Agroforestry Systems **61:** 183–194, 2004.

Managing biological and genetic diversity in tropical agroforestry

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Key words: Agroecosystems, Genetic diversity, Genetic management, Conservation, Tree genetic resources

Abstract

The issues of biological and genetic diversity management in agroforestry are extremely complex. This paper focuses on genetic diversity management and its implications for sustainable agroforestry systems in the tropics, and presents an analysis of the role and importance of inter- and intra-specific diversity in agroforestry. Diversity within and between tree species in traditional agroforestry systems and modern agroforestry technologies in the tropics is assessed, with a view to understanding the functional elements within them and assessing the role and place of diversity. The assessment shows that although the practice of agroforestry has been a diversity management and conservation system, research in agroforestry over time has de-emphasized the diversity element; nevertheless farmers do value diversity and do manage agroforestry from that perspective. Based on a profiling of various traditional agroforestry systems and research-developed technologies, a strong case is made for increased species- and genetic diversity, at both inter- and intra-specific levels. The review and analysis point to the need for increased awareness, training/education, partnerships and collaborative efforts in support of genetic diversity in agroforestry systems; of special importance is increased cross-disciplinary research.

> *All the flowers of all the tomorrows are in the seeds of today*
>
> – *A Chinese proverb*

Introduction

It has been well recognized that agroforestry can serve to bridge the conflict and the divide that often exists between the need for conservation of biodiversity and provision of needs of human society (McNeely and Scherr 2003). Generally, human demands for forest products or conversion of forests into agriculture or human settlement take priority over forest conservation. When tropical forests are modified due to commercial logging, illegal felling, shifting cultivation and conversion to pasture and agriculture, ecosystem structure is simplified, and biodiversity is destroyed. More attention should be given to the need to conserve biodiversity, through promotion of sustainable management and use of our genetic resources. Human activities that result in simplification and fragmentation of biodiversity need to be better managed, taking the above into consideration. But first, let us examine the basic concepts of biological and genetic diversity.

Biological and genetic diversity

Biodiversity consists of a hierarchy of definitions from the molecular level through taxa to the landscape level. The United Nations Convention on Biological Diversity (CBD) defines biodiversity as ‘the variability among living organisms from all sources including *inter alia*, terrestrial, marine and other aquatic ecosystems and ecological complexes of which they are a part; this includes diversity within species, between species and of ecosystems' (CBD 1992). The utility of the biodiversity concept, while imperfect given its all-inclusive nature (Lautenschlager 1997), gives us a framework on which to focus attention on ecological variability across a hierarchy of scales and levels of organization (Noss 1990). This definition of biodiversity recognizes three major levels: ecosystem diversity, species diversity and genetic diversity. In general, an ecosystem is 'a relatively homogeneous area of organisms interacting with their environment' that may occur in one of three forms: patches, corridors, or area of matrix (Forman 1995). Ecosystem diversity refers to the variation among ecosystems within a landscape, including the variety of ecological processes or habitats. Because ecosystems are not discrete biological entities like species and genes (Hunter et al. 1988), defining what constitutes an ecosystem may be problematic.

Species are the diversity units that ecologists are best able to count and so are frequently used as a practical measure of diversity. In addition, biodiversity can also be defined in terms of assemblage of species in space, such as in beta-diversity (species composition along an environmental gradient) and in gamma-diversity (species composition within similar habitats at different sites) (Whittaker 1965).

Genetic diversity is a fundamental component of biodiversity, forming the basis of species and ecosystem diversity. It represents all of the genetically determined differences that occur between individuals of a species in the expression of a particular trait or set of traits. There are three fundamental levels of genetic diversity: genetic variation within individuals (heterozygosity), genetic variation among individuals within a population, and genetic differences among populations. An understanding of the extent and distribution of genetic variation within and among plant populations is essential for determining appropriate genetic management strategies for utilization and conservation purposes. Genetic variation plays a critical role in the ability of populations to respond to changing environments. Therefore, it is usually a good strategy to ensure in modified or man-made ecosystems a broad genetic base to mitigate the effects of uncertainty, such as that associated with climate change or changing environments (Bawa and Dayanandan 1998). To buffer against risks, the intra- and inter-specific diversity of associated species such as N_2-fixing microsymbionts, mycorrhizal species, and pollination and seed dispersal vectors, also need to be conserved (Kindt 2002). In addition, the extent and causes of genetic variation provide the basis of any evolutionary studies (Weir 1996).

Biodiversity is not an issue only within forests, parks and other unmanaged or natural ecosystems but also within agriculture. Agricultural biodiversity includes all the components of biological diversity relevant to food and agriculture such as crops, trees, fish and livestock, and all interacting species of pollinators, symbionts, pests, parasites, predators and competitors (see also Qualset et al. 1995). Soil organisms, for instance, contribute a wide range of essential services to the sustainable function of agroecosystems through their role in nutrient cycling, soil carbon sequestration and greenhouse gas emission, their effects on soil physical structure and water regimes, and influence on plant life (e.g. N_2-fixation and interactions in the soil of pests, predators and other organisms) (Swift and Anderson 1999). Pollinators are essential for seed and fruit production and their number and diversity can profoundly affect crop production levels.

The importance of the different components of agricultural biodiversity, and the contribution they make to sustainable production, livelihoods and ecosystem health are now becoming generally recognized. Thus, farmers use diversity within and between crops, livestock, and productive tree species for risk avoidance, increased food security and income generation, as well as to optimize land use and help adapt to changing conditions (Brush 1995). Agroforestry contributes to agricultural biodiversity as it incorporates additional species (mainly trees and shrubs) into agriculture. This is based on the understanding that the diversity existing in the agricultural system prior to the introduction of the tree component is not sacrificed or compromised in any way. In this paper the basic need and importance of diversity in agricultural systems is accepted as a core part of the diversity within agroforestry. In addressing the issue of biological and genetic diversity in agroforestry, the paper places emphasis on the tree/shrub species that is introduced into the system, where the agroforestry practitioner can directly influence the overall diversity of the system.

The importance and nature of genetic diversity

Genetic diversity ensures the long-term survival of species and is therefore important for the sustainability of entire ecosystems (SGRP 2000). Genetic diversity generally arises in populations through mutations that can alter the DNA sequence and is maintained through a complex combination of factors. The important issue in the case of agroforestry systems is that these factors tend to operate differently in small and large populations. This is because most tree species in agroforestry systems generally occur at very low densities on farm. Recent studies of tree densities and germplasm sources in agroforestry systems in western and central Kenya, central Uganda and in Cameroon showed that 75% of all tree species observed on farms were represented at a density of one or less individual per hectare (Kindt 2002). For this reason, population genetics should be of particular interest to agroforesters. The challenge is to determine the 'genetic diversity window' into which tree species must fall to ensure a healthy balance of similar and dissimilar genes to avoid both inbreeding and out breeding depression.

Three biological reasons explain why genetic diversity is important in agroforestry systems. The first and perhaps the most powerful reason is to guard against the instability that can result from its absence. Genetic diversity enables evolution and adaptation of species to take place within changing environments, both in natural ecosystems and on farms. The fundamental theorem of natural selection (Fischer 1930) states that the rate of evolutionary change in a population is proportional to the amount of genetic diversity available. It is the variation between individuals of the same species that ensures that the species as a whole can adapt and change in response to natural and artificial selection pressures (Hawkes et al. 2000). Second, heterozygosity, or high genetic variation within an individual species, is positively related to fitness, i.e., the relative contribution of an individual's genotype to the next generation in context of the population gene pool (Hansson and Westerberg 2002). Trees often carry a heavy genetic load of deleterious recessive alleles (Boshier 2000). Avoidance of inbreeding is therefore particularly relevant for these organisms. Third, the 'blueprint' of life representing all the information for all the biological processes on this planet is locked in all the genetic diversity available (Meffe and Carroll 1994). Loss of this diversity would mean the loss of the potential for any improvement to meet changing human needs and end-use requirements. The additive and interactive effects of inter- and intraspecific genetic diversity determine both the resilience of agroecosystems and the evolutionary potential of species (Sauchanka 1997; SGRP 2000). This is becoming more important as we live in an increasingly changing environment with agricultural developments, global warming, pollution and desertification (CBD 2003).

An intense academic debate is going on currently about the relationship between complexity (and thus diversity) and stability of ecosystems (Loreau et al. 2001; Naeem 2002). The prevailing hypothesis is that diversity begets stability. This is based on the 'insurance hypothesis'; the impeccable logical notion that having a variety of species insures an ecosystem against a range of environmental upsets. Lack of convincing empirical evidence of the expected positive diversity–stability relationship has, however, led to controversy among ecologists (Kindt 2002). On the other hand, the niche-complementarity hypothesis based on the assumption that a community of species whose niches complement one another, shows that a multispecies system is much more efficient in using resources than an equivalent set of monocultures. Research on models with multiple species has shown that the effect of adding a species to a monoculture system, on the stability and the productivity of an ecosystem will be larger than adding the same species to a multispecies system (Tilman et al. 1997; Norberg et al. 2001). The effects of diversification will thus be largest when monoculture systems are targeted.

Traditionally, morphological and agronomic traits have been used to characterise patterns of diversity in plants. It is now known that these represent only a small proportion of the genome. Such traits are influenced by environmental factors, thus limiting their use for description of genetic relationships and variability. Molecular approaches such as the use of isozymes, and other genetic markers, which may be independent of environment and production responses, are likely to provide a more powerful method to gauge species relationships and origins (Dawson and Chamberlain 1996). McQueen (1996) confirmed that studies of molecular data, polyploidy and hybridization research, rather than morphological work, were needed to understand the complex patterns of variation in the species *Calliandra calothyrsus.* The same could be said for all other agroforestry species.

Management of genetic diversity

In the tropics, conservationists have focused their attention on the protection of natural forests and woodlands and, until recently (Schellas and Greenberg 1996), not given much attention to the widely dispersed forest patches throughout human-occupied landscapes. These patches are often critical components of a farmer's environment, being a source of products and environmental services of importance to their livelihood and welfare. As biogeographical islands, their role in maintaining biological diversity is crucial. Issues of scale are central to this role and thus in a landscape mosaic, forest patches and areas of agroforestry are potentially complementary, especially when considering the need for ecological equilibrium and population size vis à vis genetic diversity (Gajaseni et al. 1996).

Management of genetic resources aims at optimizing the use and benefits of the resources, while at the same time ensuring their continued availability for present and future generations. In agroforestry, management of diversity must be looked at in the context of people's livelihoods. Farmers plant trees in pursuit of their livelihood goals of income generation, risk management, household food security and optimal use of available land, labour and capital (Arnold and Dewees 1997). It is worth noting that, generally, diversity matches farmers' specific needs in specific situations; it is dynamic as it varies from household to household and from place to place and changes over time, and serves several purposes (Almekinders and de Boef 2000). For long-lived organisms such as trees, a better understanding of key factors determining the long-term conservation of these resources is vital and requires an interdisciplinary approach, integrating ecological, genetic and socioeconomic information (Bawa 1997). Equally important is an understanding of the social, economic and political factors that support the decision making processes of farmers, communities and other stakeholders to adopt (or not), certain land-use systems or management practices. Most of these factors are related to short-term gains that often influence long-term conservation and use options of genetic resources, especially of trees.

Conservation and management strategies of genetic resources may be grouped primarily into two domains: *in situ* and *ex situ* conservation. *In situ* conservation is defined as 'the conservation of ecosystems and natural habitats and the maintenance and recovery of viable populations of species in their natural surroundings and, in the case of domesticated or cultivated plant species, in the surroundings where they have developed their distinctive properties.' *Ex situ* conservation, on the other hand, is defined as 'the conservation of plant genetic resources for food and agriculture outside their natural habitat.' In *ex situ* conservation the genetic materials therefore need to be physically collected from areas of their origin, diversity or availability, and conserved through various mechanisms and approaches available (McNeely 2004).

Hughes (1998) discusses the merits of *in situ* (maintenance of natural population), *ex situ* (e.g., germplasm banks and botanic gardens) and *circa situm* (maintenance while in agricultural use, e.g., as hedgerow) conservation. Ruredzo and Hanson (1988) have applied in vitro techniques for conservation and multiplication of germplasm, and elimination of disease in the case of *Leucaena leucocephala*, *Erythrina brucei* and *Sesbania sesban.* Each of the different conservation approaches has its own advantages and disadvantages and should not be viewed as options but rather should be practiced as complementary approaches to conservation (Maxted et al. 1997; Hawkes et al. 2000). The complementary conservation strategy is defined as a: 'combination of different conservation actions, which together leads to an optimum sustainable use of genetic diversity existing in a target gene pool, in the present and future' (IPGRI 1993). Complementary conservation strategy should not be construed simply as a complementarity between *ex situ* and *in situ* conservation. It should be recognized that there is a continuum across the two approaches, extending from the conservation of wild plants in protected natural areas at one end of the spectrum to DNA libraries at the other end. The choice of the methods used will be dependant on many factors relating to the species biology, conservation and use objectives, human and financial resources, and legal issues. Further, since the ultimate goal of any conservation and management strategy of genetic resources is to make them available for use, the different conservation approaches should also examine complementarity between conservation aspects with the use of plant genetic resources.

Biodiversity issues in agroforestry systems and technologies

In this section, we attempt to chronicle and review various agroforestry systems and technologies, with a view to understanding the functional elements within them and assessing the role and place of diversity. Agroforestry practice in tropics and sub-tropics is probably as old as agriculture itself, and it is considered as a way of life of traditional farmers, although research on it started only about 25 years ago. In reviewing agroforestry systems, a distinction is made between the age-old traditional agroforestry systems and agroforestry technologies that have been developed through formal scientific research (Nair 1985). In addition to the above, a third category could be added – those born out of research, but later modified, adapted and further developed by farmers, as a result of their experiences and needs.

Table 1 provides an assessment of biodiversity and tree function considerations within traditional agroforestry systems. Many of these traditional systems are thought to maintain valued biological interactions and biodiversity at higher levels than some of the 'new' agroforestry technologies (Leakey 1998). In general, agroecosystems that are more diverse, more permanent, isolated, and managed with low input technology (e.g., agroforestry systems, traditional polycultures) take fuller advantage of ecological processes associated with higher biodiversity than highly simplified, input-driven and disturbed systems, i.e., modern row crops and vegetable monocultures and fruit orchards (Altieri 1995).

A study conducted by Backes (2001) on the contribution of agroforestry land use to the *in-situ* conservation of indigenous trees within a typical East African smallholder farming system in western Kenya shows how species diversity is ultimately linked to the loss of habitat diversity and landscape diversity.

Biological research in most research-developed agroforestry technologies has tended to focus primarily, on selection of particular tree species, and their management within the farming system, but genetic diversity has received only limited attention in such research (Table 2). It is observed that most agroforestry technologies are developed using only few selected tree species – often in mono-tree species systems, usually with preferred characteristics such as high-yielding, fast-growing, nitrogen-fixing ability and arboreal structure. The alley farming technology, for instance, became almost synonymous with either *Leucaena leucocephala* or with *Gliricidia sepium.* Improved fallows commonly consisted of mono-species fallows, with *Sesbania sesban*, *Crotalaria* spp. or *Tephrosia* spp. (Kwesiga et al. 1999). Such an approach results in low species diversity on farms, and makes the entire system vulnerable to attack by insects or diseases. This is especially so, if one considers that many of the species that are being promoted belong to the same botanical family of Fabaceae or Leguminosae (Rao et al. 2000).

Agroforestry is a diversity-enhancing land-use system, especially in the context of interspecies diversity, as it brings together crops, shrubs, trees and in some cases, livestock on the same piece of land. The question is how much research do we really see involving such levels of species mixtures and implications of genetic diversity, either between species or within particular species? Some research has been done using multiple tree species in agroforestry systems; however such research is only recent and embryonic.

Genetic diversity considerations in species and provenance screening for agroforestry

In the early days of agroforestry research, several studies were conducted involving a range of potential tree species for the different technologies (Heineman et al. 1997; Karachi et al. 1997), involving species screening and provenance testing (Duguma and Mollet 1997). This approach is believed to have led to selection of a few 'silver bullet' species used widely in agroforestry technologies. It is known, however, that in some cases, farmers have gone ahead of research recommendations and used multiple tree species in the technologies. For example, research into the local knowledge on interspecific diversity in western Kenya showed that farmers were maintaining and even increasing diversity in such technologies, where they could see complementarities among species (Kindt 2002).

The second type of tree screening research has been provenance testing; it involved the screening of populations within particular species. For example, in an effort to extend the geographic domain of the species capirona (*Calycophyllum spruceanum*), a priority agroforestry species in the Peruvian Amazon basin, Weber et al. (2001) carried out provenance trials to select those adapted to certain soil types and rainfall regimes. The study showed that most genetic variation was within rather than between populations, but that there were significant differences among populations, and some were more diverse than others (Weber et al. 2001).

Gliricidia sepium is another agroforestry species in which a lot of provenance screening has been done. Concerned about the low genetic diversity of the germplasm of this Central American species, which is in use in West African region as well, a research project launched in 1983, introduced new accessions of the species into the region (Sumberg 1985; Atta-Krah 1988). Through this project, different accessions and genes of *Gliricidia* were introduced into the environment. It is believed that due to its out-crossing

Table 1. Biodiversity dimensions in traditional agroforestry systems in the tropics.

Agroforestry system	Tree(s) function(s)	Biodiversity issues
Shifting cultivation or slash-and-burn	Nutrient replenishment, weed suppression, and control of pests and diseases	Long fallow periods of 15 to 20 years preserve wild species diversity (Ruthenberg 1980). Short fallow periods of 5 to 10 years due to increased human and livestock pressure on land use diminish species and functional diversity. Fallows consist of multiple species; and biological diversity, in both inter- and intra species, is intense.
Homegardens and compound farms	Sustainable production of diverse products for subsistence and markets to a limited extent, and nutrient cycling	These man-made complex systems represent high inter- and intra-species diversity involving a number of fruit, fodder and timber trees and shrubs, food crops, medicinal and other plants of economic value (Kumar and Nair 2004).
Forest gardens/agroforests	These systems practiced mostly in humid tropics resemble forests structurally and functionally.	They maintain high species diversity similar to natural forests but dominated by a few carefully managed economically valuable tree species (Kaya et al. 2002; Wiersum 2004).
Parkland systems	Trees in these traditional agrosilvopastoral systems practiced in the arid to semiarid regions of Africa provide economic products and ecological services.	Parks range from monospecific to multispecific with up to 20 tree species (Depommier et al. 1991). A variety of crops grown in association with naturally propagated trees ensure wide species diversity (Teklehaimanot 2004).
Trees on farmlands (boundary plantings, scattered trees)	Trees are primarily meant for products (e.g., poles, timber, fodder etc.) but other functions include boundary marking and shelter.	Trees are planted on farms in different niches (Nair 1993; Tejwani 1994). Diversity is more at the landscape level rather than at field level in terms of both inter- and intra-species. Recent plantings with fast growing exotic species has the tendency to reduce tree species diversity.

Table 2. Biodiversity dimensions in research-developed agroforestry technologies in the tropics.

Agroforestry technology	Tree(s) function(s)	Biodiversity issues
Alley cropping/ hedgerow intercropping/alley farming	Basic function of hedgerows is nutrient replenishment; they assume the additional functions of soil conservation on sloping lands and fodder production when livestock are integrated	Experimented and promoted mostly using mono-tree and -crop species (Kang et. al. 1985; Atta-Krah 1990; Kang et al. 1990); diversity is limited to intraspecies. Emphasis on a few tree species has raised concerns on pests and diseases (Rao et al. 2000). Tree diversity can be increased through multispecies hedgerows, and crop diversity increased by adopting intercropping in the alleys to increase efficiency of nutrient cycling.
Improved fallows or planted fallows	Soil fertility replenishment	Mostly based on mono-tree species (Buresh and Cooper 1999). Multispecies fallows combining coppicing and non-coppicing species (Chirwa et al. 2003) or species differing in leaflitter characteristics (Mafongoya et al. 1998) are likely to enhance fallow function as well as reduce risk from pests (Desaeger and Rao 2001).
Fodder banks	Year-round production of high quality fodder for stall-fed livestock	Fodder banks could be sole stands of either leguminous trees or shrubs or high yielding fodder grasses; however, systems combining trees and fodder grasses (Cooper et al. 1996), or different tree species can be cultivated to increase productivity, quality of pure grass fodders and sustainability production.
Rotational woodlots	Products (e.g., pulpwood, poles, construction material, etc.) and site enrichment and C-sequestration	Rotational woodlots have been planted using sole stands of fast growing species for short-cycle harvest (Nyadzi et al. 2003). Mixing of N_2-fixing species with non- N_2-fixing species will improve nutrient cycling and site enrichment compared with non- N_2-fixing species alone (Khanna 1998).

nature, these materials may have crossed out with other lines already existing in the region, and have therefore broadened the genetic base of the *Gliricidia* in the region.

Toky (2000) examined intraspecific variation in three important agroforestry tree species in semiarid India, viz. *Prosopis cineraria*, *Albizia lebbeck*, and *Acacia nilotica.* Based on the evaluation of eight provenances of *P. cineraria*, 12 of *A. lebbeck*, and 21 of *A. nilotica*, he reported large provenance variations in growth, fodder quality and nitrogen fixing ability (See also Puri and Nair 2004). The author opined that the wide range of intraspecific diversity has helped these species to survive much greater biotic and abiotic pressures over the past centuries. Genetic diversity within these species was also said to be of great value for rural development.

Strengthening species and genetic diversity in agroforestry research

There is a need to strengthen the inter- and intraspecific diversity dimensions in agroforestry technologies. For example, research in a system such as alley farming could involve the use of multiple tree species in the same field. Alternate hedgerows could consist of different tree species, or different provenances of the same species, or mixed species within the same hedgerow. Tree species with complementary characteristics and use that will add value to the overall system could also be explored. For example, a species with high nitrogen fixation and fast foliage decomposition rate could be combined with one that has foliage with slower decomposition rate, and better mulching characteristics (Mafongoya et al. 1998). The system as a whole therefore benefits from both the nitrogen fixation and the improved soil-water retention through improved mulching. Fast growing species could also be combined with slower growing species in order to reduce the frequency and intensity of pruning of the hedgerows. Such combinations could also stagger the pruning schedules so that farmers would not be under pressure to prune their entire field at the same time, thereby introducing an element of flexibility into the management of trees in the system.

The issues raised above for alley farming are relevant to any other agroforestry technologies. There is no reason for instance, why improved fallow technologies need to be established using only one tree species. Multiple species fallows will provide an additional level of stability and resilience and minimize the chances of pest and disease outbreaks. Recent history has examples of single species promoted on a wide scale that have then crashed as a result of insect or pest outbreaks. The damage wrought by the *Leucaena* psyllid (*Heteropsylla cubana*) is a good example of the perils of relying too much on one species or one cultivar (Rao et al. 2000). Future plantings should contain not only a range of species, but probably also a range of varieties within species. This should safeguard against major disasters due to diseases or insects (Bray 1998). A diversification strategy could investigate differences between genera or families, as introducing new species of the same genus or family may not decrease risk very much.

Even more efforts are needed in research for understanding the intraspecific diversity issues in agroforestry. Various trials have been undertaken on agroforestry species, with the aim of assessing intraspecific diversity, identifying superior lines and ultimately, broadening the genetic base for priority species; but many of these agronomic trials do not include the molecular characterization and analysis that is required for a proper assessment of genetic variation. Furthermore, no mechanisms appear to be in place to move such research beyond provenance screening on stations, to get new provenances and species into farmers' fields. Consequently, there are very few examples of successful introduction of new provenances and genetic lines released for wider scale use, as happens in the case of agricultural crops (see also Simons and Leakey 2004). Part of the reason for this may be the nature of trees and their long cycle growth. Major complexities also come in with regard to maintaining particular provenances as pure lines, due to out-crossing characteristics, and the difficulty of maintaining discrete seed production fields for the selected provenances.

In line with the need for increased genetic diversity research in agroforestry, the World Agroforestry Centre (ICRAF) has recently established a molecular characterization laboratory as part of its program on Tree Domestication. This development is laudable and has contributed in a great way to strengthen genetic diversity analysis in agroforestry species. Various studies have been undertaken or are underway for priority species for domestication in Africa and Latin America, including *Calycophyllum spruceanum, Irvingia gabonensis, Gliricidia sepium, Leucaena* species, *Prunus africana, Sesbania sesban, Uapaca kirkiana, Vitex keniensis* and *Warburgia ugandensis* (Dawson and Powell 1999; Russell et al.

1999; Lowe et al. 2000; Simons and Leakey 2004). The study on *Calycophyllum spruceanum* was for example the first systematic molecular study of genetic variation in any tree species of the Peruvian Amazon (Russell et al. 1999). These studies have focused on the partitioning of genetic diversity within and among populations. Many of these studies have confirmed the general pattern within trees that most genetic variation occurs within rather than among populations, although significant differentiation may still occur among populations.

The objective of agroforestry domestication should not be just to select super species or provenances but should include promoting genetic diversity and match intra-specific diversity to the needs of farmers, markets and diversity of environments (Simons and Leakey 2004). Different farmers could be using different provenances. Therefore on landscape basis, one could experience great diversity among a particular species that may be in use. As a result of out-crossing, it is expected that there will be gene-mixing in seed production, with a continuous creation of new hybrids and complexes that would be adding to broadening of the genetic base. Sometimes mixtures of populations will have lower fitness as genetic diversity related to local adaptation gets disrupted in mixtures (Young and Boyle 2000).

Seed systems also influence the maintenance of genetic diversity or the promotion of genetic erosion in agroforestry. The basic question is ‘from where do farmers get their seeds for agroforestry practice?’ In most cases farmers obtain seeds from other farmers who may also have harvested the original seeds from a single tree on their farm. It is possible that a particular species could spread very fast, even though it may have a very narrow genetic base. A number of authors have indicated that farmers and nursery managers frequently collect germplasm from a relatively narrow range of maternal parents (mother trees) during propagation (Weber et al. 1997; Holding and Omondi 1998). The long-term viability of on-farm tree stands depends upon a wide genetic base providing the capacity to adapt to environmental fluctuations or changing farmer requirements, such as a change in species use, planting niche or pest outbreak. Moreover, many tree species are out-breeding. They therefore require a wide genetic base to withstand potential inbreeding depression, which may result from an increase in homozygosity and subsequent expression of unfavourable recessive alleles during generations of farmer propagation (Boshier 2000; Simons 1996).

Seeds of some agroforestry trees are also obtained from established institutions such as tree seed centres in various countries. Often these institutions are acting more as seed stores, with responsibilities for seed collection, processing, storage and distribution. Most tree seed centres in Africa and other developing countries in the tropics have no facilities or capacity for genetic analysis and therefore no consideration is given to avoiding genetic erosion or promoting genetic diversity.

Do farmers value diversity in their agroforestry systems?

The fact that farmers actively plant and/or protect trees on their farms can be seen as an indicator of the fact that they appreciate trees in their farming systems. There is increasing evidence that as natural forests recede or get degraded, farmers in many situations have historically taken up planting and managing of trees on their lands to provide the needed outputs. In a study conducted in the Middle Hills of Nepal, Gilmour (1995) reported a fourfold increase in the density of trees on farms in crop-growing areas of Nepal. Similar trends have been observed in Kenya (Pretty et al. 1995) and other regions of the tropics (Murray and Bannister 2004).

Farmers generally do care for diversity in their farming systems. This is particularly so in the context of subsistence and smallholder farmers in the tropics. Farmers plant trees in pursuit of their livelihood goals of income generation, risk management, household food security and optimal use of available land, labour and capital (Arnold and Dewees 1997). The diversity of plant and animal species maintained in traditional farming systems over many centuries, and the knowledge associated with managing these resources, constitute key assets of the rural poor in Africa (Brush 1999). In marginal and difficult farming conditions, these assets and practices are especially important. Diversity management can constitute a central part of the livelihood management strategies of farmers (particularly pastoralists) and communities in different production systems throughout Africa (Rege et al. 2003).

It needs to be stressed, however, that most farmers will not maintain or promote diversity just for the sake of it. Nor will they readily keep diversity solely on grounds of long-term ‘stability’ of the system or the need to conserve particular species or genetic types for future generations. Diversity must be useful to farmers for them to decide to keep and conserve it. Species that may be of neither immediate nor perceived future benefit are unlikely to be conserved by farmers in their field. One possibility for conserving tree species diversity may be to reward farmers for the biodiversity conservation service that they provide to the global community. This may be especially relevant for species that cannot be conserved *ex situ* – for instance species with recalcitrant seed that cannot maintain viability for long-term periods, or species that require conservation of co-evolved organisms that cannot be conserved *ex situ.* The question always remains as to who pays for the cost of such conservation efforts?

Institutional and policy aspects of genetic diversity in agroforestry

National gene banks and tree-seed centers are often the institutions with lead responsibility for agrobiodiversity conservation, while the agriculture research institutions are responsible for technology development and crop improvement research. One of the biggest weaknesses in agricultural research and development in most tropical countries is the inadequate interaction between the national institutions responsible for agriculture research and conservation and management of genetic resources. Without such a partnership, germplasm may be collected and stored in gene banks, but may not be put to productive and sustainable use for the enhancement of agriculture and food security.

Agricultural scientists are also not adequately familiar with the issues of biodiversity and agrobiodiversity; fewer still may have skills for genetic diversity analysis. Genetic diversity issues and skills need to be built into different aspects and levels of agricultural training. It is therefore important that universities and other institutions of training are fully involved in this work. More graduates need to be trained in plant genetic resources and in genetic diversity, particularly of tree crops. Curriculum development should also aim at incorporation of genetic diversity elements into standard agriculture and natural resources training.

Past agroforestry research was dominated by scientists dealing with crops, forestry, soils or databases and it suffered from too little insight from social scientists, anthropologists and economists. As a result, we ended up knowing more about the biology of agroforestry (crops, trees, water and soils), and less or little about the driving forces of what people preferred, whether in existing farming systems or in terms of potential new crop plants. Agroforestry is not alone in having this problem – it applies to the conservation field as well. Gradually, interdisciplinary team research – incorporating local farmers and innovative methods – is improving the recognition and use of local knowledge within agroforestry (http://www.rbgkew.org.uk/peopleplants/handbook/handbook5/interviews.htm).

Policy studies in agricultural research should include genetic resources policies and how they impact on biodiversity conservation and use. Agricultural scientists must be made aware of the policy and legislation aspects of genetic resources, and be encouraged to be involved in the development of policies that will promote the proper use, management and legal aspects of genetic resources. Essential issues in this regard include those of access of genetic resources, benefit sharing, intellectual property rights, farmers' rights, and documentation and capacity development. Agriculture and natural resources scientists also need to be fully informed on global policy conventions and instruments on genetic resources, and be able to offer technical advice to governments in this area.

Future research directions

Traditional agroforestry systems are rich in biological and genetic diversity. Modern agroforestry technologies developed through research have not adequately addressed the genetic diversity issue. Increased efforts should be made to promote diversification of species in agroforestry technology development. Methods should be explored of incorporating the element of risk in promoting species in agroforestry technologies, whereby risks and benefits of monoculture technologies should be contrasted with those of mixed species technologies.

There should be increased efforts at studying the intraspecific diversity in agroforestry species, and for expansion of diversity in this domain. The use of molecular techniques for characterization and management of diversity in agroforestry needs to be encouraged. In most species and provenance screening trials conducted for agroforestry, the emphasis appears to have been on identifying the most suitable species or provenances, according to a particular defined set of criteria, rather than to explore the existing diversity and finding mechanisms for the use of the diversity. There is need to review agroforestry research objectives, and integrate genetic diversity concerns, to strengthen sustainability and stability of production systems.

The knowledge base in genetic resources management and conservation and in genetic diversity analysis needs to be broadened. This could be done through training and capacity development, and through the incorporation of genetic diversity modules into educational program in universities and colleges, even in primary and secondary schools. Agricultural extension officers should also be trained in the importance of genetic diversity, and how it can be managed through on-farm seed systems, tree domestication and other agroforestry approaches.

It follows, therefore, that a major requirement to obtain the full benefit of agroforestry is the incorporation of diversity and conservation elements into it. This will require improved levels of knowledge of the biodiversity in production systems, of its functions and benefits, of the consequences of changes in different elements, and of the ways in which agroforestry supports conservation of different components of biodiversity (e.g., crops, livestock, trees, soil micro-organisms, pollinators, etc.). Research scientists in agroforestry, agriculture, environmental sciences, etc. are challenged and encouraged to be fully involved in genetic diversity analysis and its links with agriculture.

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