has been implemented in collaboration with the Ethiopian Seed Corporation to assist the areas most affected by the drought of 1984/85. Following the drought, local NGOs established a network of community seed banks to provide local seeds, especially farmer varieties, managed by community assemblies. Their activities have focused on involving native seed stocks in landrace conservation, improvement and sustainable utilization by small-scale farmers.
> (from Berg 1993; Worede 1992; Worede *et al.* 2000)

10.3.4 Incorporating local crop resources into agricultural extension packages

Training extension personnel in the value of local crop genetic resources and the importance of landrace conservation could be an important step in creating extension programmes that support, rather than hinder, maintenance of diverse crop resources on-farm. This training could be incorporated into the curriculum of extension workers at a national level or offered as in-service training to experienced extension workers. If extension personnel recognize the importance of local landraces for conservation and local livelihoods, their work could act as a means of spreading local crop diversity and knowledge while strengthening the relationship between farming communities and national PGR systems.

In conjunction with the training of extension workers, it may be possible to make landraces a part of the extension packages offered to farmers. This would bring agricultural development mechanisms into the seed supply network, as extension workers could make local varieties available to farmers along with modern varieties. If extension personnel understand the benefits of on-farm conservation and value of diversity, they can become active promoters of the use of local landraces.

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[2] IRD is an informal and simple method of testing, choosing and multiplying seeds of choice for development (Joshi and Sthapit 1990). The main purpose of IRD is to overcome the limitation of poor access to new crop cultivars by farmers that exist in the conventional research and extension systems. IRD, first used at Lumle Agricultural Research Centre (LARC) in Nepal, is now increasingly being used for participatory variety testing and dissemination by different organizations in the marginal as well as high production environments of Nepal and India (Joshi and Sthapit 1990; Joshi *et al.* 1997). A small quantity of seed of released and/or nearly finished varieties is distributed to a few farmers in a community to grow in their own management conditions.

10.3.5 Diversity fairs

A diversity fair is a means of raising awareness in farming communities of the value of crop diversity. It brings together farmers from one or more communities to show the range of landraces that each grows. Rather than giving prizes for the best individual variety (e.g. on the basis of yield or size), diversity fairs award farmers or cooperatives for the greatest crop diversity and related knowledge.

In some communities, gatherings similar to diversity fairs already exist as traditional events, where farmers converge to show their landraces and share both seeds and knowledge. These fairs may become markets as well, where landrace material can be bought and sold.

To maximize their appeal as 'events', diversity fairs are probably best held infrequently but on a regular basis, perhaps once a year. Their timing should be suited to the agricultural season, perhaps just after harvesting, or just before a new crop is planted. In some cases, several diversity fairs are held each year, each one focusing on a specific type of crop.

Diversity fairs provide an important forum for the public recognition of farmers and their crop diversity. They can play a role in on-farm conservation programmes as a strategy to:

- recognize farmers who maintain large amounts of genetic diversity, possess unusual knowledge of crop diversity, and/or are widely recognized and respected by other farmers
- prepare an inventory of landraces for a community or region, including the identification and location of rare or endangered landraces
- locate pockets of particular diversity and identify sources of formal and informal seed supply within a community
- allow a range of farmers, or community members generally, to converge and evaluate new germplasm, whether in the form of modern varieties or the product of participatory plant breeding activities.

A periodically held diversity fair could complement other benefit-enhancing strategies like seed exchange networks and community genebanks. These combinations would have the added benefit of helping to empower local communities in the control over their genetic resources.

Roadside Diversity Drama, "Such is the Happenings of a Village", organized by women's groups in Khola Ko Chew village, Kaski district, Nepal. The play is based on a true story from the village that demonstrates the value of growing wild rice in the surroundings of landraces.

Steps taken in the organization of a diversity fair in Vietnam are as follows:

- Formation of groups for competition
- Selection of target crops
- Development of competition procedures
- Formation of a board of judge
- Determination of method of competition
- Evaluation and award.

There were four rounds of competition:

- **Round one.** Farmers' knowledge on collected varieties: 7 rare varieties were selected secretly from the show and wrapped in closed boxes numbered 1, 2…7. Each group was assigned one variety by a draw and then answered 5 questions related to the (1) variety identification, (2) origins (when it was first planted in the community, who was the first grower(s) and where it came from), (3) description of major characteristics to be identified from others, (4) how to grow, and (5) how to keep seed for next season.
- **Round two.** Farmers' knowledge on crop diversity: Each group was asked two identical questions: (1) What is crop diversity, and (2) Why do we need to maintain crop diversity in the community?
- **Round three.** Genetic erosion and its reasons: Each group was assigned one crop also by a draw among 7 main crops (traditional rice, taro, cassava, sweet potato, yam, mung bean and groundnut) and then asked to (1) list as many extinct cultivars as possible, and (2) state why they disappeared.
- **Round four.** Diversity conservation and development: Each group was asked three identical questions: (1) Is there a need to conserve local genetic resources? if no, (2) why, if yes (2) how to do it, and (3) How to improve local genetic resources diversity qualitatively and quantitatively.

(Source: Dipak Rijal *et al.*, Nepal project and Mr Ngyen Ngoc De, Can Tho University)

10.4 Increasing consumer demand

If diversity can be more highly valued in the marketplace through the creation of consumer demand for certain products, and farmers can access those markets, their incentives to maintain diversity may be increased. Strategies to increase consumer demand for diverse crop resources include improved processing, packaging and marketing of landrace products, public awareness initiative to educate consumers about the value of agrobiodiversity, and linking with other types of products in demand, such as organic produce.

Example: Improving marketing of local crop diversity

In Kaski district, Nepal, privately run cottage industries like Gunilo and Bandobasta are marketing products made from local crops that have a special value for local food culture and a market niche for tourism. A network of such entrepreneurs was established and linked to farming communities. An NGO facilitated a meeting, and farmers and entrepreneurs jointly identified local products of high value to consumers to make production and marketing decisions. *Anadi*, a local sticky rice variety, is in high demand in the market, but previously, farmers were not able to receive benefits because it is grown in small areas for special festival purposes. With organized market outlets, farmers are willing to grow *Anadi* in larger areas so they benefit from the high price. Local products from taro, buckwheat, medicinal rice and finger millet are processed and marketed in an attractive presentation using popular culture to enhance domestic and international demand. An association of hotels and restaurants was also sensitized to use more local products in daily cuisine, and chefs have adapted local recipes to make the best use of the new products. (Source: LI-BIRD, personal communication)

Potential consumers may be unaware of the range of available crop or the positive features of particular varieties (taste, nutrition, etc.). A media campaign may be used to generate interest – and with it, demand. In addition, farmers' access to such potential markets, through transportation and the recognition of the value of diversity by traders and middlemen, must be adequate for them to see the benefits of increased income.

Value-added products from Nepal.

10.4.1 Adding value through processing

In many instances it may be difficult to secure stable markets for raw agricultural products. This is particularly the case for crops requiring processing before they can be used. In these cases it may be possible to enhance the benefits to farmers of local varieties by processing them for particular markets.

Increasing benefits to farmers through processing is one of the more costly and time-consuming options available to enhance on-farm conservation. Detailed economic research and sample pilot studies are usually necessary to establish whether an initiative can be profitable and sustainable. Processing plants may be capital-intensive. Moreover, developing an industry to supply an agricultural product is likely to require government permission and regulation. One advantage to this approach is that interventions to increase benefits to farmers through processing can provide a sustainable mechanism for economic development and (after an initial outlay) may require only minimal monitoring and maintenance.

Example: Adding value to cassava through processing in Colombia

A pilot plant was set up in Colombia to determine if it would be economically feasible to produce high-quality cassava flour for the food industry. An initial study found that some aspects of the process were efficient, such as the artificial drying of cassava chips, and the end product met Colombian quality standards for total and coliform bacteria levels.

Nonetheless, the pilot plant indicated that the artificial drying system was performing inefficiently and that product quality was inadequate, especially with respect to microbial standards. Research conducted at the plant identified two major problems. First, there were delays of up to 2 days between harvest and processing. Second, drying time was long when the plant was run at full capacity (3 tons of fresh chips per batch).

The solutions were: tighter control over the supply of fresh roots to ensure that no more than 24 hours elapsed between harvest and processing, and the purchase of an additional coal-fired burner to raise drying temperature, reduce drying time, and improve the quality of the dried chips. With these improvements, the plant was able to produce chips and flour for human consumption that satisfied quality standards. It obtained a licence for food product manufacture and began selling flour to the local food industry (Wheatley *et al.* 1995).

10.4.2 Organic farming

Benefits to farmers may be increased through linking on-farm conservation to organic farming, which shares many of the goals of on-farm conservation, such as agroecosystem health, sustainable production, and low-input and locally adapted farming systems. As health and environment become increasing concerns of consumers, on-farm conservation may profit from association with these issues through consumer awareness and education.

The general ethos of respect for the environment has gained prominence in much of the developed world through widespread association with indigenous peoples and traditional ways of life. This has been achieved largely through public awareness campaigns which use the media to disseminate messages about the potential success of ecologically sound environmental management practices. Although they have played a relatively small part in such media campaigns to date, local agricultural systems could figure prominently in these types of messages, disseminating information about the processes and implications of genetic erosion, as well as the importance of on-farm conservation.

Restrictive policies may limit the use of locally improved varieties. In Mexico, when a landrace was crossed with a modern variety, formal registration was difficult because the new variety was not developed through traditional breeding channels.

10.5 The role of policy

The role that national economic and agricultural policies play in the support, or lack thereof, of farming systems maintaining crop diversity remains to be investigated. If market failures are identified that prevent the farmer from capturing the full benefits of the market's valuation of diverse landraces, policy changes can serve to correct these market failures. Current national policies may serve to deter the maintenance of landraces. Farmer varietal classification systems often do not fit the criteria of uniformity required for seed certification through national systems, which may hinder local-level seed innovations. In addition, linkages are weak between public agricultural research and commercial seed providers, limiting distribution of farmer varieties. The support of farmer seed marketing may be necessary for landraces to become widely available beyond the local level. However, the effects of specific policies on farmers' choices of varieties are not fully understood. For example, an extension programme promoting an agronomic package of MVs, fertilizers and pesticides may discourage landrace cultivation. On the other hand, even if farmers adopt these packages, the increased income that may result could enable farmers to continue to maintain preferred varieties on smaller land areas.

Depending on the efficacy of the strategies listed above in conserving crop genetic diversity over time, subsidies may be considered as an option to support farming systems if the opportunity costs of conservation become too high for farmers to continue cultivating diverse landraces. However, the level of actual genetic diversity being maintained by farming systems must be evaluated before enacting such a costly endeavour.

Example: How national or international agricultural policies can be changed to promote on-farm conservation

A cursory review of past and present agricultural policies adopted by the Nepal Government reveals that many of them may provide disincentives to on-farm conservation of landraces. The block production programmes initiated during the 1980s favoured the production of a few modern varieties with a package approach of associated subsidized external inputs (fertilizer), credit, extension and training of farmers (Shrestha 1998; Sthapit and Joshi 1998; Vaidya 1998). The agricultural development model focused on the research, extension, and marketing of modern varieties, even in areas with a comparative advantage in the production of traditional crops and varieties. Modern crop varieties are promoted indiscriminately, often to men farmers, without an analysis of the consequences on crop diversity, seed security and gender relations in farming communities (Shrestha 1998). The national food sufficiency policy, which distributes subsidized food through the Nepal Food Corporation (NFC), discourages local production of foods in marginal remote areas (Koirala 1996). The pricing policies also favour imported food and other products at the expense of local, traditional products (Barbier 1988).

The government's present policies, as envisaged by the Agricultural Perspective Plan (APP) (APROSC/JMA 1995) and the Ninth Plan (NPC/HMG 1998), lack policies on *in situ* conservation of crop genetic diversity for future food security and sustainability of agricultural production systems. They still tend to focus on production of a few well-researched uniform modern varieties in favourable pockets with intensive input use and the package approach without analyzing the consequences for on-farm genetic diversity (Vaidya 1998).

Presently 50% of the total rice area is under local varieties, while 10% of seeds (modern varieties) are supplied by the formal system (i.e. Agricultural Input Corporation) (Sthapit *et al.* 1996). This means that 90% of the seed supply system is covered through informal mechanisms, which receive no form of policy and institutional support from the government. In addition, there are strong institutional and policy constraints to legitimizing and institutionalizing the participatory plant breeding (PPB) approach that provides farmers the option of choosing diverse cultivars (Sthapit *et al.* 1996; Sthapit and Joshi 1998). The existing regulatory framework also provides disincentives to on-farm conservation through inequity problems for the farming communities (women and smallholders) living in marginal, risk-prone environments who maintain diverse landraces and related valuable indigenous knowledge.

Source: Gauchan *et al.* 2000.

10.6 Deciding on an appropriate initiative

The activities discussed here only begin to outline of the range of potential options to support farming systems participating in on-farm conservation. The strategies employed must be customized to the particular contexts of farmers and communities. Moreover, there is still much room for the creation of new types of activities to promote on-farm conservation. The determination of the content, structure and combination of methods to support farmers will be fostered by returning the results of on-farm research to the farming communities.

In addition, these and other options to support farming systems must be monitored over time for their genetic, ecological and economic impacts on farming systems to see if they do indeed fulfil the goal of maintaining high levels of genetic diversity on-farm, as well as achieving the benefits of supporting agroecosystem health and improving farmers' livelihoods in different contexts. For instance, improvement of seed supply systems, as discussed in Section 10.3 may increase farmers' access to genetically diverse crop varieties, but it also has the potential to decrease genetic diversity by decreasing differentiation among populations. Interventions must be monitored not only at the farm level, but also at the different levels of the diversity hierarchy.

10.7 Evaluating benefit-enhancement options

Once an option has been proposed for "adding value" to crop populations that are identified as targets for on-farm conservation, it will be important to design a mechanism for monitoring its progress and assessing its impact. On-farm conservation research must develop indicators to assess the effects of any initiatives on **genetic diversity over time**, as well as evaluating the benefits to farmers' livelihoods and agroecosystem health. Time series data will be needed from the on-farm conservation sites in order to make comparisons with the baseline data.

Economic analysis is one tool for the assessment of one among many possible types of impact (Alston *et al.* 1995). Genetic diversity analysis is a tool to understand the loss or gain of genetic diversity within the system, while other measures are needed to understand the impact of intervention on ecosystem health and services. It is useful to begin by identifying the type of impact we hope to achieve through implementing these "add value" options. Then, for each type of impact, we can select quantifiable indicators for assessment purposes. For example, we may conclude that Option A fails miserably in terms of economic indicators of efficiency, ranks better in terms of equity, has an indeterminate effect on ecosystem health, but is likely to have a major impact on genetic diversity. By comparing Option A with Option B, we can learn the nature of the social trade-offs that occur when we pursue one option versus another in the target area. We can generalize across target areas and options, looking for patterns associated with genetic diversity and market development.

Estimating the economic efficiency and equity of a participatory breeding activity

To estimate the total private benefits and relative economic efficiency of a participatory breeding activity, the following information is needed, for each type of participation:

- An estimate of the yield gain or savings per hectare that is associated with the strategy, in farmers' fields.
- An estimate of the cost of achieving that yield gain or savings, in terms of both research investment and the time invested by farmers.
- Appropriate prices to value the yield gain and the time invested by farmers.
- The incidence of use of the strategy, by variety, among farmers and over time.
- An understanding of which factors shift the demand and supply of particular varieties in the target area, including migration, changes in income, and long-term trends in crop area and yields.
- An understanding of how current economic policies affect the demand for and supply of particular varieties.

To investigate the distribution of benefits, or in other words, the equity of the project, the following type of information also is needed:

- Items 1-4 above, disaggregated by social group.
- Estimates of supply and demand elasticities for local maize markets, labour and land markets.
- Estimates of the share of total maize produced and consumed by social group.

(Source: Bellon *et al.* 1999)

Example of assessing the economic efficiency and equity of add-value options

Type of impact	Indicator	Option A	Option B
Economic efficiency and equity	1. internal rate of return 2. incidence of benefits by income group	1. 60% 2. benefits greatest for wealthier farmers and consumers	1. 5% 2. benefits greatest with landless labourers
Social and cultural			
Genetic diversity			
Ecosystem health			

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