Valuing Crop Biodiversity

On-farm Genetic Resources and Economic Change

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Valuing Crop Biodiversity

On-farm Genetic Resources and Economic Change

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Foreword

Societies depend on agricultural innovation processes for food security on local, regional and global scales. Crop genetic resources, embodied in the seed planted by farmers, are the building blocks of these processes. Farmers, plant breeders, gene bank managers and other crop scientists draw on diverse crop genetic resources to innovate, supporting their own livelihoods and benefiting society at large.

Sustainable management of crop genetic resources means assuring their diversity, both in trust collections and on farms. In agricultural systems, crop biodiversity is essential to combat the risks farmers face from plant pests, diseases and climatic shocks. Crop biodiversity also underpins the range of dietary needs and services that consumers demand as economies change.

Crop genetic resources are natural assets that are renewable but vulnerable to losses from either natural or human-made interventions, including the disruptions caused by droughts, floods or wars, as well as the gradual process of social and economic change. Technological changes in agricultural production over the past century, spurred by crop genetic improvement combined with the use of other farm inputs, have transformed rural societies in many parts of the world. Not all of these changes have been positive. Local communities, governments, research organizations and NGOs have expressed growing concern about the potential loss of crop biodiversity associated with social and economic change. The common challenge they now face is to develop strategies that enable crop genetic resources to be managed in ways that satisfy the needs of farmers and consumers at present and in the future.

This book contributes to a better understanding of the challenges involved in maintaining crop biodiversity on farms within a rapidly changing global food system. It is one of the first to assemble a set of empirical case studies conducted in the field with farmers and crop scientists across a range of agricultural economies and income levels, applying economics tools and methods adapted specifically to research about valuing and managing crop biodiversity on farms. All of the case studies were implemented with national and international research partners, most by the International Food Policy Research Institute (IFPRI), the International Plant Genetic Resources Institute (IPGRI) and the Food and Agricultural Organization (FAO) of the United Nations. As a set of studies about the *in situ* (on-site) management of crop genetic resources and their diversity, the findings reported here complement those recently published by CABI about the costs of saving seeds *ex situ* (in gene bank collections), prepared by IFPRI and other Future Harvest Centres for the System-wide Genetic Resources Program.

The collection of studies is intended to illuminate the practical meaning of crop biodiversity to farmers, to specify the sources of its value and to indicate how it might be supported by national policies. It is also intended to be used as a tool kit for applied researchers, particularly those working in national and international research programmes or projects in developing economies. As such, the book extends the dialogue launched in 1992 when the Convention on Biological Diversity (CBD) established international legal norms with respect to biodiversity. The CBD recognizes farmers' contribution to crop improvement and urges the equitable sharing of benefits as an incentive for farmers to conserve their biological resources. This book contributes constructively to these policy debates, and to the development of strategies that can facilitate the sustainable management and conservation of crop genetic diversity for future generations.

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> Neither man nor his crops have obeyed set rules for a sequence of events or stages of development....Simple solutions simply do not work very well. This is an age of great knowledge and little wisdom, but we have no choice; we must blunder on.
>
> Jack R. Harlan, *Crops and Man*, 1975; 1992

The research reported here was supported first by the men and women farmers who generously shared their knowledge and perceptions in personal interviews. Time to talk is increasingly scarce – whether on the hillsides of Nepal or Ethiopia, in the home gardens of Hungary, in the maize fields of Mexico or in an office. The research was also supported patiently through the tutelage of geneticists, plant breeders and ethnobotanists, in particular Toby Hodgkin, István Már, László Holly, Bhuwon Sthapit, Devra Jarvis, Deborah and Eldad Karamura, W. Tushemereirwe, Mauricio Bellon, Julien Berthaud, Dominique Louette, Richard Jones, Prem Mathur and Muhabbat Turdieva. Insights have been contributed by other economists and social scientists, including Pablo Eyzaguirre, Erika Meng, Michael Morris, Paul Heisey, Ruth Meinzen-Dick, John Pender and Douglas Gollin. Paul Winters, Leslie Lipper, Phoebe Koundouri and IFPRI provided valuable review of the work, as did Amanda King. Amanda, Patricia Zambrano and Maria Meer offered a combination of solid advice and opinions, editorial recommendations and clear thinking. Patty Arce and Annie Huie provided tireless administrative support to enable the research to happen. Funds and resources in kind were provided by a number of institutions, cited in the acknowledgements of each chapter, along with other personal thanks from the authors.

1 Concepts, Metrics and Plan of the Book

M. Smale

A Question of Value

There has been considerable public debate about the economic value of biodiversity and whether economists should attempt to value it at all. Some contend that it is inherently unethical to employ a utilitarian discipline like economics to assess the relative costs and benefits of species survival (Ehrenfeld, 1988); others argue that biodiversity must be priced to ensure that what matters to society is conserved (Randall, 1988). Economists' emphasis on value has often distanced them from natural scientists, especially if the purpose of valuation is to justify rather than to explain human behaviour (Roughgarden, 1995; Dyer, 2002). In recognition of divergent perspectives, the balance of this book is tipped more heavily towards the use of economic concepts to explain and predict human choices than to estimate prices expressed in cardinal terms.

The world's array of crop varieties is a consequence of human choices in close interaction with natural selection processes – on-farm (*in situ*), where crop genetic resources are managed by farmers, and off-farm (*ex situ*), where they are managed by plant breeders or gene banks. Relative to other areas of public policy, economics has contributed relatively little to debates about the value of these resources. In a landmark collection of writings about species preservation (Orians *et al.*, 1990), Brown (1990) explained that 'since most of the genetic resources of interest do not trade in markets, there are no prices'. This is still largely the case. The challenges involved in measuring the value of non-market goods are substantial, despite continued progress in the theory and applications of environmental economics.

Price data remain 'sparse' for crop genetic resources, as is true for many other resources of economic significance to society, because it costs a lot to exclude users. One reason is that crop genetic resources are mixed goods with multiple traits or attributes, some of which are not equally 'visible' to all of the people who manage and exchange them. Such information asymmetries do not contribute to good market performance.

There are signs that new markets for crop genetic resources are being created, and if so, more prices may soon be evident. Private companies supplying crop genetic resources have in recent years sought to strengthen the intellectual property rights over crop varieties, isolated genes and enabling tools such as promoters and markers. Simple economic theory predicts that stronger proprietary regimes will decrease the costs of excluding others from using the same resources, generating incentives for innovation and market formation. Non-governmental organizations and a battery of interest groups have countered with claims over other property rights, ostensibly on behalf of farmers and their communities.

The catch is that as on-farm suppliers of crop genetic resources, farmers, in contrast to plant breeders, also use them as planting material – a reproducible production input. These farmers are different in some respects from those working in fully commercialized agriculture in industrialized economies. Many reside in places that have benefited comparatively less from the green revolutions. For example, although it is now generally accepted that Asia's seed-based

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green revolution generated substantial benefits beyond (the adopting) farmers in irrigated production environments, large numbers of food-insecure families remain in the less productive lands of that continent. Farmers like these, who manage and supply crop genetic resources, often face unpredictable and undifferentiated markets for their products, relying on their own harvests for at least some of the goods consumed by their families.

The decisions of these farmers are the subject matter of this book. There is a growing recognition that some of them are de facto custodians of socially valuable resources. Acknowledging this role, the International Undertaking on Plant Genetic Resources drew the concept of 'farmers' rights' into the public arena during the 1980s. Ratified by over 40 country signatories, the International Treaty on Plant Genetic Resources for Agriculture became law in 2004. The Treaty establishes a multilateral system for sharing genetic resources for 64 key food crops and 24 forage species through a standard agreement, reducing the costs of bilateral transactions among the many parties exchanging lines and progenitors in the development of improved crop varieties – principally professional scientists.

In 1992, the Convention on Biological Diversity (CBD) established international legal norms (not laws) encouraging nations to manage biodiversity in ways that support already declining levels against greater loss. The CBD recognizes farmers' contribution to crop improvement and urges the equitable sharing of benefits as an incentive for farmers to conserve their biological resources. Though farmers' privilege to save seed from harvests has long been recognized, farmers' rights now specifically refer to the right to claim ownership over their varieties as do plant breeders, and the right to be rewarded for the use of these genetic resources by others. The evolution of the plant variety and farmers' rights legislation in India illustrates the ethical, political and scientific complexity of the issues (Srinivasan, 2003; Ramanna and Smale, 2004). It remains to be seen whether this legislation will be 'effective' as a *sui generis* system under the Agreement on the Trade-Related Aspects of Intellectual Property (TRIPS); a requirement for members of the World Trade Organization (WTO) (Koo *et al.*, 2004a).

A goal of this volume is to advance practical thinking about how levels of crop biodiversity may be sustained in ways that do not conflict with but contribute to sharing benefits from economic change. Arguably, sustaining crop biodiversity on farms makes most sense in locations where both society and the farmers who manage it benefit from the process, i.e. where both the private and public values associated with it are relatively high, taking into account any opportunity costs. Conservation initiatives need also to recognize the dynamic nature of human interactions with crop plants, conforming more to a notion of resource management than to that of preservation or curatorship.

Past economics research has treated related topics that bring much to bear on the methods applied and hypotheses tested in this book. The economic benefits of increasing crop productivity through the diffusion of crop varieties bred by professional plant breeders have been documented comprehensively (Byerlee and Traxler, 1995; Morris and López-Pereira, 1999; Alston *et al.*, 2000; Heisey *et al.*, 2002; Evenson and Gollin, 2003), and state-of-the-art tools developed to assess them (Alston *et al.*, 1998). Surveys discussing the sources of economic value in crop biodiversity are numerous, including Pearce and Moran (1994), Swanson (1996) and Gollin and Smale (1998). The value of diversity in crop or animal species diversity has been modelled theoretically (Brown and Goldstein, 1984; Weitzman, 1993; Polasky and Solow, 1995; Simpson *et al.*, 1996; Rausser and Small, 2000; Brock and Xepapadeas, 2003). Costs and benefits have also been estimated for plant genetic resources conserved in gene banks, destined principally for use by commercial farmers (Evenson and Gollin, 1997; Virchow, 1999; Gollin *et al.*, 2000; Johnson *et al.*, 2003; Koo *et al.*, 2004b). The global values of genetic resources and other ecosystem services (Costanza *et al.*, 1997) as well as the values of plant genetic resources and their diversity in crop breeding (Evenson *et al.*, 1998) have been assessed.

Far less work has investigated the value of increasingly scarce, local varieties to the farmers who grow them. This book is an attempt to address the research gap. The studies assembled here explore the economic incentives farmers and their communities have to maintain crop biodiversity across a range of agricultural economies. The opportunity costs associated with growing diverse crops and varieties depend on the farming system and economic context. Developing economies are represented from Asia, Latin America and Africa, as well as transitional and richer economies in Europe. The structure of crop biodiversity depends also on the crop reproduction system. Authors investigate cash crops and food crops, cereals, tubers and fruits – crops that are self-pollinating, cross-pollinating or vegetatively propagated.

Several features of these studies distinguish them from related economics research. The first is an obvious emphasis on farmers' varieties as compared to modern varieties, sometimes called 'folk varieties' (Cleveland *et al.*, 1994) or 'landraces' (Harlan, 1992; Zeven, 1998). Almost exclusively, data were collected through personal interviews with samples of farm families and other stakeholders. The disciplinary approaches are grounded in microeconomic models of farmer decision making and environmental valuation, although the research has in most cases entailed interdisciplinary work with crop scientists. Values are local rather than global; approaches are often enriched with genetic or taxonomic information.

The collection of studies in this book portrays a glimpse of the relationship between economic change and the determinants of agricultural biodiversity. Much of the research represented was conducted by doctoral students in the context of national projects that were internationally funded and facilitated. Thus, this book is intended to serve as a source for tools and examples that can be further adapted or applied by economists working in national and international research programmes and to provide information of relevance for conservation and development practitioners.

The following sections of this introduction define a common vocabulary of biodiversity and economics concepts as they are invoked throughout the chapters of this book. There are many ways to define these concepts, and some simple conventions are followed. After a discussion of terms and cross-cutting themes, the contribution of earlier economics studies about crop biodiversity on farms is summarized. A roadmap for chapters in this book, and how they interrelate, is then presented.

Common Vocabulary and Concepts

Biodiversity of crop plants

Agricultural biodiversity is a component of biodiversity, referring to all diversity within and among species found in crop and domesticated livestock systems, including wild relatives, interacting species of pollinators, pests, parasites and other organisms (Wood and Lenné, 1999). Since agricultural landscapes are fluid, the term component does not imply that boundaries are firm. Domesticated biodiversity (crops, aquaculture and livestock) is located within agricultural landscapes, complemented outside these systems (*ex situ*) by wild relatives in gene banks, breeders' collections or reserves; it serves as both a component of production and a resource for genetic improvement (Cassman *et al.*, forthcoming). Agricultural landscapes also contain non-domesticated species as weedy or 'casual' elements, or just as a part of natural (non-protected) ecosystems. Species diversity pertains to the diversity among species within which gene flow occurs under natural conditions. Genetic diversity in crops comprises all the variation in the genes of individuals. Some have argued that genetic diversity is the fundamental building block of ecological and organism diversity (Cox and Wood, 1999).

The emphasis of this book is the *in situ* (in place of origin, or source) management of crop diversity by agricultural households and communities, or on farm conservation. Here, on-farm conservation implies the choice by farmers to continue cultivating biologically diverse crops and varieties in their communities in the agricultural ecosystems where the crops have evolved historically through processes of human and natural selection (from Bellon *et al.*, 1997; Jarvis *et al.*, 2000).

In this book, 'crop biodiversity' refers to the biodiversity of crops. The biodiversity of crops encompasses phenotypic as well as genotypic variation, including cultivars recognized as agromorphologically distinct by farmers and varieties recognized as genetically distinct by plant breeders. The terms 'cultivars' and 'varieties' are used here to describe either farmers' varieties or those bred by plant breeders. Typically, farmers' varieties do not satisfy International Union for the

Protection of New Varieties of Plants (UPOV) definitions of variety because they are heterogeneous, exhibit less uniformity and segregate genetically. Where it is necessary to distinguish between varieties selected and managed by farmers and those bred by professional plant breeders, the terms 'landraces' and 'modern varieties' are assigned.

Landraces are understood simply as variants, varieties or populations of crops, with plants that are often highly variable in appearance, whose genetic structure is shaped by farmers' seed selection practices and management, as well as natural selection processes, over generations of cultivation. As Harlan (1992) described them, landraces generally exhibit high degrees of local adaptation, with particular properties or characteristics. Genetic variation in landraces is considerable but not without structure, since their composition is often deliberately manipulated by farmers. Landraces 'usually produce something' (Harlan, 1992: 148; Ceccarelli and Grando, 2002: 305), but they do not have high expected yields like modern varieties.

In this book, an effort has been made to understand the genetic structure of the crop and the units of diversity as managed and understood by farmers, in accordance to the extent possible with recent research by geneticists assessing crop biodiversity levels on farms (Jarvis *et al.*, 2004; Sadiki *et al.*, 2005). For example, banana types grown in the East African highlands (Chapter 7) are classified by genome, use group and phenotype, drawing on primary data elicited from farmers about distinguishing characteristics and published taxonomic work. A similar approach was applied in the research on millet crops presented in Chapter 13, where varieties were also sorted by categories of improvement status hybrids, improved open-pollinated variety and improved pure-line selection. Research by geneticists was the basis of the classification used for rice in Nepal (Chapter 10) and potatoes in Peru (Chapter 9). The distinctiveness of sorghum landraces grown in Eastern Ethiopia was validated by merging information from farmers and geneticists (Chapter 14). Botanical and genetics research supports the classification of crops and varieties for Chapters 3, 8 and 15 about Hungary.

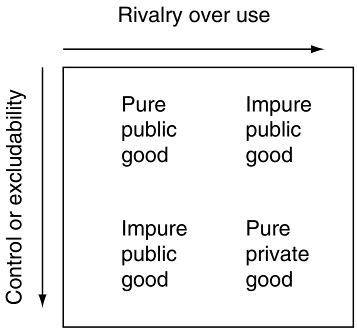
Crop biodiversity on farms has both interspecific (among crops) and intraspecific (within a crop) components (Bellon, 1996). Since the crops studied in this book have variable taxonomic status, the terms 'intercrop' and 'intracrop' designate diversity between and among common crops, respectively.

Economic value

All classes of economic value have a basis in human preference. Total economic value includes current use value, option value and existence value. Current use value derives from the utility gained by an individual from the consumption of a good or service, or from the consumption by others of a good or service. Option value, also a use value, is the value associated with retaining an option to a food or service for which future demand is uncertain. Existence value, a non-use value, derives from human preferences for the existence of the resource as such, unrelated to any use to which the resource may be put.

The global spectrum of genetic variation in crops and livestock has expanded and contracted over the centuries as a direct consequence of human interest. That human interest is practical because crop varieties and livestock races are functional units of food production. The premise of this book is that, compared to an endangered, wild plant or animal species, proportionately more of the economic value in domesticated components of agricultural biodiversity resides in current use and option values, as compared to existence value.

The basic policy dilemma of on-farm conservation stems from the mixed good properties of crop genetic resources. All goods can be situated along two axes defined by the extent of rivalry overuse and ease of exclusion in consumption (Romer, 1993; Fig. 1.1). An impure public good has characteristics of both private and public goods. Seed is highly rival with low cost of exclusion, but the genetic resources embodied in seed are non-rival and the costs of controlling their use can be high. The handful of seed or planting material a farmer places in the ground is a private good that is consumed as a production input. No two farmers can plant the same physical unit of seed. To those same farmers, the genetic resources embodied in the seed and their diversity are public goods. Both can grow the same variety simultaneously, and it is



Characteristics of impure public goods that affect the form of institutional intervention required to manage them optimally

Characteristic		Examples
Intragenerational	Regional	Waterways
	Global	Satellite transmissions
Intergenerational	Regional	Regional fisheries
	Global	Ocean fisheries

Fig. 1.1. Private, public and impure public goods. Adapted from Romer (1993: 72) and Sandler (1999: 24).

costly to prohibit others in one's community from doing so. Clearly, the costs of exclusion vary by the type of crop genetic resource in question and the institutional context. Controlling the flow of genes among fields is difficult, especially with predominantly cross-pollinating crops as they are managed by farmers in semi-subsistence agriculture. At the same time these are crops for which self-reinforcing forms of intellectual property, such as a professionally bred hybrid, are likely to be profitable for seed companies and encourage private investments (Morris *et al.*, 1998).

The combinations of seed types grown by farmers produce a harvest, which they consume and/or sell and from which they derive private value, but the pattern of genotypes across the landscape contributes to the diversity of the crop genetic resources from which people residing elsewhere and in the future may benefit. The public value of crop biodiversity includes option value for any unforeseen events, such as changes in consumer tastes. Since farmers' decisions on the use and management of crop varieties in their fields can result in smaller plant populations and loss of potentially valuable alleles, their choices have intergenerational and interregional consequences (Sandler, 1999; Fig. 1.1).

Since the diversity of crop genetic resources is never fully apparent to the farmers who provide and use it and is undervalued in markets, farmers are unable to consider the contributions of all other farmers in their community or elsewhere when they make their decisions. Economic theory predicts that, as long as crop biodiversity is a (desirable) 'good', farmers as a group will underproduce it as a group relative to the social optimum and institutional interventions are necessary to close the gap (Cornes and Sandler, 1986; Heisey *et al.*, 1997).

Situations in which individual interests conflict in some way with group interests are called social dilemmas (Sell *et al.*, 2002). Other features of the social dilemma of on-farm conservation are noteworthy. Although some poor farmers in the world depend directly on the biodiversity of the crops they grow, most farmers do not, and most consumers depend on it only indirectly. Those who encourage conservation, and perhaps those who are willing to pay for it, reside largely in other political jurisdictions (Brown, 1990). Sell *et al.* (2002) classify social dilemmas into public goods problems, in which the individual must decide whether or not to contribute to a common resource, and common property resource problems, in which the individual must decide whether to refrain from taking the resource. They find that individuals are more cooperative when faced with a resource dilemma than a public goods dilemma. On-farm conservation has features of a public goods dilemma.

High benefit–cost ratios for on-farm conservation

Because crop genetic resources are impure public goods, their costs and benefits have both private and public dimensions. Conceptually, the highest benefit–cost ratios for managing crop genetic resources on farms (as compared to their management *ex situ* in breeding programmes or gene banks) will occur where the utility farmers derive from managing them as well as the public value associated with their biodiversity is high (area II of Fig. 1.2). Since farmers are already bearing the costs of maintaining diversity in those areas and they reveal a preference for doing so, the costs of public interventions to support conservation will also be least. Where genetic diversity is assessed as relatively low, no unique traits have been identified in local genetic materials, and farmers derive few benefits from it, there may be no need to invest in any form of conservation (area III of Fig. 1.2). Where the contribution to diversity is great but farmers derive little private value from it, *ex situ* conservation is the only option (area I of Fig. 1.2). Where there is little diversity but farmers care a lot about it, there is no need for public investment at all since no value is associated with conservation (area IV of Fig. 1.2). None the less, some societies might decide to pay farmers to grow certain landraces (examples are found in Tuscany and Ethiopia).

The empirical findings presented in this book and elsewhere demonstrate clearly that in some places in the world, rural people depend on the diversity of their crops and varieties to cope with climatic risk, match them to specific soil and water regimes and meet a range of consumption needs when markets are unreliable. In such environments the opportunity costs of maintaining diversity are likely to be low because development alternatives are limited. Cash-earning opportunities may be few. These locations are often characterized as 'less-favoured', or 'marginalized'. The people who live in them are often considered to be poor on a global scale. Resolving the social dilemma requires some comprehension, however, of how the distribution of costs and benefits from managing crop biodiversity changes with economic changes.

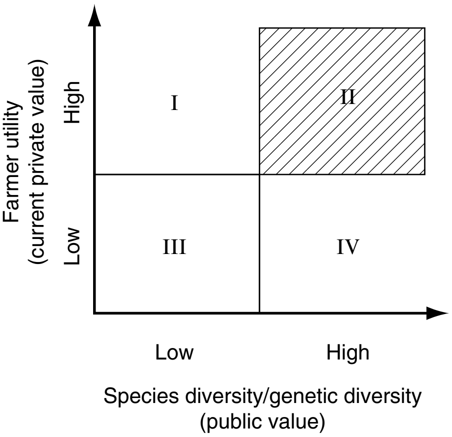


Fig. 1.2. Sites with high benefit–cost ratios for on-farm conservation. Adapted from Smale and Bellon (1999: 395).

Productivity and diversity trade-offs

Across a crop-producing region diversity is expressed in more distinct genetic types distributed more evenly or equitably. Economics principles suggest that as an economy changes, maintaining intracrop diversity on farms should occur to the extent that trade-offs between productivity and diversity maintenance are consistent with social preferences. Figure 1.3 sketches a hypothetical frontier with points determined by different combinations of biologically distinct cultivated varieties in a reference region with fixed area. The fixity in the area in any growing period or season ensures the concavity of the relationship between the amount that can be produced and the genetic diversity of the crop varieties planted.

Planting all the area in a region to a single variety with the highest expected yield generates the greatest production levels in a given growing season, hypothetically. The short-term costs to farmers of sacrificing expected crop production for the sake of maintaining areas in more numerous but less higher-yielding varieties could be great in the zones with high productivity potential and homogeneous production environments, such as the loci of the Asian green revolutions. Planting all the area to one variety will also augment genetic vulnerability to pests and diseases. Greater equity in the spatial distribution of different varieties, or less genetic uniformity, can improve yield stability over time even in those environments. In more environmentally heterogeneous zones with lower productivity potential, the short-term yield losses to the national economy of growing numerous varieties more equitably distributed across the landscape are likely to be less.

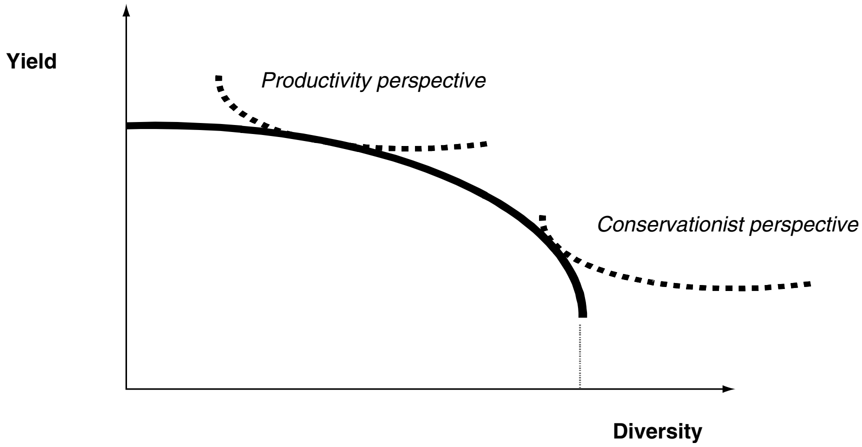


Fig. 1.3. Hypothetical relationship between productivity and crop biodiversity in a reference cropping region with a fixed area. Adapted from Heisey *et al.* (1997).

The social costs and benefits of crop biodiversity will depend on social preferences, the contour of the yield–diversity relationship and actual production combinations. Although trade-offs are inevitable on the frontier, production does not always occur on the frontier. In some seasons, it is likely that the actual mix of varieties and areas allocated generates both lower overall yields and less diversity than is feasible, so that production points lie within the frontier (Heisey *et al.*, 1997).[1] The social indifference curves depict different preferences for points on the frontier. Some richer societies may be willing to pay for conservation if they produce more than they need; in general, poorer societies are thought to prefer short-term production gains to long-term conservation interests.

Diversity metrics

Metrics for assessing the public value of crop biodiversity (the horizontal axis in Fig. 1.2) can be based on criteria that plant breeders and geneticists employ to identify useful genetic materials for future crop improvement. For example, greater public value might be associated with genes that are locally common but globally rare, on the supposition that these carry both the greatest potential for adaptation and scarcity value. Landraces can be identified for conservation according to rarity, heterogeneity or adaptive traits (as in Chapter 10). Diversity indices can serve as proxies for the public value of a set of crop varieties; these are the dependent variables of the econometric analyses in this book.

To select the appropriate diversity index for an economic analysis several issues must be resolved through interaction with farmers in the study region, knowledgeable crop scientists and geneticists (Meng *et al.*, 1998a; Table 1.1). Different indices represent different diversity concepts; none is universally correct, and more than one may be appropriate in a particular empirical context. For example, the diversity that is ‘apparent’ to farmers or crop scientists in the physical characteristics of crop populations growing in a field contrasts with the ‘latent’ diversity revealed though molecular or pedigree analysis. Crop biodiversity can also be differentiated according to its distribution within or among crops or crop varieties; it can express spatial or temporal dimensions.

The diversity concept (latent or apparent; spatial or temporal) is distinguished from the measurement tool that enables the concept to be incorporated into an economic model as a

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[1] A similar approach to Heisey *et al.* (1997) has been developed in a game-theoretic framework in Heal *et al.* (2004).

Table 1.1. Criteria to consider when choosing an index to measure the biodiversity of crop plants.

Crop reproduction	Farming system	Diversity concept	Level or scale	Conservation goal	Data used to construct index
Self	Modern	Latent/apparent	Household	Rarity	Biochemical
Cross	Traditional	Spatial/temporal	Community	Heterogeneity	Molecular
Vegetative	Mixed	Inter/intra[a]	Region	Adaptation	Agromorphological descriptors
	Microecosystem		Nation		Pedigree
					Ecological

[a] Inter/intra could refer to population, variety or species.

diversity index. Diversity indices are scalars constructed from any one of several types of data, and numerous metrics are available in the literature. For example, data may record physical measurements on crop plants grown in controlled experiments. Alternatively, data may document the variation in DNA taken from plant tissue and expressed as patterns on gels.

Fundamental is the definition of the crop population under study. Farmers, plant breeders, molecular biologists and germplasm collectors each have taxonomies or systems for distinguishing among plants. Though a single taxonomy is internally consistent, integrating any pair of taxonomies can be challenging. There is also considerable scientific evidence that the level of diversity identified in a crop plant when measured by one tool, such as molecular markers, may not correspond to the level identified by another, such as morphological descriptors.

This book focuses deliberately on diversity indices that are meaningful to farmers. As a result, the dependent variables in most of the models estimated are diversity indices that are apparent to farmers. Two considerations drove the decision to emphasize apparent over latent diversity concepts. The first reflects the subject matter of human-managed, 'domesticated' as opposed to wild species. Because farmers choose to grow varieties based on the traits and attributes they observe rather than those they cannot see, the relationship between farmers' decisions and molecular or biochemically based indices is far-fetched. Since our dependent variables are derived from the choice variables in models of farmer decision-making, we have adhered to the units that farmers recognize and manage.

Second, molecular and biochemical assays are relatively high cost in terms of laboratory time and materials and the sample sizes that would be required to link them statistically to crop populations as they are managed by farmers. This is especially true for the heterogeneous landraces of open-pollinating crop species. Professionally bred varieties are more uniform and stable genetically across environments than are landraces, though the difference diminishes when they are saved and replanted in successive generations, and applies less to crop species with high rates of outcrossing. Measurement costs of high magnitude are not warranted by the exploratory phase of empirical research conducted in this book, though such investments might be justified once a conservation programme is under implementation.

Named varieties, even when they represent genetic distinctness, are admittedly poor units of analysis for constructing diversity indices because they inform us little about genetic distances. Names can mask genotype redundancies, especially among landraces whose names are linguistic, cultural artefacts. In most of the chapters of this book, variety names have been cross-checked with morphological or genetic evidence to determine genetic distinctness to the extent possible. Distance metrics constructed from taxonomic trees have desirable mathematical properties (Weitzman, 1992; Solow *et al.*, 1993), though for the reasons cited above, chapters in this book have adhered to simpler mathematical constructs. After some experimentation with metrics, the literature concluded that the more sophisticated the construction of the index, the more obscure is its relationship to the decisions of farmers and consequently, the more difficult the interpretation in the context of farm-level data (Meng *et al.*, 1998a, 1999; Van Dusen, 2000). For crop breeding and conservation programmes, on the other hand, understanding latent diversity is of critical importance. During the design of conservation programmes, distance metrics are best handled by scientific experts whose units of analysis are linked to information about farmer-managed units.

With the exception of the attribute-based index used for coffee in Chapter 7, the diversity indices used in this book are adapted from ecological indices, which express spatial diversity concepts for species (Magurran, 1998; Table 1.2). In most cases, the data are compiled from cross-sectional surveys of farm households across villages in sub-national regions. Each represents a unique diversity concept. Richness is measured by a count or Margalef index. The index is constructed from the numbers of crop species, varieties or both encountered per unit of area that is geographically defined, such as the household farm, the village or the region. In the richness index, units are distinct but each has equal importance. Relative abundance, or the distribution of individuals associated with each of the species or varieties, is represented by the Berger–Parker index of dominance (Berger and Parker, 1970). Relative abundance accounts for the frequency that a species or variety is counted. An index that combines both richness and relative abundance (or evenness) concepts is the Shannon index of proportional abundance, sometimes called a heterogeneity index for that reason (Magurran, 1998). The Shannon index, originally used in information theory, embodies no particular assumptions about the shape of the underlying distribution in species abundance, and has been widely used in the agronomic literature to compare diversity within varieties as well as in the ecological literature to evaluate species diversity. The Margalef and Shannon indices have a lower limit of zero if only one variety is grown, while the Berger–Parker index has a lower limit of one when a single variety occupies all of the area.

The proportion of crop area planted to a variety (or area share) is used as a proxy for the number of individual plants encountered in a physical unit of area. Though area shares are not distributed spatially in the same way as plants (since they combine plants of the same crop or variety from several different locations on a farm or in a community), using area shares emphasizes the choice variable that is central to economic analysis. Crop-area shares allocated to modern varieties, as categories, have been choice variables in the constrained optimization models of the adoption literature, representing the 'extent' of adoption (Feder *et al.*, 1985; and later Feder and Umali, 1993). The notion that area shares represent the constrained demand for

Table 1.2. Spatial diversity indices used in this book.

Index	Concept	Construction	Explanation
Count	Richness	$D = S$	S = number of farmer-managed units of diversity
Margalef	Richness	$D = (S-1)/\ln A_i$ $D \geq 0$	A_i = total area planted or total population count over all farmer-managed units of diversity
Shannon	Evenness, equitability, proportional abundance	$D = -\Sigma\alpha_i \ln \alpha_i$ $D \geq 0$	α_i = area share or population share occupied by ith farmer-managed unit of diversity
Simpson	Proportional abundance	$D = 1-\Sigma\alpha_i^2$ $0 \leq D \leq 1$	α_i = area share or population share occupied by ith farmer-managed unit of diversity
Berger–Parker	Inverse dominance (relative abundance)	$D = 1/\max(\alpha_i)$ $D \geq 1$	Max (α_i) is the maximum area share planted to any single farmer-managed unit of diversity

Note: As understood here, a farmer-managed unit of diversity is a plant population, cultivated variety, crop, use group or class recognized by farmers as distinct based on observable genetic and/or agromorphological descriptors.

variety traits was described in the analysis of maize landrace diversity in Mexico (Smale *et al.*, 2001) and modern wheat diversity in China and Australia (Smale *et al.*, 2003).

Previous Economic Studies about On-farm Conservation

Earlier applied research by Brush *et al.* (1992) in Peru, Meng (1997) and Meng *et al.* (1998b) in Turkey and Van Dusen (2000) and Van Dusen and Taylor (in press) in Mexico developed the approach that serves as a starting point for much of this book. Although the studies are similar to each other, they are not derived from an identical theoretic framework. Like most of the chapters in this book, each involved an econometric estimation accomplished with data collected in household and plot surveys, supplemented by information about the genetics and taxonomy of the crop.

These studies evolved from microeconomic models of crop variety choice, formulated to analyse farmer adoption of high-yielding varieties during the early green revolutions of the 1970s. The models of that period implicitly assumed that the new seed varieties were superior to those grown by farmers. Therefore, the practice of growing both modern varieties and landraces at the same time ('partial adoption') reflected the inefficiencies associated with farmers' learning processes (e.g. Kislev and Shchori-Bachrach, 1973; Hiebert, 1974). In a final equilibrium state, 'efficient' farmers would plant all of their crop area to modern varieties. Later theoretical approaches depicted farmers as efficient but motivated by their attitudes towards risk (e.g. Feder, 1980; Just and Zilberman, 1983). Subsequently, economists argued that partial adoption could be attributed to any one of a number of competing explanations (Smale *et al.*, 1994), including attitudes towards risk, the differential costs that farmers face while transacting in imperfect markets (de Janvry *et al.*, 1991) or by environmental heterogeneity such as soil type differences on farms (Bellon and Taylor, 1993).

Brush *et al.* (1992) were motivated by what they called the 'displacement hypothesis' – that the rapid of diffusion modern varieties leads inescapably to the loss of potentially valuable landraces and gene complexes, as was observed in Asia during the early phases of the green revolution (Frankel, 1970; Harlan, 1972; Hawkes, 1983). Their model explained the area farmers allocate to improved potato varieties and the effect of adopting these varieties on the number of potato landraces they grow. Whether adoption of improved potato varieties reduced landrace diversity depended on how recently modern varieties had been introduced. Expansion of land per farm into modern varieties displaced landraces among adopters in earlier stages of adoption, but not later. The authors proposed that 'if there are compelling reasons for farmers in cradle areas to retain a minimum level of diversity on their farms, we would expect to find any negative association between the area in improved varieties and diversity to approach zero at late stages of the adoption process…' (Brush *et al.*, 1992, p. 369). In contrast to earlier perspectives, their findings led to the conclusion that the replacement of landraces by modern varieties is not inevitable and cultivation of both types may be optimum for farmers.

Meng's (1997) and Meng *et al.*'s (1998b) approach reflected both of these perspectives. Her model explained the choice to grow wheat landraces, and conditional on that choice, landrace diversity. She demonstrated that multiple explanations, including missing markets, risk and agroclimatic conditions, influenced the probability that Turkish households grew a wheat landrace on any particular plot. Hence, during processes of economic development and change, a shift in any single factor would be unlikely to cause farmers to cease growing landraces. She found that factors affecting the probability that households grow landraces were independent of those that influence wheat landrace diversity, implying that different policies would be instrumental for maintaining landraces in general as compared to diverse landraces.

Two fundamental aspects of Meng's study distinguished it from that of Brush *et al.* (1992). First, her economic model was motivated not by the decision to adopt, but by the decision to grow landraces. Variety choice was no longer viewed as equivalent to adoption; nor was diversity viewed as equivalent to growing a landrace. Her policy concern was not whether modern varieties would replace landraces, but how best to target households with genetically diverse wheat landraces in a conservation programme. Second, she used diversity indices calculated with experimental data measuring qualitative traits of wheat landraces that had been sampled from households. One of them, the Shannon index, is among the most widely used in the agronomic literature.

Other hypotheses articulated in these first two studies recur in the chapters of this book. Consistent with biogeographical theory in ecology, Brush *et al.* (1992) found that greater farm fragmentation was associated with a larger number of landraces per farm in one of the regions. Off-farm employment opportunities for the household head were negatively associated with the number of landraces grown on the household farm in both regions, supporting their hypothesis that maintaining more potato landraces required more labour. Wealth affected the number of landraces cultivated only indirectly, through its influence on adoption in the region with more recent introduction. The rich planted less area in modern varieties, possibly because of the luxury status of some potato landraces; the poor were also less likely to grow them due to imperfect credit and insurance markets.

Meng also found that farmers owning more land or more fertile land, and those with higher wealth indexes (refrigerators, tap water and electricity) had higher probabilities of growing wheat landraces. Variables measuring consumption demand by farm families, the share of wheat output marketed and the distance to market or road quality, all supported the hypothesis that farmers located in areas of less wheat market activity rely on their own production to meet their consumption needs. Some findings for the wheat landrace diversity equation contradicted working hypotheses. Fragmentation was negatively associated with the diversity of wheat landraces, while, unexpectedly, an increase in the percentage of district-level output marketed influenced it positively. A ‘striking finding’ from the diversity estimations was that ‘the effects of explanatory variables differ by diversity index’ (Meng, 1997:164). The finding led to the hypothesis that policies influencing an explanatory factor, such as market infrastructure, could have negative effects on one conservation criterion and positive effects on another; in other words, policies may not be neutral to conservation goal. The hypothesis is tested in several chapters of this book.

Building on the last two studies, Van Dusen (2000) developed a model of the household farm with missing markets to explain both species and variety diversity within the *milpa* farming system of Puebla, Mexico. Smale *et al.* (2001) also analysed the area shares allocated among maize landraces by farmers in the state of Guanajuato, Mexico, considering variety traits, introducing the notion of impure public goods and including a variable to represent the supply of distinct landraces at the community level.

The Plan of this Book

The chapters are grouped according to the approaches used to value crop biodiversity on farms and investigate its determinants. The value of crop biodiversity can be measured with stated or revealed preference approaches. Chapters included in Part II apply stated preference approaches. The applications and case studies found in Part III explore revealed preferences within the modelling framework of farmer decision making with constraints. Approaches used in Parts II and III generate direct or indirect metrics for identifying varieties, farmers or locations that are associated with high private values for managing crop biodiversity on farms situated in the upper segments on the vertical axis of Fig. 1.2. The valuation metrics are partial by construction, since they reflect only use values. In Parts II and III, only the private value to farmers is addressed. The unit of analysis is the farmer. Chapters in Part IV explore aspects of on-farm conservation that are related to public values, the role of institutions and seed systems and conservation within a larger social unit of analysis than the individual farm household.

Part II

Chapters in Part II are applications of stated preference methods. In part, stated preference methods were developed to address the limitations of revealed preference approaches. For example, hedonic pricing methods, a revealed preference approach, have been applied by environmental economists or to estimate trait values in crop or livestock production (Von Oppen and

Rao, 1982; Unnevehr, 1986; Hamath *et al.*, 1997; Scarpa *et al.*, 2003b). Hedonic models relate prices of goods in markets to the attributes that are implicitly traded. There are two major constraints to the use of hedonic pricing methods in valuing agricultural biodiversity during economic change. First, as for many other environmental goods, real or surrogate markets may not exist for the attributes of genetic resources, and even if they do, their value may not be well represented in observed prices due to incomplete markets. Markets for varieties may be thin or lacking in the grades and standards that enable consumers to differentiate quality. Governments may establish uniform pricing. Second, even if markets exist, the market price might not be a good approximation of the value of the environmental resource because, by definition, market values tend to reflect use values only.

By contrast, stated preference approaches have the potential to reveal the total economic value of a change in the provision of a non-marketed good, given that the surveys used to elicit them are properly designed. Contingent valuation is a direct elicitation method. Dyer (2002) applied a contingent behaviour method and computable general equilibrium model to investigate the supply response of maize growers in Mexico to the North American Free Trade Agreement. He presents the method and discusses implications of economic change for farmer valuation of maize landraces in Chapter 2.

Controversy over contingent valuation has led more recently to the development of alternative stated preference methods, including attribute-based choice modelling, and indirect elicitation procedure. These involve rankings or ratings by respondents across alternative options, each of which is associated with a set of attributes, one of which may be a price. Similar to contingent valuation, they are implemented through survey research. Like hedonic pricing methods, they are grounded conceptually on Lancaster's (1966) theory of consumer choice. Two examples from the literature on valuing livestock genetic resources have applied choice experiments. Scarpa *et al.* (2003a) compared the value of the attributes of creole pigs to those of more productive, but less well adapted, exotic breeds in the Yucatán peninsula of Mexico. Scarpa *et al.* (2003b) compared, revealed and stated preference methods in valuing cattle traits for indigenous livestock breeds among the Maasai in Kenya.

Birol (2004) developed a choice experiment to estimate the value of home gardens and their agrobiodiversity attributes in Hungary. Birol's modelling framework combines the random utility approach and the Lancaster (1966) theory of consumer choice. In Chapter 3, Birol *et al.* combine these findings with secondary data on settlements to test hypotheses about economic change and farmer valuation.

Wale and Mburu (Chapter 4) discovered that coffee farmers in Ethiopia do not name varieties, although they distinguish among types according to attributes. They propose an attribute-based index of diversity in their investigation of smallholder production decisions, also drawing on random utility and the Lancaster approaches and incorporating household vulnerability to risk.

Part III

Not all farmers in sites with high benefit–cost ratios today will continue managing diverse crop genetic resources in the future. Encouraging them to do so will have efficiency and equity implications at local, regional and global levels. A first step in designing appropriate policy mechanisms is to identify the factors that increase and decrease the likelihood that farmers will continue to manage crop biodiversity in a given context. Next, farmers with high predicted probabilities of maintaining crop biodiversity in the presence of economic change can be profiled statistically.

To accomplish this, Part III of this book applies econometric models of variety choice derived from the theoretic framework of the agricultural household (Singh *et al.*, 1986; de Janvry *et al.*, 1991). Crop biodiversity levels on individual farms are explained by testing hypotheses about the factors that influence their variation. A combination of microeconomic theory, principles of population genetics and ecology define the set of conceptual explanatory variables that are measured empirically in each case. The incidence, measurement and predicted effects of each variable are location-specific because they depend on the farming system, crop reproduction system and physical features of the environment. Hypotheses test the significance of environmental heterogeneity in the region or on the farm, market infrastructure, human capital, income and assets and the use of improved varieties.

A summary of the theoretical model developed by Van Dusen (2000) is presented in Chapter 5, with an econometric application that focuses on the policy issue of migration. This model provides the analytical basis and format for a number of the chapters in Part III and Part IV. Benin *et al.* (Chapter 6) analyse the determinants of both intercrop and intracrop diversity of cereals on farms in the northern highlands of Ethiopia. Edmeades (2003) formulated a complete trait-based model of variety demand within the theoretical framework of the household farm. In Chapter 7, Edmeades *et al.* apply the model to analyse the biodiversity of bananas in the East African highlands. Birol *et al.* (Chapter 8) explain the revealed preferences of farmers for four attributes of agrobiodiversity in home gardens, based on the Singh *et al.* (1986) model of the agricultural household. Winters *et al.* (Chapter 9) re-examine the determinants of potato diversity on farms in Peru, testing hypotheses about rural development interventions and policies.

Part IV

Culled largely from research in progress, the approaches used in Part IV are more disparate than those presented in Parts II and III. Gauchan *et al.* (Chapter 10) investigate the factors predicting that Nepalese farmers will choose to grow rice landraces that are also of public value for future crop improvement, based on the choice sets identified through interviews with breeders and conservationists. Gebremedhin *et al.* (Chapter 11) augment the social unit of analysis from the farm household level to the village level in the northern highlands of Ethiopia, expanding on the approach presented in Chapter 6. Seed institutions, including social networks that transmit seed-related information, as well as bazaars and formal seed suppliers, are explored for fruits and nuts in Uzbekistan. (Van Dusen *et al.*, Chapter 12). In Chapter 13, Nagarajan and Smale investigate seed systems for major and minor millet crops in South India, introducing seed system parameters into a village-level estimation of biodiversity determinants. Lipper *et al.* (Chapter 14) analyse the impact of seed programmes in drought-prone areas of eastern Ethiopia on intercrop diversity. Bela *et al.* (Chapter 15) use an institutional economics approach to analyse stakeholder interests and strategies for managing crop genetic resources in Hungary, complementing and expanding the findings of the revealed and stated preference approaches reported in Chapters 3 and 8. Di Falco and Perrings (Chapter 16) advance the work by Heisey *et al.* (1997), estimating diversity–productivity relationships in South Italy, where farmers are organized into producing and marketing cooperatives in a highly articulated, controlled market for durum wheat.

Part V

The concluding chapter presents the combined sense of the authors about the innovative contributions of this book, their limitations and future directions for research that assesses the value of crop biodiversity on farms. An annotated bibliography of related research, focusing explicitly on published articles that apply economics methods and principles, is provided in Chapter 18.

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