

# The conservation of agrobiodiversity on-farm: questioning the emerging paradigm

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Received 27 June 1995; revised and accepted 16 January 1996

The genetic diversity of traditional varieties of crops is the most economically valuable part of global biodiversity and is of paramount importance for future world crop production. The Biodiversity Convention has given a clear mandate for on-farm conservation. However, very little formal research has been done and no agreed set of scientific principles yet exists for on-farm conservation of genetic resources. This lack of scientific knowledge has not prevented an explosion of recommendations on how to conserve agrobiodiversity on-farm and it is possible to identify an emerging paradigm. Through a review of some of the assumptions on which this paradigm is based, we clearly show that if attempts to conserve agrobiodiversity on-farm are based on these misconceptions, they are likely to fail. By assessing the present activities of farmers, we propose a research agenda to increase the diversity available to farmers and to enhance farmers' capacity to manage this diversity dynamically. Increasing genetic diversification, combined with farmers' experimental abilities, and underpinned by the formal system, will ensure greater on-farm conservation of more useful genetic resources.

*Keywords:* agriculture; agrobiodiversity; *in situ* conservation; plant breeding; plant genetic resources; traditional farming.

## Introduction

The considerable genetic diversity of traditional varieties of crops is the most immediately useful and economically valuable part of global biodiversity. Traditional varieties (landraces) are directly used by subsistence farmers as a key component of their cropping systems. Such farmers account for about 60% of agricultural land use and provide approximately 15–20% of the world's food. (Francis, 1986). In addition, landraces are the basic raw materials used by plant breeders for all modern varieties, which provide the remainder of the world's crop production, on which most of us depend for food.

The 'Convention on Biological Diversity' (hereafter the Biodiversity Convention) now provides an international legal framework to obtain equitable global and national benefits from the conservation and utilisation of biodiversity, including the genetic resources of domesticated and cultivated species. Article 8 c of the Biodiversity Convention imposes on contracting parties the need to 'Regulate or manage biological resources important for the conservation of biological diversity whether within or outside protected areas with a view

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to ensuring their conservation and sustainable use'. The Biodiversity Convention (Article 2) defines 'domesticated and cultivated species' as species in which the evolutionary process has been influenced by humans to meet their needs. For such species, *in situ* conservation means 'in the surroundings where they have developed their distinctive properties' – that is, on-farm.

The coming into effect of the Biodiversity Convention, and the associated 'Agenda 21' process, has sharply focused global attention on the importance and potential value of conserving agricultural biodiversity – we use the term agrobiodiversity (Wood, 1992) – on-farm. In addition, Article 8 j of the Biodiversity Convention specifically demands of any contracting party 'subject to its national legislation, respect, preserve and maintain knowledge, innovations and practices of indigenous and local communities embodying traditional lifestyles relevant for the conservation and sustainable use of biological diversity and promote their wider application...'. This is a clear mandate for on-farm conservation.

### **Neglect of on-farm conservation by formal research**

There has been very little institutional research specifically for on-farm conservation: it is a topic of recent interest and past neglect. However, there is substantial relevant information which has been collected for other reasons – for example, by anthropological studies or during farming systems research.

Anthropologists and sociologists have studied farming systems as an important part of understanding indigenous rural culture (de Schlippe, 1956; Conklin, 1957; Barrau, 1961; Netting, 1968; Waddell, 1972; Nations and Nigh, 1980; Rhoades, 1984). However, the lack of parallel technical studies has severely limited the understanding of the role of diversity and varietal adaptation in traditional farming systems. Similarly, traditional cropping systems have been studied by agricultural scientists as a source of information for improving the varietal and technological base of traditional farming. Some of these studies are relevant to on-farm germplasm management, such as farming systems: (Simmonds, 1985; Haugerup and Collinson, 1990; Thurston *et al.*, 1994); farmer seed management: (Cromwell, 1990; Wright and Taylor, 1994; Almekinders *et al.*, 1994); intercropping: (Mutsaers, *et al.*, 1981; Francis, 1986); traditional disease management: (Thurston, 1992); farmer participatory research: (Ashby and Sperling, 1994); agricultural sustainability: (Ceccarelli *et al.*, 1992); agroecology: (Dover and Talbot, 1987; Altieri and Merrick, 1988); varietal demography: (Sperling and Loevinsohn, 1992; Janssen and Ruiz de Londoño, 1994); and varietal characteristics: (Morishima and Oka, 1979; Clawson, 1985; Martin and Adams, 1987; Ceccarelli *et al.*, 1992; Petersen *et al.*, 1994). Most of this literature has never been analysed for its relevance to on-farm conservation.

As a result of past neglect, no agreed set of scientific principles and practice yet exists for on-farm conservation of genetic resources despite the paramount value of such resources in feeding people (Groombridge, 1992). Much of the information on the conservation and use of genetic diversity in traditional agricultural systems remains largely empirical and anecdotal and the causes for farmers retaining (or abandoning) traditional varieties are not well researched. This is in great contrast to the extensive knowledge base generated by research with the objective of strengthening the *in situ* conservation of wild biodiversity (arguably of far lesser practical importance). This past research effort on wild biodiversity – ranging from population genetics to ecology – has resulted in the discipline

of conservation biology, which now provides the research methodology to support an elaborate global system of protected areas and national parks.

The lack of targeted scientific and technical research for on-farm conservation has not prevented a considerable explosion of recent recommendations on how to conserve agrobiodiversity on-farm. For example, a wide range of reports and publications has included FAO (1984); Brush (1986, 1994, 1995); Oldfield and Alcorn (1987); FAO *et al.* (1989); Berg *et al.* (1991); Cooper *et al.* (1992); de Boef *et al.* (1993); Hodgkin *et al.* (1993); Chauvet and Lefort (1994); Cleveland *et al.* (1994); CBD/CP (1994); Einarsson (1994). Other authors have been driven by a variety of concerns such as social equity (Altieri and Merrick, 1988; Altieri, 1989); indigenous knowledge (Norgaard, 1985; Rajasekaran *et al.*, 1991); gender issues (Shiva, 1989); sustainability (Vellvé and Hobbelink, 1992; Cleveland *et al.*, 1994); the broader conservation of biodiversity (Groombridge, 1992); and the survival of rural communities and indigenous cultures (Alcorn, 1984; Nabhan, 1985; Juma, 1989).

Many of these papers have a similar content – so much so that it is possible to identify an emerging paradigm for the on-farm management of agrobiodiversity. This paradigm consists of a series of assumptions, the technical merits of which will be discussed in the following section.

### **An emerging paradigm for on-farm conservation of agrobiodiversity**

Common elements of the paradigm to promote on-farm conservation include the following.

- That the spread of modern varieties has been mainly responsible for an overall loss of traditional varieties;
- That *ex situ* conservation is static, and *in situ* conservation dynamic and therefore preferable;
- That natural crossing on-farm between crops and their wild relatives results in characters of use to farmers;
- That all traditional varieties are ‘locally adapted’, and therefore of greater value to farmers than modern varieties.

We now look in some detail at the evidence for these four assumptions.

*Assumption 1: that the spread of modern varieties has been mainly responsible for an overall loss of traditional varieties*

It has been claimed that the spread of modern varieties has been mainly responsible for a great loss of indigenous varieties. For example, Berg *et al.* (1991) claim that the spread of varieties produced by the International Agricultural Research Centres (IARCs) has led to the near disappearance of ancient centres of crop genetic diversity. Vellvé and Hobbelink (1992) note that a major reason for the loss of farmers’ varieties is their replacement by modern high yielding varieties disseminated in the name of the Green Revolution. Cooper *et al.* (1994) claim that genetic erosion is due to the replacement of diverse genetic material on-farm by modern varieties. Fowler and Mooney (1990) propose that the major cause of genetic wipeout is the replacement of traditional varieties by cultivars developed by crop breeding institutes and large multinational seed companies.

*Assumption 1 reviewed*

The spread of modern varieties is only one of the many, unquantified, reasons for the loss of landraces.

Rather than inevitably replacing traditional varieties, modern varieties may play an important role in maintaining and even enriching the genetic diversity of traditional cropping systems. Firstly, modern varieties may co-exist in cropping systems with traditional varieties. Many farmers grow both modern varieties under high input technologies and landraces, often for their own consumption, under traditional management (Brush, 1995 for potato in Peru; Bellon, 1991 for maize in Mexico; Smale and Heisey, 1995 for maize in Malawi).

Secondly, small-scale farmers may use a mixture of modern and native varieties without making any clear agronomic distinction between the two categories (Montecinos and Altieri, 1992). For example, in Zimbabwe distinctions between 'old', and 'new', 'traditional' and 'modern' were hard to discern in most cases (van Oosterhout, 1993). Morse and McNamara (1994) showed that new crop varieties were easily adopted by farmers and inserted into existing cropping systems.

Thirdly, the agricultural integration of modern varieties into traditional systems may lead to the genetic integration of modern and traditional varieties. The modification of modern varieties by traditional farmers is known as 'criolloization' (Lamola and Bertram, 1994) or 'rustication' (Prain, 1993), and appears to be widespread. During this process, modern varieties exchange genes with landraces. Valuable features of modern varieties are integrated under farmer management, with desirable features of traditional varieties. For example, for two African countries, Wright and Taylor (1994) stress that 'local' varieties are usually a mix of original landraces combined with genes from degraded introduced varieties, and that true local varieties no longer exist.

Assumption 1 is further suspect in specifically linking the 'Green Revolution' with genetic erosion on-farm. Most of the areas in which the Green Revolution has had the greatest impact are relatively high potential areas (and not ancient centres of crop genetic diversity – *fide* Berg *et al.*, 1991). Such areas had been targeted by agricultural research for decades or more before the Green Revolution. For example, the Punjab in India and Pakistan had received early attention from locally-based plant breeders who developed heavy-yielding rust resistant wheats (Royal Commission on Agriculture in India, 1928). By 1945, 2.8 million ha of the Punjab were under improved wheat (Gill, 1978). In another example, there had been successful attempts to replace traditional rice varieties with introduced varieties in Indonesia from 1855 onwards (van der Eng, 1994). Politicized claims of 'genetic wipeout' associated with the Green Revolution (Fowler and Mooney, 1990) have been made without firm evidence that original and unique local varieties – rather than previous generations of modern varieties – have been lost during recent varietal replacement.

Assumption 1 goes beyond our knowledge of the facts of genetic erosion. Brush (1995) has noted that 20 years after the genetic erosion alarm was raised, neither the extent of genetic erosion nor the efficacy of the existing farmer-based conservation have been measured quantitatively. Ceccarelli *et al.* (1992) have pointed out that, 'little is known about the actual rate of genetic erosion of crops and their wild progenitors...'

Assumption 1 is based on an overly-static view of the management of varieties by farmers: it assumes that lost varieties are irreplaceable. In reality, varietal management on-farm is dynamic, with considerable experimentation by farmers associated with a complex

process of the demographic change of varieties (Wood and Lenné, 1993). The on-going process is open-ended and includes the accessing of new variation, the on-farm evolution of new varieties, and the discarding of varieties no longer of interest to farmers.

There is an untested further assumption often made, that equates the loss of individual landraces within a crop with genetic erosion – that is, a loss of genes from the species. However, it is quite possible to have a considerable loss of landraces with no genetic erosion whatever. Most landraces will have been derived by farmers from genetic recombination of existing landraces (Quiros *et al.*, 1992 gives examples for potato in the Andes) – no ‘new’ genes are involved. If either derived or existing landraces are subsequently discarded by farmers, there is no genetic erosion. This parallels the process used by institutional breeders to generate advanced lines for testing: most of these are discarded, rather than maintained, as they can be readily regenerated if needed – extinction is not for ever.

Rather than a conflict, there appears to be a useful complementarity between the farmers’ demonstrated ability to continually generate varietal diversity (and to manage it dynamically), and the very widest access to agrobiodiversity possible through the formal system. This complementarity could be of the highest value to traditional farmers, but has been ignored by those promoting alarmist calls of genetic wipeout, based on the false premise that the ‘farmer/community system’ does not benefit in any manner from advances in plant breeding (CBDPC, 1994).

*Assumption 2: that ex situ conservation is static, and in situ conservation dynamic and therefore preferable*

It has long been accepted that *ex situ* conservation of genetic resources has provided a service to global plant breeding (Cohen *et al.*, 1991). For more than a century, plant breeders have been collecting crop varieties for use in selection and breeding programmes. To ensure continued availability, samples are stored in increasingly sophisticated cold stores and tissue culture banks.

However, recently there have been criticisms of this well-established *ex situ* system and suggestions that *in situ* conservation of crops by farmers is preferable (Cleveland *et al.*, 1994) and should be promoted, either as a complementary system to *ex situ* (Montecinos and Altieri, 1992) or as an alternative. The main arguments against *ex situ* conservation are: it is static, preventing evolutionary changes in samples; that poor management can reduce the useful variation within samples; and that samples are not available to farmers. In contrast, *in situ* conservation by farmers is claimed to be dynamic, with crops adapting to changing environmental conditions; to allow farmers to manage variation within varieties according to their needs; and to permit samples to be continually available as needed.

*Assumption 2 reviewed*

The polarized arguments between *ex situ* conservation by the institutional system and *in situ* conservation by farmers are suspect: they are not comparing like with like. *Ex situ* and *in situ* conservation consist of both storage and management. Attention has been focused on the shortcomings of *ex situ* ‘storage’, in a comparison with the advantages of on-farm germplasm ‘management’. This not a valid comparison.

If we consider the *ex situ* and *in situ* systems for sample storage only, there are far greater shortcomings with on-farm storage than with *ex situ* storage. Farm stored seed is subject to loss of viability, genetic changes in store, insect and fungal infestation, and seed and tuber-borne diseases. The considerable formal (and informal) effort that has been put

into improving seed (and grain) storage on-farm is a reflection of these problems (Cromwell and Wiggins, 1993). *In situ* storage may also be jeopardized by famine, drought, pest and disease epidemics, and wars that can totally destroy crops and stocks of farm-stored seed.

In contrast, seed storage *ex situ* can be achieved at low cost, without loss of viability or genetic damage, for decades or centuries under conditions of low moisture content and temperature (Frankel and Soulé, 1981). It is the constant multiplication of samples to provide sufficient material for use (rather than storage) that causes problems with *ex situ* germplasm management. The vast range of crop diversity now stored *ex situ* can readily be distributed to farmers at low cost, if needed.

*Assumption 3: that natural crossing on-farm between crops and their wild relatives results in characters of use to farmers*

Many crops have conspecific or congeneric weedy and wild relatives with which they are sympatric in part of their range (Pickersgill, 1981). Where crops and their relatives are sympatric, there is a potential for gene flow between crop, weed, and wild components (Harlan, 1965, 1975; Bennett, 1970). However, claims that the mere presence of wild relatives in traditional farming systems will result in the flow of useful genes from wild to cultivated plants through introgressive hybridization have exploded in the literature during the past few years. This supposed common occurrence of natural gene exchange between weedy and wild relatives and crops is now being promoted to support on-farm conservation (Nabhan, 1985; Altieri and Merrick, 1987; Berg *et al.*, 1991; Worede, 1992; Brush, 1992, 1994; Prain, 1993; Hardon and de Boef 1993; Amanor *et al.*, 1993; Solieri and Smith, 1995). In addition, a role for farmers in the manipulation of gene exchange between weedy and wild relatives and crops is being assumed.

*Assumption 3 reviewed*

A critical review of the literature shows (a) there is limited evidence for introgression between wild relatives and crops in traditional farming systems (and then only in out-crossers, rather than in the more predominant self-pollinated crops); (b) no proof for the movement of valuable traits from wild relatives into crops; and (c) the largely anecdotal nature of the evidence to support the direct involvement of farmers in the manipulation of wild relatives. The most extensive literature on crop-wild introgression relates to maize and the paper by Wilkes (1977) on which many subsequent claims are based.

Wilkes (1977) surveyed the areas of contact of maize and annual teosinte (*Zea mexicana*) in Mexico and Guatemala. From morphological evidence, he concluded that exchange of genes occurred, and in some areas was extensive. However, in most of its sympatric range, isolating mechanisms based on spatial and seasonal separation prevent or limit genetic exchange between teosinte and maize (Wilkes, 1989). The observations of Wilkes (1977) and Benz *et al.* (1990) also suggest that gene flow, when it does occur, is from maize to the teosintes and less commonly, in the opposite direction.

Based on Wilkes (1977), there are now growing claims that farmers play an active role in fostering populations of wild teosinte where they occur with maize as an integral part of farmers' strategy 'to maintain local germplasm' (Altieri and Merrick, 1987; Berg *et al.*, 1991; Hardon and de Boef, 1993; Amanor *et al.*, 1993). An appraisal of Wilkes (1977) in fact shows firstly that in *not one* locality surveyed do farmers foster populations of *wild* teosinte. It commonly grows on field margins and in uncultivated land and if recongnized

early, it is weeded out 'because it injures good plants'. In addition, in only one of the six major localities surveyed was evidence given 'that the maize  $\times$  teosinte hybrid is knowingly planted and desired by native cultivators'. Also based on Wilkes (1977), is the expanding belief that farmers play an active role in fostering populations of wild teosinte where they occur with maize as a strategy 'to improve local germplasm' (Altieri and Merrick, 1987; Berg *et al.*, 1991; Hardon and de Boef, 1993; Amanor *et al.*, 1993). In reality, Wilkes (1977) only gives anecdotal evidence to support that introgressive hybridization is beneficial to the crop. As controlled studies were not carried out, there is no quantitative base to support Wilkes (1977) conclusion that 'native cultivators exploit the heterotic nature of maize to increase their harvest'.

In the Sierra de Manantlan of Mexico, another wild relative of maize, perennial teosinte 'milpilla' (*Zea diploperennis*) occurs in a traditional maize-based agroecosystem (Benz *et al.* 1990). Some farmers intercrop milpilla and maize so that maize pollen is available for the milpilla. After three years, seed from maize-like milpilla plants is planted with maize. However, Benz *et al.* (1990) could find no evidence to support farmers' claims of increased yield or increased resistance to fungal diseases in maize from this system, and the milpilla itself was observed to be affected by such diseases. Whether any positive characteristics result from hybridization, introgression and selection is still conjectural and merits further study (Benz *et al.*, 1990).

While hybridization and reciprocal introgression between maize and teosinte have been reported by some, and accepted by many, considerable uncertainty still surrounds this phenomenon (Benz *et al.*, 1990; Eagles and Lothrop, 1994). From a careful examination of the chromosome morphology of maize and teosinte from highland areas where they are sympatric, Kato (1984) concluded that reciprocal introgression was not occurring. This view is supported by isozyme data (Doebly, 1990). Furthermore, the existence of gene flow from maize to milpilla is doubted by Kato and Lopez (1990). Reproductive isolation is undoubtedly assisted by late flowering of perennial teosinte and probably also by genetic incompatibility factors (Kermicle and Allen, 1990 cited in Eagles and Lothrop, 1994). Moreover, in a recent review, Wilkes (1989) now suggests that there may be genetic mechanisms to conserve the 'distinct chromosome morphologies' of teosinte and maize whenever they grow together. A similar genetic isolation mechanism has been suggested between pearl millet and its wild relative in West Africa (Marchais, 1994). Future investigations at both the nuclear and cytoplasmic levels are needed to resolve these controversies (Benz *et al.*, 1990).

In a more general review of crop-wild introgression, Harlan (1965) expressed his feelings that intermittent gene flow from the weed to the crop probably occurs yet Harlan states that in every case studied so far, weed races only occasionally hybridize with crop plants. Hybridization is seldom if ever on a massive scale. There are usually rather formidable barriers to gene exchange and selection pressure for either the weed or the crop is apparently strong. Harlan (1965) is clearly presenting an untested hypothesis which should not be used as the basis for arguments to support on-farm conservation. What is now obvious is that earlier views of crop-wild introgression were simplistic or incorrect, and, further research is urgently needed.

In contrast to the many claims of the benefits of crop-wild introgression, the presence of wild relatives can have at least three severely damaging effects on the value of crops to farmers: the generation of weedy hybrids; the introgression of deleterious characters, including toxins, into the crop; and the harbouring of crop pests and diseases.

*Assumption 4: that all traditional varieties are 'locally adapted', and therefore of greater value to farmers than modern varieties*

There is a widespread assumption that varieties maintained by traditional farmers are 'locally adapted'. The implications of this assumption are (a) that such varieties are uniquely adapted to specific local conditions, and, therefore, (b) their loss would both damage local farming and be a loss to the global genetic resources system. For example, Berg *et al.* (1991) make two specific claims: (a) that farmers selecting different varieties for different fields results in specific adaptation to micro-level agroecological niches; and (b) that following the spread of crops, traditional farming systems ensured local adaptation everywhere. Amanor *et al.* (1993) state that for thousands of years, farmers have been adapting crops to diverse environments. NGOs, in particular, have promoted conservation of agrobiodiversity by farming communities on the basis of the perceived value of local adaptation. A recent proposal for Community Biodiversity Development and Conservation (CBDPC, 1994) claims that planting material is continuously adapted to the environment by farmers, and that the process leads to site specificity. Cleveland *et al.* (1994) suggest that farmer management results in a specific adaptation of genetic resources to the local environment.

*Assumption 4 reviewed*

Local adaptation results from evolutionary change whereby a variable population of a crop variety becomes better adapted to a specific local environment as a result of environmental and farmer selection. Examples include salinity tolerance in traditional rice varieties, and precise photo-period sensitivity in sorghum (Bunting and Curtis, 1968). However, such local adaptation is usually assumed, rather than demonstrated.

Any claim that farmers are selecting specifically for local adaptation must be validated. If a farmer selects from a range of varieties available and uses them for specific purposes, increase in local adaptation cannot be assumed (as by Berg *et al.*, 1991). Criteria other than environmental adaptation may be used by the farmer (for example, taste or appearance). Indeed if a farmer selects strongly for one character of interest – for example, seed coat colour in beans – variation of value for adaptation to site-specific environmental conditions, for example, disease resistance, could be lost. Although Berg (1993) has argued that specific adaptation is normally advantageous from a farmer's point of view, specific local adaptation may be at some cost to broader adaptation. The varying environmental conditions under which traditional agriculture is carried out may not favour specific local adaptation (Hardon and de Boef, 1993). When there is climatic variation between years, and differences between fields, local selection may favour broad adaptability.

For wild species, a review of local adaptation indicates that local genotypes may *not* be optimally adapted to local conditions (Namkoong, 1969). Genotypes from elsewhere may perform better in the location, and the local genotype may perform better in other locations. If traditional varieties of crops are also not optimally adapted to local conditions, farmers may find better adaptation in modern varieties, which are usually selected by the research system following multi-regional trials for near optimum performance in a broad range of conditions.

Evidence against specific local adaptation in crop varieties is provided by the extensive interchange of traditional varieties of all crops. As a result of a case study of potato in the Andes, Brush (1995) argues that farmer management would seem to minimize specific adaptive fit to highly local field conditions. Wide exchange indicates that varieties nor-



mally have general adaptation to a range of conditions. On a broader scale, this view is supported by the widespread and rapid adoption of introduced crops (Wood, 1988). Varieties of introduced crops cannot be specifically locally adapted at the time of introduction, yet appear to perform better than local crops and varieties (Jennings and Cock, 1977).

Rather than varieties becoming progressively better locally adapted over time, it can be argued that traditional varieties may become progressively dys-adapted to local conditions. While 'local adaptation' is not a concept used by farmers, local varietal 'degradation' often is. Farmers often note that varieties become 'tired' and need replacing. Andean farmers also produce true seed when the tubers become 'tired' (Quiros *et al.*, 1992). Almekinders *et al.* (1994) noted that farmers gave their 'tired' seed to farmers in cooler and more fertile areas for multiplication. In other examples of the need for fresh sources of seed, Worede and Mekbib (1993) note that in Ethiopia local varieties become 'degraded' by cross pollination and that new sources of seed are needed from other areas, while Andean farmers attempt to keep potatoes free from virus by producing seed potatoes in a zone 1000m above the zone of crop production (Baumann, 1992). This forced movement of propagating material between zones is direct evidence against specific local adaptation in crops.

There seems to be no sound evidence that farmers increase the specific local adaptation of varieties, except perhaps in marginal, stress-prone environments. A more realistic view is that farmers have created and managed environments where crop varieties could evolve under a range of changing and often contrasting selective pressures. Given the uncertainties about the level and significance of local adaptation in traditional varieties, the concept of 'local adaptation' should not yet be used to justify on-farm conservation. It is, however, an exceptionally interesting research topic.

## Revising the paradigm

### *What farmers do now*

There are flaws and misconceptions in the assumptions which contribute to an emerging paradigm for on-farm conservation of crop genetic resources. Attempts to conserve agrobiodiversity on-farm, if based on these flawed assumptions, could fail. In place of these dubious assumptions, we propose three very positive characteristics of traditional farming:

- the constant search by farmers for *novel variation*;
- the abilities of farmers to *experiment* with this variation; and
- the management by farmers of a *dynamic 'portfolio' of varieties*.

### *Proposition 1: farmers search for novel variation*

One of the marked characteristics of traditional farming is the need and the constant search by farmers for genetic novelty. Traditional farmers acquire new varieties by exchange (Grisley, 1994); through new encounters while travelling (Johnson, 1972); by purchase from markets (de Schlippe, 1956); or through natural hybridization between varieties and the seeding of varieties normally propagated vegetatively (Wood and Lenné, 1993). Moreover, in a highly traditional system of shifting cultivation in Africa, de Schlippe (1956) noted that many varieties and even crops in Zande practice were of recent

introductions, and that varieties continued to flow into Zande agriculture from different directions. Brookfield and Hart (1971) note that ‘Modern Melanesian farmers are always ready to experiment with new planting material that comes their way, and are eager to acquire such material whenever travelling away from home. If an innovation is empirically successful, they will adopt it readily. The prehistory that we are reviewing rather suggests that this has for very long been so, and certainly new introductions that have taken place in the past 400 years have advanced swiftly and far ahead of European penetration’.

Distant origin of varieties may be a positive criterion for farmers. Johnson (1972) reports an earlier observation (by Salisbury) that experimental plots near houses are used for “exotic plants from distant areas”. Chambers *et al.* (1989) reported that farmers set up their own personal genebanks as well as far-flung exchange systems for acquiring genetic resources.

Outsiders usually consider the genetic diversity of traditional cropping systems to be wide. However, the search by farmers for new diversity may be their rational response to less-than-adequate genetic diversity in traditional agroecosystems. There are many factors that could reduce or restrict the diversity available to farmers:

- bottlenecks in access to diversity;
- strong environmental selection of the farmer’s crop under marginal or changing conditions;
- accidental loss of varieties from the farm.

There is remarkably little evidence on what are appropriate levels of diversity in traditional crops. What evidence there is rings warning bells. Tuan and Trinh (1995) warn that diversity needs to be further investigated as recent works on biochemical diversity showed that many traditional varieties of rice in S.E. Asia belonged to the same genotype group. Tuan and Trinh further argued that the number of traditional varieties or modern varieties in an ecosystem was not a criterion of genetic diversity.

#### *Proposition 2: farmers experiment*

Brosius *et al.* (1988) warn that ‘the use of the word “traditional” may convey the impression of strategies, tactics, and information that are unchanging because they have proven adaptive through countless generations and in countless situations’. However, the reality is that farmers have a high capacity for experimentation, and through this capacity can take advantage of varietal improvement by other farmers and by institutional plant breeders. De Schlippe (1956) emphasized farmer experimentation and inventiveness (in Africa), and argued that this was a ‘mechanism of change’. Johnson (1972) argued that in traditional agriculture there is systematic experimentation with the new and exotic; Richards (1989) suggested that farmers’ ability to experiment is a neglected resource. With justification, this experimentation has been termed ‘indigenous research’ (Lightfoot, 1987).

Most traditional farmers experiment when they acquire new varieties (Boster, 1985; Dove, 1985; Voss, 1992; Cleveland *et al.*, 1994). This usually involves growing the variety for one or more seasons in household gardens to evaluate agronomic and culinary characters; if further evaluation is merited, it is grown under a range of field conditions. This process of experimentation determines whether a new variety will be retained or rejected. In long-established traditional bean systems in Rwanda, farmers have particularly finely-tuned mixtures (Trutmann, personal communication). New varieties are stringently tested prior to incorporation into the farmer’s portfolio of varieties. In new areas of settlement,

farmers are far less particular and will grow whatever is available. Farmers also visually select seed for the subsequent planting from superior plants within the varietal population (Dove, 1985; Haciwa, personal communication). Not surprisingly, farmers have incorporated this information into their knowledge base (Bellon, 1991).

*Proposition 3: farmers manage a dynamic 'portfolio' of varieties*

The result of farmer experimentation is a dynamic, open, system of on-farm management of genetic resources, with both recruitment and loss of varieties. Varietal change may be frequent. For example, a survey of 30 households growing rice in Sierra Leone revealed 73 cases of new or unfamiliar varieties adopted in the last 10 years (Richards, 1985). Monde and Richards (1994) showed that varieties persisted in rice production systems in Sierra Leone for an average of only five years. The persistence of rice varieties among Kantu farmers in Indonesia is longer, ranging from 0–4 human generations, with a mean of 1.5 to 2.1 (Dove, 1985). In Papua New Guinea, farmers change sweet potato varieties constantly (Bourke, 1982) and movement of planting material from farmer to farmer is very fluid. Other examples include Almekinders *et al.* (1994) for maize and beans in C. America, and Sperling and Loevinsohn (1992) for beans in C. Africa, and, more generally, Brookfield and Padoch (1994). As noted under Assumption 1, a farmer's 'portfolio' of varieties may include modern varieties.

The benefits of this dynamic open system of access, experimentation, and management are obvious. Farmers can access the results of varietal improvement made by others, experiment to choose appropriate varieties to meet their own needs, and maintain sufficient agrobiodiversity on-farm to meet changing and unpredictable economic and environmental conditions.

## **Research agenda**

There is a serious lack of specific technical research for on-farm conservation (already noted by Hardon and de Boef, 1993; Wood and Lenné, 1993; Cleveland *et al.*, 1994). The possibilities for enhancing and complementing the existing management of varieties on-farm are immense. We suggest that at least the following are necessary:

### *Review of literature*

There is considerable information from a range of sources which is of direct value in supporting on-farm conservation of agrobiodiversity. In designing research approaches to conserving agrobiodiversity, this literature should be reviewed, rather than ignored.

### *Identification of benchmark sites*

Guidelines for selecting priority locations for research are pre-requisite for a well-focused research agenda. Choice of location should depend on: ecological conditions; cropping system complexity; range of varieties used; communal tradition of varietal maintenance and experimentation; and socio-cultural factors. Systems with a history of dynamic traditional management could provide models. Marginal agriculture, where access to diversity may be low, and selection pressure high, will need priority attention.

### *Varietal acquisition*

Farmers need continual access to diversity, in the form of varieties. Yet farmers may encounter a series of bottlenecks in their access to diversity. These include: 'domestication

bottlenecks', with only part of the genetic diversity of wild ancestral species being incorporated in crops during the domestication process; 'access bottlenecks', where the crop originated elsewhere, and farmers do not have ongoing access to the diversity in the region of origin; and 'diffusion bottlenecks', where the movement of seed from farmer to farmer is based on few seeds not fully representative of the genetic diversity of the variety. The formal research system can identify and help overcome these restrictions.

#### *Varietal characterization*

There have been several efforts by plant scientists to classify sub-specific variation within crops (Wellhausen *et al.*, 1951 for maize; Harlan and Stemler, 1976 for sorghum). However, Ng and Padulosi (1992) note that a simple and precise technique for measuring the overall genetic diversity of a crop is not yet available. Farmers' own local folk-classification systems, although precise and usable locally (and meriting much further study), cannot be transferred to other regions. The lack of a broadly usable general classification and nomenclature system for landraces is a serious constraint facing on-farm conservation. A taxonomic framework is needed before study of the evolutionary history, function, and ecogeographical distribution of variation within a crop species.

In addition to a quantitative characterization of the diversity of traditional varieties, there is need for qualitative characterization. The relative importance to farmers of different varieties is unknown. It may be possible to recognize 'keystone varieties' which are more important, more widespread and more productive, or which are a source from which farmers can derive other varieties.

#### *Assessment of the genetic base (genetic distance)*

The range of diversity within a crop – the genetic base – is a measure of the evolutionary resilience of the crop. Rather than continuing to assume that the obvious morphological diversity of traditional varieties assures a broad genetic base on-farm, diagnostic surveys of genetic variation and genetic distance between varieties are urgently needed. A range of methodologies has been developed to recognize narrow diversity within crops, but these have only rarely been applied to traditional varieties (for example, Lefèvre and Charrier, 1993, for cassava in Africa). An excellent example of how the institutional system can broaden the genetic base of cropping systems is the integrated study of the potential of the American yam bean. Grum *et al.* (1994) included a clarification of the taxonomy and genetic diversity, agronomic trials, and the trans-continental introduction of higher yielding varieties to Pacific islands.

#### *Varietal evaluation and selection*

Selection on-farm between varieties will be done mainly by small-scale experimentation before varieties are incorporated in the cropping system; selection within varieties during subsequent cropping cycles. Farmer selection may be positive, as when seed is selected for priority multiplication from plants with an obvious mutation or genetic recombination such as earliness or, for example, seed colour variation. Farmer selection may be negative, when plants with obvious undesirable characters are rogued from the field. Both these processes result in strong selection for favoured characters, and could lead to rapid genetic change in varieties. However, farmers are unable to select characters of value if these characters are cryptic, as for low incidence of disease resistance genes and multiple resistances (Teveson *et al.*, 1994, 1995).

Natural selection also acts on crop populations. Compared with rapid positive selection by farmers, natural selection is a relatively slow process: it could take many cropping cycles for an initially rare but useful mutation or recombination to spread through the variety. With the rapid turnover of varieties characteristic of dynamic management, potentially useful genes may be lost before they become frequent enough to demonstrate their usefulness to the farmer. An additional problem is that the level of natural selection for characters such as pest and disease resistance in diverse ecosystems is considerably lower than in less diverse systems (Lenné *et al.*, 1994). The diversity of traditional systems (multiple cropping, varietal mixtures) may therefore allow survival of inferior components of the crop population and may *reduce* the selection intensity for the evolution of disease resistance.

Very little is known of the role of traditional farming practices on enhancing (or diminishing) pest and disease resistance. It is exactly here that formal research can identify and promote useful variation. Once characters of value have been identified by formal evaluation, resistant components can be multiplied and fed back into the cropping system. There is also the possibility of increasing the selection pressure on-farm for indigenous diseases (and other biotic constraints, Brown, 1991).

#### *Assessment of local adaptation*

The entire concept of local adaptation deserves more scrutiny on-farm, and over a period of time. We need answers to questions such as: Does it occur? Is it under farmer control? Does it reduce general adaptation? Does it reduce intra-varietal genetic variation? Is it a useable concept for clonally-propagated crops? Does the level of selection associated with local adaptation lead to genetic uniformity and inbreeding depression? Can it be exploited through GIS systems by moving germplasm to other equivalent localities?

#### *Effect of crop breeding system*

The level of genetic diversity within a crop depends only marginally on the breeding system of the crop (clonal, self-pollinating or outcrossing). However, the packaging of diversity into crop varieties depends strongly on both the breeding system, and on farmer management. Generation of new varieties by farmers may be very simple. For example, crops that are normally clonally propagated (roots and tubers; fruit trees) are often heterozygous. Plants derived from seed can release great variation and allow a cycle of re-selection of useful varieties (Quiros *et al.*, 1992 for potatoes; Boster, 1985 for cassava; Yen, 1982 for sweet potato). Also, growing normally self-pollinated crops in mixtures can produce considerable variation through occasional outcrossing (Martin and Adams, 1987 for beans; Richards, 1985 for rice). Research is needed to relate breeding systems with diversity and farmer management.

#### *Crop-wild introgression*

It is difficult to show the value of gene flow under natural conditions between crops and their wild relatives, even in strongly outcrossing crops such as maize. The importance of gene flow will be much less for predominantly self-pollinating crops. There is not one clearly proven case of natural gene exchange between crops and wild relatives contributing useful characters to the crop. Plant breeders, however, have developed techniques of routinely exploiting the diversity of useful characters present in wild species in the improvement of, for example, wheat, barley, potato, tomato and cotton (Lenné and Wood,

1991). Backcrossing to a crop variety and strong selection for many generations is needed to remove deleterious genes from the wild species.

Useful genes from the wild incorporated in improved varieties by plant breeding can directly add to the genetic diversity managed on-farm. There may be subsequent transfer of 'wild' genes by crossing between different varieties grown on-farm, thereby enriching useful on-farm diversity. More than 20 years ago, Harlan (1975) noted that this is an area in urgent need of research. It is also an area where the formal system can readily assist farmers in overcoming a genetic bottleneck in transferring genes from the wild.

#### *Varietal demography*

There is little known about the movement of varieties into and out of cropping systems – varietal demography. This information is vital to understand the dynamic nature of on-farm germplasm management. At a minimum, there is a need to know the source of varieties and how the farm portfolio of varieties changes over time. A time span of at least ten years is recommended for research. It will be important to study the reasons for loss of varieties: whether accidental and random, or by deliberate rejection by farmers. It will be of utmost importance to determine if varieties are rejected by farmers because of their perceived degradation, and if so, its nature.

#### *Seed production and storage*

Research support is needed for traditional seed production, with particular emphasis on the role of seed-borne pests and diseases in reducing diversity during the seed production/storage cycle. While much is known of traditional seed supply (Cromwell, 1990), it has rarely been specifically investigated for its effects on increasing, maintaining, or reducing genetic diversity. An example of productive cooperation between farmers and formal researchers in increasing the effectiveness of local seed systems is given in Prain (1993).

#### *Transfer of technology*

Research is needed on the transfer of appropriate technology between farming systems known to manage great diversity. These include shifting cultivation and tropical home gardens. Where farmers have developed general solutions to managing crop diversity, the farmers themselves could be encouraged to transfer the technology widely. This would be an ideal role for NGOs. The formal research system could help tailor this technology to the new conditions (Thurston, 1992, for traditional pest and disease management; Thurston *et al.*, 1994, for appropriate traditional agronomy).

### **Complementarity between on-farm and institutional management of agrobiodiversity**

#### *Access and local evaluation*

Many millions of traditional farmers are able to evaluate and manage varietal diversity in a great range of agro-ecological conditions. However, their access to the needed quality and quantity of crop diversity may be a bottleneck. In contrast, the formal *ex situ* system has in store enormous resources of plant diversity, but a bottleneck in manpower to evaluate samples adequately for the necessary wide range of conditions. There is an ideal complementarity here between the strengths and weaknesses of the formal research system and farmers.

### *Secure conservation*

The continuing loss of varieties seems to be normal in traditional farming. Varieties may be lost by accident, in which case appropriate *ex situ* samples should be available to replace the loss. However, varieties may be deliberately discarded as not meeting the farmer's requirements. Unique varieties which are discarded by one farmer could have characters of wider value, either to farmers elsewhere or to plant breeders. In particular, potentially valuable genes at low frequency in crop populations could be lost before the cumulative effect of many generations of selection became apparent. Obsolescent varieties should therefore be identified for collection and passed into secure long-term *ex situ* storage to ensure their future availability.

### *Increased economic viability of traditional farms*

When farms are abandoned for economic reasons, all agrobiodiversity can be lost. The formal system can help to ensure the economic viability of traditional farms through both genetic diversification and the provision of more productive varieties. For example, Maurya *et al.* (1988) showed that if the formal breeding system provides advanced lines closely corresponding to accepted farmer varieties, there may be a substantial uptake by farmers, a diversification of the genetic base, and, as showed by Simmonds and Talbot (1992), significant yield increases under farmers' own conditions. In Nigeria, the provision of a range of new crop varieties for traditional farming systems increased the options available to farmers, did not reduce genetic diversity, and resulted in yield increases averaging 22% (Morse and McNamara 1994).

## **Conclusions**

A departure point for the on-farm conservation of agrobiodiversity should be farmers' own activities. There is increasing evidence that on-farm management of crop genetic resources is both dynamic and open-ended. Stages of this dynamic system include access to variation, farmer experimentation to choose appropriate varieties, and the management of a dynamic portfolio of varieties. At each stage there is an important complementary role for the formal agricultural research system, in increasing access to variation, understanding and assisting with farmer experimentation and management, and conserving abandoned varieties *ex situ* for possible future use (Table 1).

There are both local and global advantages in supporting a dynamic traditional system of agrobiodiversity management. Local benefits include the productive genetic diversification of traditional agriculture; the enhanced ability of the cropping system to evolve adaptations to environmental and economic changes; and decision-making on varietal management remaining under the control of farmers. There will be two contrasting global benefits: a more rapid and cumulative evolution of useful diversity in crop plants – to benefit plant breeding but also farmers directly; and a stimulus to more productive agriculture, taking pressure off marginal and fragile ecosystems.

We feel that it is not enough to argue that the next revolution in agriculture will be based on the human minds of informal innovators (Mooney, 1992). Given the physical, environmental, socio-economic and cultural constraints under which traditional agriculture is now functioning, this is a recipe for agricultural stagnation and declining crop diversity. Despite farmers' demonstrated ability for adoption and adaptation of variation, bottlenecks in access to and management of varieties have certainly repeatedly constrained

**Table 1.** Potential of the formal research system to enhance and complement existing dynamic management of agrobiodiversity on-farm

Research topics	Farmers' activities		
	accession	experimentation	management
Varietal acquisition	+ <sup>b</sup>		
Varietal characterisation		+	
Assessment of genetic base	+	+	
Varietal evaluation and selection <sup>a</sup>		+	
Assessment of local adaptation		+	
Effect of crop breeding system		+	
Crop-wild introgression	+	+	+
Varietal demography	+	+	+
Seed production and storage			+
Transfer of technology			+

<sup>a</sup>With emphasis on resistance/tolerance to biotic (diseases and pests) and abiotic (drought, low soil fertility etc.) constraints.

<sup>b</sup>+ indicates the potential of the formal research system to enhance and complement existing farmer activities.

traditional agriculture. To overcome these constraints there is a crucial need for synergy between traditional farming and formal agricultural research in the management of agrobiodiversity.

It has been argued (Plucknett and Horne, 1992, quoting Soulé) that "Conservation biology is the biology of scarcity"; in contrast, agrobiodiversity conservation is the biology of farm productivity. Without supporting and maintaining human interest in the productive capacity of agroecosystems, genetic diversity will not survive on-farm.

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