‘Diversity makes a difference’

Farmers managing inter- and intra-specific tree species diversity in Meru Kenya

Promotor:	Prof. Dr. Ir. LJG van der Maesen Hoogleraar in de Plantentaxonomie Wageningen Universiteit, Nederland
Co-Promotors:	Dr. IK Dawson Tree Genetic Resource Specialist World Agroforestry Centre (ICRAF), Nairobi, Kenya
	Dr. AJ Simons Team leader Tree Domestication World Agroforestry Centre (ICRAF), Nairobi, Kenya

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Prof. Dr. Ir. EA Goewie	Wageningen Universiteit

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Ard G Lengkeek

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Summary

Farmers plant trees in pursuit of their livelihood goals of income generation, risk management, household food security and optimum use of available land, labour and capital. Trees also play a crucial role in the cultural life of people. The many products, services and roles needed by people to be fulfilled by trees cannot be provided by only a few species. This research project was conceived to address the problem of Meru farmers in central Kenya relying heavily on a single tree species, *Grevillea robusta* A. Cunn. (Proteaceae). This Australian species is used mainly for construction, firewood and as a boundary marker.

With the disappearance of natural forest around Meru, Kenya, this over-reliance increasingly poses economic and environmental risks. Building on earlier research, this project started in 1998. To ensure that farmers would benefit maximally, a research approach that was participatory and constructivist was chosen. Initial research questions therefore had to be both broad and flexible. How can tree species improve farmers' livelihood goals? As a secondary question, how can the use and conservation (in the face of continued natural deforestation) of tree species in the region be improved? Given an over-reliance on *Grevillea robusta*, my starting point was to undertake on farm tree species trials in Meru to identify a number of suitable species for diversification purposes. Additionally a general nursery survey in Meru was conducted to improve the understanding of nursery practices and delivery pathways of tree species to the farms.

Chapter 1 showed that the project had a flexibility to learn of the continuous input from the farmers, extension workers and scientists thereby shaping a research activity. Starting as a species preference trial, the research project developed into an analysis of the opportunities and constraints of domestication of the total tree component in the landscape of Meru district.
In Chapter 2 the various research activities that evolved in the process (Chapter 1) of carrying out the project are discussed. Results were triangulated, giving a detailed analysis of the Meru farmers' perception of tree species diversity and tree diversity management in general. Concerns for losses of local knowledge and biodiversity (including genetic erosion) were observed.
Chapter 3 showed that many findings of the Meru case study (Chapter 2) are supported by other case studies from Cameroon, Western Kenya and Uganda. This larger data set allowed for more thorough statistical analyses and provides options for diversification. Again, concerns for genetic erosion were observed.
Chapter 4 addressed some of the constraints identified in Chapters 2 and 3; with low densities and a limited amount of germplasm from outside the farming community, some species may be vulnerable for inbreeding and genetic erosion in the landscape.
Chapter 5 surveyed the current practices and knowledge of on-farm nurseries in Meru. Nurseries are an important part of future on-farm tree cover. This study supported the results about knowledge losses and biodiversity losses, in particular the vulnerability for genetic erosion.
Chapter 6 expanded on the results of Chapter 5 regarding seed collection practices. The research was extended by additional surveys from Arusha in Tanzania, Nairobi in Kenya, Kabale in Uganda and Mukono in Uganda. These showed that current seed collection procedures practiced by nursery managers provide a clear bottleneck in delivering genetic diversity to farmers.
Chapter 7 provides an in-depth case study of a single species (*Vitex fischeri*), in order to quantify the anthropogenic effect on the domestication process as identified in Chapters 2 to 6.

Most research activities described in this book were conducted in Meru. The inclusion of data from other locations provided a greater quantitative basis to address the specific research questions highlighted (Chapters 3, 6 & 7). Another reason to include data from other locations was because the inventory and nursery survey were of different geographic scale.

This study observed a limited access to species, a risk of losing knowledge and vulnerability for genetic erosion. These factors likely cause short-term productivity and long-term stability losses in agroforest ecosystems and hamper farmers from making decisions to optimise their livelihood goals. It also erodes the biodiversity on which farmers depend. The best option to prevent this degradation of agroforest ecosystems is to assist farmers in diversifying the farm in terms of species as well as species evenness through increasing the number of trees of rare species, or through a substitution of the more common species. Farmers, extension workers and scientists active in tree domestication could focus on improving access to germplasm of a wider range of species. Addressing access to germplasm and knowledge simultaneously will allow farmers to decide for themselves, instead of research and extension only concentrating on a few 'high priority' species.

Tree species preferences are largely determined by knowledge and this may lead to a bias for common species. Therefore, species preference lists must be interpreted with great caution.

Using two common species, *Vitex fischeri* and *Prunus africana* (not in this thesis), as examples, no indications were found that genetic erosion has as of yet occurred in the domestication process. The on-farm stands are still suitable as seed source and farmers can continue accessing their own germplasm. The species, although both classified as locally vulnerable on the CITES list, are conserved through their use.

Because of the large number of species concerned, interventions in the genetic resource management of the species diversity on farm should be facilitating and training farmers in accessing their own germplasm, preferably from other farms not within the near vicinity. For indigenous species sources within the same agro-ecological zone are preferred to ensure productivity and conserve the genetic integrity of the local populations.

An efficient means to support the use and conservation of tree biodiversity is through local interactions and including the poor.

Samenvatting

‘Variatie maakt een verschil’ Hoe boeren in Meru, Kenia diversiteit binnen en tussen boomsoorten beheren

Boeren planten bomen voor hun levensonderhoud, zoals het verschaffen van inkomen, voor risico spreiding en voedselzekerheid, gebruik makend van het hun beschikbare land, arbeid en kapitaal. Bomen hebben ook een belangrijke culturele waarde in het leven van mensen. De vele producten, diensten en gebruiken waar bomen in voorzien, kunnen niet door slechts enkele soorten geleverd worden. Dit onderzoek project is opgezet omdat de boeren uit Meru erg afhankelijk zijn van één enkele boomsoort, *Grevillea robusta* A. Cunn. (Proteaceae), een van oorsprong Australische soort, welke voornamelijk gebruikt wordt voor constructie, brandhout en grensmarkering.

Met het verdwijnen van het natuurlijk bos op Mount Kenya zijn de boeren te afhankelijk van deze soort, met economische en biologische risico’s tot gevolg. Dit onderzoek vervolgde in 1998 bestaand onderzoek. Om er zeker van te zijn dat de boeren maximaal rendement uit het onderzoek konden halen was de methodiek participatorisch (samen met boeren) en constructivistisch (opbouwende gedurende de loop van het onderzoek). De eerste onderzoeksvragen moesten daarom breed en flexibel zijn: hoe kunnen boomsoorten bijdragen aan het optimaliseren van het levensonderhoud van boeren? Op het tweede plan; hoe kan het gebruik en de conservering (gezien de ontbossing) van boomsoorten worden verbeterd? Gegeven de te grote afhankelijkheid van *Grevillea robusta*, was het uitgangspunt een boomsoorten geschiktheid proef op boerderijen in Meru, met als doel soorten te identificeren voor diversificatie. Tevens werd een inventarisatie naar boomkwekerijen uitgevoerd, om de praktijken van boomkwekers en de aanvoer van bomen naar de boerderij in kaart te brengen.

Hoofdstuk 1 gaat over de flexibiliteit waardoor dit onderzoek kon evolueren. Door de continue input van boeren, voorlichtingswerkers en wetenschappelijk onderzoekers veranderde dit project van een soorten preferentie test tot een analyse van de mogelijkheden en onmogelijkheden van een domesticatie van de totale bomen diversiteit in Meru Kenia.
Hoofdstuk 2 omschrijft de verschillende activiteiten en uitkomsten die ontstonden in het onderzoek proces. Dit gaf de mogelijkheid om de resultaten van de verschillende onderzoeken te koppelen, zodat een gedetailleerde analyse van de perceptie van boeren kon worden uitgevoerd ten opzichte van boomsoortendiversiteit en beheer van diversiteit in het algemeen. Verontrustend was het dreigende verlies van locale kennis en biodiversiteit.
Hoofdstuk 3 voegt resultaten toe van studies uit Kameroen, West Kenia en Oeganda en ondersteunt daarmee de resultaten uit hoofdstuk 2. Deze uitgebreide data leverden een meer gedetailleerde statistische analyse met diversificatie als doel. Weer bleek de dreiging van het voorkomen van genetische erosie.
Hoofdstuk 4 behandelt enkele onderwerpen die in hoofdstuk 2 en 3 verontrustend bleken. Met lage dichtheden en weinig instroom van zaad of pollen van buiten de boeren gemeenschap, kunnen enkele soorten vatbaar zijn voor inteelt en genetische erosie.
Hoofdstuk 5 is een inventaris van de kennis en praktijken op boomkwekerijen op de boerderij. Een belangrijke hoeveelheid bomen op de boerderijen stamt uit deze kwekerijen. Hier ziet men eveneens een risico van kennis verlies over bomen bij boeren en een verlies aan biodiversiteit, met name door genetische erosie.
Hoofdstuk 6 bouwt verder op de resultaten van hoofdstuk 5 ten aanzien van het oogsten van zaad voor vermeerderingsdoeleinden. Met resultaten van kwekerijen uit Arusha Tanzania, Nairobi Kenia, Kabale Oeganda and Mukono Oeganda, laat dit hoofdstuk zien dat zaadoogst

op kwekerijen door boomkwekers als een ‘flessenhals’ fungeert voor het doorgeven van de genetische variatie aan boeren.
Hoofdstuk 7 is een case studie van een enkele soort, *Vitex fischeri,* om de effecten van domesticatie te kwantificeren, zoals aangegeven in hoofdstuk 2 tot en met 6.

De meeste activiteiten vonden plaats in Meru. Door gebruik te maken van data uit andere locaties (hoofdstuk 3, 6 & 7) was het mogelijk ook een meer gekwantificeerde analyse toe te passen. Een andere reden voor deze toevoeging was het ondervangen van de geografische ongelijkheid tussen de kwekerijen en de boerderijen: de kwekerijen zijn over een groter gebied geïnventariseerd dan de boerderijen.

Wij constateerden een beperkte toegang tot soorten, een risico van kennis verlies en genetische erosie. Deze factoren kunnen op korte termijn productie verlies en op lange termijn stabiliteitsverlies in agroforestry systemen veroorzaken. Dat werkt boeren weer tegen om de beslissingen te maken die hun levensonderhoud kunnen optimaliseren. Bovendien erodeert de biodiversiteit waar boeren zo afhankelijk van zijn. De beste optie om dit verlies te voorkomen is door boeren te assisteren in de diversificatie van hun boerderij, diversificatie in zowel soorten als in gelijkheid van soortenverdeling (proportionele gelijkheid). Dit kan door een toename van aantallen bomen die nu weinig op de boerderij voorkomen, of door een vervanging van de veel voorkomende soorten door deze minder voorkomende soorten. Boeren, voorlichtingswerkers en onderzoekers zouden daarom hun domesticatie programma aan kunnen passen om een grotere beschikbaarheid van zaad van deze en vele andere soorten te bewerkstelligen. De vergroting van toegankelijkheid van dit zaad alsmede toegang tot kennis, zal boeren beter in staat stellen hun eigen beslissingen te nemen, in plaats van dat onderzoek en extensie zich beperken tot een paar zogenaamde ‘prioriteitssoorten’.

Voorkeur voor boomsoorten wordt voor een groot gedeelte bepaald door de kennis van deze soorten en dat leidt tot een vooringenomenheid voor de bekendere, veel voorkomende soorten. Voorkeurslijsten moeten daarom met de nodige voorzichtigheid worden geïnterpreteerd.

Met *Vitex fischeri* en *Prunus africana* (niet dit proefschrift) als voorbeeld, zijn er geen indicaties gevonden dat domesticatie van deze soorten leidt tot een vermindering van de genetische variatie. De populaties van deze soorten (als kwetsbaar geclassificeerd op de CITES lijsten) op de boerderijen kunnen daarom nog steeds voor zaadoogst worden gebruikt, boeren kunnen hun eigen zaden blijven gebruiken.

Vanwege de vele soorten zouden de ingrepen in het beheer van genetische bronnen van deze diverse soorten op de boerderij zich kunnen richten op het faciliteren en trainen van boeren om hun eigen zaden te verzamelen, liefst van andere boerderijen die niet in de directe omgeving van de eigen boerderij. Voor inheemse soorten is gebruik van zaad uit dezelfde agro-ecologische zone beter, om zo de productie en genetische integriteit van de locale populaties te waarborgen.

Een efficiënte methode om het gebruik en de conservering van de diversiteit van boompopulaties en boomsoorten op de boerderijen te bevorderen is door ondersteuning van locale onderlinge samenwerking met participatie van de armere boeren.

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General introduction

Tree domestication in agroforestry

Crop domestication is believed to have started around 10 000 (Diamond 1997) years ago (the Neolitic Revolution) when humans began the deliberate selection of desired variants in cereals, cucurbits and pulses. In contrast, most tree species are far more recent subjects of selection than agricultural crops, since they did not need to be cultivated as their products could be relatively easily collected from trees in the natural forest. Due to a declining natural forest base, trees were introduced onto agricultural land. The practice of growing trees on farms, commonly known as agroforestry, will continue to increase in order to produce more products, services and income for farmers.

Agroforestry has been defined as a dynamic, ecologically based, natural resource management system that, through the integration of trees into farm and rangeland, diversifies and sustains smallholder production for increased social, economic and environmental benefits (Leakey 1996). 'Trees' in agroforestry comprise all woody perennials, that is all trees, shrubs and lianas growing over 1.5 meters tall. Planting trees (and other crops) remains a trade-off: if a species product or service is more beneficial than the growing of other species, in a particular farm niche with a certain amount of labour, the farmer will plant that species, which includes sustainability and risk management. This may not be practised by weighing the characteristics of every species, but this is farmers' practice that has evolved over many generations, based on indigenous or local knowledge as well as 'new' knowledge. Farmers will only plant species if benefits are expected, therefore information on the species is important for farmers to optimise farm production.

Optimum and sustainable farm productivity requires quality germplasm for farmers, such as species diversity, species choice and selected cultivars or provenances. In order to achieve this, both farmers and researchers domesticate trees. Domestication was generally defined as the transformation into forms that are useful to humans and involves selective breeding, with consequent reduction of the genepool of the species involved (Hudson 1992). More scientifically generally accepted, however, is to use the term domestication as a dynamic term referring to a process rather than a state of existence (Harris 1996). Different interpretations of the concept of plant domestication will still prevail. This is not surprising in view of the fact that scientist from diverse disciplinarily backgrounds, ranging from botany to anthropology, geography and agricultural sciences have been involved in describing the process of plant domestication (Wiersum 1997). The ICRAF tree domestication programme's definition of tree domestication is also more dynamic and process oriented: domesticating agroforestry trees involves an accelerated and human induced evolution to bring species into wider cultivation through a farmer-driven and market-led process. This is a science-based and iterative procedure involving the identification, production, management, and adoption of high quality germplasm. High quality germplasm in agroforestry incorporates dimensions of productivity, fitness of purpose, viability and diversity. Strategies for individual species vary according to their functional use, biology, management alternatives and target environments. Domestication can occur at any point along the continuum from the wild to the genetically transformed state. The intensity of domestication activities warranted for a single species will be dictated by a combination of biological, scientific, policy, economic and social factors. In tandem with species strategies are approaches to domesticate landscapes by investigating and modifying the uses, values, inter- and intra-specific diversity, ecological functions, numbers and niches of both planted and naturally regenerated trees (ICRAF 2000).

Tree domestication is gaining importance since farmers increasingly use and conserve many trees and tree species. In this research alone, the 40 farmers mentioned as benefits (Appendix 7 to 9):

- food: fruit, nuts, vegetables, fat, soup and drinks, as well as food additives, such as stimulants, spices, ferments, meat tenderisers, fruit ripeners, colouring and wrapping;
- medicines: against a wide range of diseases;
- wood for timber, firewood, charcoal, poles, construction, furniture, beehives, mortars, wedges, tools and tool handles;
- cash: stimulants (mainly coffee), fruit/nuts and wood;
- animal requirements: food, fodder, bee fodder and animal medicines;
- various other uses: ropes, weaving and thatching material, decorations, tannins, gums, animal traps, insecticides and fungicides, etc.;
- services: for erosion control, weed control, plant supports, windbreaks, soil fertility (sources of compost, N-fixing), fencing/ boundary markers, shade, to attract rain, ornamentals and status symbols; and
- rituals, cultural life and emotional well-being.

Although most tree species provide several products and services at different times, a considerable number of species and genotypes/cultivars are necessary to provide the multiple uses needed by individual farmers. With decreasing forest cover, farmers increasingly manage the biological diversity on their farms.

Biodiversity and tree domestication

The CBD in Rio (1992) defines biodiversity as the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part; this includes diversity within species, between species and of ecosystems. In short, biodiversity is generally split up according to genes, species and ecosystems, including the processes that form and sustain them all. Biodiversity can be broken down genetically as well: into base sequence, gene, genome, gene pool, genocoenosis, genosphere, whereby the latter is the product of the co-evolution of species (Sauchanka 1997). Non-living components are often considered to be part of biological diversity as well.

Biodiversity is an active phenomenon - it is ever changing over time and is not usually in equilibrium as all its components fluctuate in number; it does not reflect any status quo, is not frozen and does not have a memory. On one hand, biodiversity is a buffer against environmental changes and disturbances and on the other hand, it adapts to changes through selection. The prevailing view in ecology is that diverse ecosystems consisting of viable components are more resilient than ecosystems with few species (SGRP 2000); (i) the more species, the greater the likelihood that some organisms exist that are tolerant towards changing conditions; (ii) the asynchronicity of species' responses to environmental conditions (the basis for the diversity effects) increase resilience of ecosystems. Likewise, Lovelock (1995) describes ecosystem diversity as the survival mechanism of the entire earth.

'Tree domestication on the landscape level' is a concept recently developed at ICRAF (Kindt 2002; Simons et al 2000; this thesis). In contrast to domestication of agroforestry species aimed at using the diversity present in individual species - for instance selection, domestication of the landscape proposes using the diversity of the tree component in agroecosystems. This includes a number of factors, such as species diversity, the origin of the germplasm, the number of trees in the landscape, the value of the tree, their farm niche, their functional uses and, probably most important, the farmer perception of tree species and diversity management. Farmers, as well as scientists and extension workers, have four possible interventions on the tree component on farm; these are 'replacement' of a tree by a tree of the same species, 'substitution' of a tree of another species, 'addition' of new trees and 'modifications in tree management' (Simons et al. 2000; Chapter 4). These four options allow farmers to address their needs for products, services and risk management, farmers can use, maintain and integrate tree species diversity on their farms in a productive and sustainable manner.

These 'man-made' ecosystems, such as agroforests, do not in principle differ from natural ecosystems. Natural ecosystems use diversity to maintain their function; likewise, the use and conservation of agricultural and agroforestry biodiversity is widely practised as a risk management tool by especially poor, small-scale farmers (Guarino *et al*. 1997; Tapia & De la Torre 1998; Kindt 2002; Lengkeek this thesis). The poor are therefore dependent on extant biological diversity, and are hence the ones who suffer first in cases of biodiversity loss (CBD 2003).

Indigenous and local knowledge

Encouraging the interaction between farmers' research and formal research brings about extra expertise because participatory research, the process by which this interaction can take place, can draw on both indigenous and scientific knowledge systems (Martin & Sherington 1996). An effective integration of indigenous or local knowledge (ILK) in research projects is essential because: (i) it assists in local empowerment and increases self-sufficiency and self-determination, and (ii) it gives valuable information about the local environment and how to effectively manage its natural resources. Through empowerment and a better understanding of the local situation, the farmer and the scientist are more capable of setting proper research objectives; also, avoiding options that farmers have already rejected may save resources. ILK is creative and experimental, constantly incorporating outside influences and inside innovations to meet new conditions (Langill 2001). This characteristic also creates risks as ILK can quickly be lost, for instance due to the insensitivity of institutionally organised scientists. Nevertheless, Tripp (1989) provides a cautionary note on the utility of ILK, by enumerating cases of 'doing the right thing for the wrong reason' - farmers practices can be more valuable than their theories.

Obviously, no two individual farmers have the same level or diversity of ILK; apart from their personal differences, their knowledge base is likely to have been influenced by differences in perceived opportunities and constraints. Frequently cited reasons for group differences are socio-economic factors, gender and age. For example, wealthier individuals are generally better able to generate ILK, incorporate outside knowledge into ILK and communicate their knowledge to scientists (Farrington & Martin 1987). Whereas in agroforestry, men are usually keen to have large trees for the sale of timber, to manage and introduce new species and to exercise all other kinds of decision management, women are more interested in the use and harvesting of other tree products (FAO 1996). Finally, older people are more likely to know more about the medicinal uses of species, and children to know more about the location and production of fruit trees. With regard to expertise, however, different levels go beyond the above frequently cited characteristics. For example, some farmers are known to be able to astutely distinguish between cultivars in crops for particular farming contexts (Sperling & Scheidegger 1995); likewise, some ATDAM (association of Ameru Traditional Doctors of African Medicine) members use 300 plant species whereas others only use 25 species (Lengkeek unpublished data). Because of the diverse knowledge bases that exist, farmers can and do share ideas; however, there is often no time and no place to exchange the knowledge (FAO 1996). On the other hand, there are some types of knowledge that farmers prefer to keep private, a factor especially valid for the traditional medicinal uses of plants (ATDAM personal communication).

Working with a farming 'community' does not guarantee that the community needs are served; underestimating existing differences and incomplete knowledge can distort the fundamentals of any participatory research project. To obtain greater efficiency in getting the farmers' problems addressed and in empowering the resource-limited farmers there should be a much greater scope for informal research methods. A research agenda should be as flexible as possible; it is an ongoing interactive process that builds on a continuous interchange of knowledge between farmers, extension workers and scientists.

Study area

The research for this study was conducted in the Meru Central district, on the slopes of Mount Kenya (Figure 1), in collaboration with three farming groups and with the Meru office of the Ministry of Agriculture.

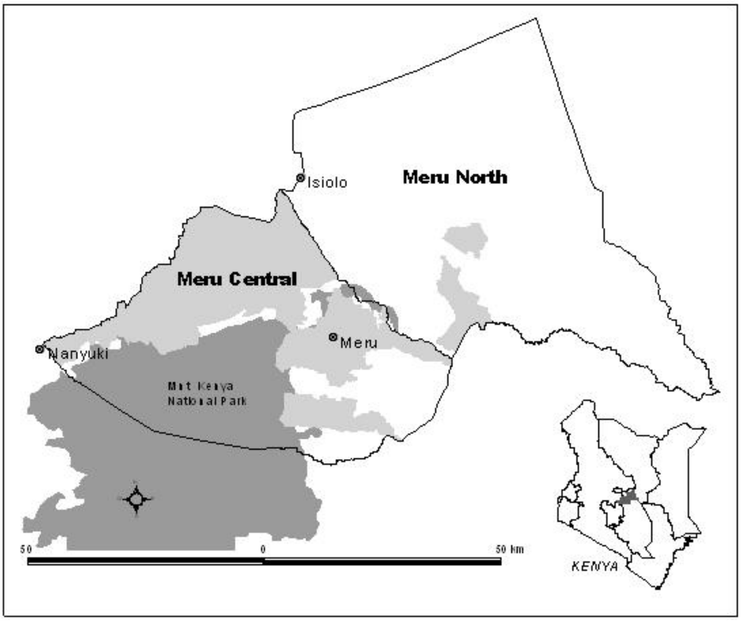

Figure 1: Map of Kenya showing Meru Central District

Meru Central is one of 13 districts in the Eastern Province, Kenya. It lies between latitudes 1° 30' South and 0° 35' North and between longitudes 30°20' and 39°5' East (Pelley et al. 1985) and covers an area of about 3 012 square kilometres, with over 705 square kilometres of potential livestock and agricultural farming. It is bordered on the north and northeast by Isiolo District and Meru North, Laikipia to the west, Meru South to the south and Tharaka to the east. The topography ranges from the flat lands of Giaki/Gaitu and lower Nkuene, Igoki and Abogeta at 1 400 m above sea level to Mt Kenya, at 5 200 m above sea level. Most agro-ecological zones found in Kenya also occur in Meru Central (Pelley et al. 1985). These include: the pyrethrum/dairy zone, tea/dairy zone, coffee zone, marginal coffee zone, marginal cotton zone, sorghum/millet zone and ranching zone.

Soils in Meru are moderately to highly fertile with higher fertility generally occurring in the middle altitudes (Jaetzold & Schmidt 1983). The climate and rainfall are greatly influenced by Mt Kenya and the Nyambene Hills. The short rains occur between March and May and the long rains from October to December (Pelley et al. 1985). Rainfall varies from 2 600 mm annually in the upper highlands of Mt. Kenya to 500 mm in the lower dry parts of the district. To the northern side of Mt. Kenya, rainfall is scattered because of the mountain's rain shadow. This is mainly in the Timau Division, extending into Laikipia District. Average annual temperatures range from 10 ºC around Mt Kenya area, to 30 ºC in the lower parts of the district (MoA 2000a).

Meru Central has a population of 500 000; over 80 % of the people (ca 90 000 families) live in the rural areas. The district capital is Meru town.

Agriculture and Agroforestry

Meru District is one of the districts with high agricultural potential in Kenya. Successful and productive rainfed agriculture, however, is limited to a comparatively small part, but the output is one of the highest in the country (Jaetzold & Schmidt 1983). The farming community in Meru District comprises of ca 100 large-scale farms (> 20 ha) and ca 90 000 small-scale farms. The average farm size is about 2 ha (MoA 2000a). The Meru people predominantly practise mixed farming, i.e. crop and tree cultivation with animal husbandry. Meru farmers are well known for their tree planting culture (MoA 2000a). Farmer John Kanyamu explained that when settling in, other tribes threatened the Meru, but by planting trees around homesteads, the Meru were able to hide in the forest. Tree planting has stayed with them ever since.

Maize, beans, potatoes, sorghum, pigeonpeas, green grams, cassava, yams, arrowroots and millet are used as staple crops. Oil crops produced in the area include sunflower, cotton, groundnuts and soybeans (MoA 2000a). The most important cash crops include coffee, tea, tobacco, cotton, miraa / qat (*Catha edulis*) and macadamia nuts, showing the importance of woody perennials in Meru.

The most widely planted tree species in Meru is *Grevillea robusta* A. Cunn. Proteaceae (e.g. Betser et al. 2000; MoA 2000b), excluding coffee, tea and the species planted in hedges. *Grevillea robusta* was introduced from Australia in East Africa from around 1910 (Harwood 1992). Initially introduced as a shade tree in tea and coffee plantations, it is a popular agroforestry tree species used for timber/construction, firewood and boundary marker. Other high value tree species are the indigenous *Cordia africana* and *Vitex fischeri* (syn. *Vitex keniensis*). Farmers planted these timber and firewood species mainly for their own use or local markets, though timber marketing efforts and firewood shortages suffered by tea companies have recently increased the options for sales (Holding & Carsan 2001). The sale of medicinal plants is still in its infancy.

Forests

There are six gazetted forests in Meru: Mt. Kenya, Ngare Ndare, Upper and Lower Imenti, Timau and Kiangu, covering a total area of about 87 000 ha. The main species in the gazetted forest include: *Brachylaena* sp., *Calodendrum capense, Catha edulis, Cordia africana, Croton macrostachyus, Croton megalocarpus, Ficus thonningii, Hagenia abyssinica,* *Juniperus procera, Lovoa swynnertonii, Markhamia lutea, Milicia excelsa, Ocotea usambarensis, Olea capensis, Olea europaea* ssp. *africana, Olea welwitschii, Premna maxima, Prunus africana* and *Vitex fischeri* (KWS 1999). The plantation forests in Meru cover a total area of about 4 300 ha and are situated at Mucheene, Marania, Ontullili and Ruthumbi. They consist of exotic species: *Cupressus lusitanica*, *Pinus patula, Pinus radiata* and *Eucalyptus* species. The native species of *Vitex fischeri* and *Cordia africana* have also been planted there (Francis Ndiege Meru forest department personal communication 2000). Large-scale charcoal production and illegal logging have caused a heavy impact on the natural forests. Some of the most wanted species for this purpose include: *Ocotea usambarensis, Juniperus procera, Olea europaea* ssp. *africana* and *Hagenia abyssinica* (KWS 1999).

Research conducted

This thesis focuses on the opportunities and constraints of the domestication of the total tree component within the landscape of Meru, Kenya. The objective is to address farmers' needs, thereby conserving the biological diversity by bringing it onto the farm. Meru farmers rely heavily on *Grevillea robusta,* and with the disappearance of the natural forest on Mount Kenya (KWS 1999) this is increasingly posing economic and environmental risks. Building on earlier results (Betser *et al.* 2000; NARP 2000), a project was begun in 1998 to address this over-reliance, and to find alternatives by testing various tree species with farmers on the farms. To ensure that farmers would benefit most, the research approach was participatory, keeping in mind possible analytical research activities that could contribute to the objective. The project had an in-built flexibility in order to be able to learn from the continuous input from the farmers, extension workers and scientists, thereby shaping the research activities: 'designing the program as we go' (Binswanger 2000).

Given the over reliance on *Grevillea robusta,* the starting point was to have on farm tree species trials in Meru to identify a number of suitable species for diversification purposes. Although diversity is often equated with richness, it is a function of the number and the evenness in distribution (Magurran 1988; Purvis & Hector 2000). Additionally a general nursery survey in Meru was conducted to improve understanding the delivery pathways of species to the farms.

Chapter 1 consists of a detailed description of the set up and accomplishments of this participatory research, a collaborative effort involving 40 Meru farmers, the Meru Ministry of Agriculture and ICRAF. This case study focuses on the whole research process: what was the initial plan, how and why did it evolve over time, and how was it finally conducted.

Chapter 2 describes the outcomes of the research. The research questions consist of the 'what', 'why' and 'how much' tree diversity farmers want on farm, including the opportunities and constraints. The research activities included a species planting trial, a species preference exercise, questionnaires, a census of the total on-farm tree cover and concludes with an evaluation of all the activities. By triangulating the various results, it gives a detailed analysis of farmer perception of tree species diversity and tree diversity management in general.

Chapter 3 takes the Meru results to a geographically larger perspective, by comparing them with data from Cameroon, Western Kenya and Uganda. The primary objective of the surveys was to explore options for diversification of farms. The larger data set allowed for more thorough statistical analyses, using diversity profiles for all species and species belonging to the dominant on-farm niches and use groups in each landscape. This then enabled a diversification process in which use groups with low diversity could be targeted.

Chapter 4 builds on the constraints identified in Chapters 2 and 3: These constraints are that tree species are unevenly distributed over the landscape and occur in low densities. Due to these low densities as well as the absence of seed from outside the farming community, the research question is: what can be done to address the vulnerability for species to inbreeding and genetic erosion in the landscape.

Chapter 5 surveys the current knowledge of on-farm nurseries in Meru. For a significant part, the future on-farm tree cover begins in the nurseries; therefore, determining the existing opportunities and gaps is vital for a successful diversification of the agricultural landscape. It is a broad fact finding survey, however this chapter focuses in particular on mapping the understanding and approaches of farmers of tree propagation and germplasm management, especially selection, access and sourcing of germplasm.

Chapter 6 was triggered by results from Chapter 5 on seed collection practices and germplasm pathways. The research was extended by additional surveys from Arusha (Tanzania), Nairobi (Kenya), Kabale near Bwindi Impenetrable Forest (Uganda) and Mukono near Kampala (Uganda). Surveying the current nursery practices in East Africa, this chapter identifies the genetic parameters that determine the vulnerability of the farming poor to economic and environmental risks.

Chapter 7 is a case study to quantify possible levels of genetic erosion in the domestication process. It compares forest and farm stands of an important timber species in central Kenya (Meru and Nyambene) using Molecular markers (RAPDs). A secondary objective was to provide knowledge on the relative partitioning of genetic variation between and within central and western Kenya, since *Vitex fischeri* (syn. *Vitex keniensis*) has only recently been considered a single species.

The thesis is closed with a concluding chapter. In this chapter, general conclusions will be drawn, from the whole study. To obtain the specific conclusions and recommendations, the individual chapter publications remain the best source of information.

The various chapters have been submitted to journals, hence some overlapping information among the chapters could not be avoided. The chapters are adapted for this thesis to ensure uniformity in referring to articles; it also has one overall reference list for all articles.

Chapter 1

The process of a participatory tree domestication project in Meru, Kenya

Ard G. Lengkeek [12] and Sammy Carsan [2]

[1] Wageningen University and Research centre, Biosystematics Group, Gen. Foulkesweg 37, 6703 BL, Wageningen, The Netherlands
[2] World Agroforestry Centre (ICRAF) PO Box 30677 Nairobi Kenya

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Abstract

Although participatory research methodologies have been widely advocated, most projects do not involve the radical reversal of approach implied. Though theoretically defined, participatory research is hard to implement and more precision in description is required. Here, we describe a participatory research project on agroforestry tree domestication undertaken in the Meru area of Kenya. Continuous interaction between participants allowed the project to evolve from a tree species suitability test, to a species saturation study, and finally to a perception of tree species diversity survey. By allowing evolution through interaction, research results more relevant to the actual needs of farmers were obtained.

Introduction

The recognition that farmer participation should be central to adaptive agricultural research means that most applied research projects are no longer accepted for funding without participatory research mentioned as a methodological approach. Despite this incorporation of ‘participatory research’ as a requirement in project design, most projects do not involve the radical reversal of approach and attitude advocated in truly participatory research (Martin & Sherington 1996). Some progress has been made (Scoones & Thompson 1994; Röling & Wagemakers 1998), but there remains a gap between rhetoric and reality, with participation often not proceeding beyond contractual obligations or, at best, consultative approaches to problem characterisation. A valid criticism of many projects is that scientists use participatory problem diagnosis to validate their own previous research perspectives. As a result, farmers may be persuaded into research activities that they have ‘agreed upon’, and may be blamed for the subsequent failure of projects. Sometimes, the failure to adopt truly participatory approaches reflects the inability of scientists to fully understand and accept the perceptions and decision-making processes of farmers. In many cases, as research concerns change, traditional scientists encouraged to enter for the first time into participatory research have not been adequately trained in appropriate methodologies, fear that they may not meet research targets, or that they may be unable to publish research results in traditional formats.

In participatory research, innovation emerges from interaction rather than the imposition of technology (Röling & Wagemakers 1998). Research activities are based on the different knowledge systems of farmers, extension workers and scientists (Martin & Sherington 1996), but specific objectives remain flexible and are continually reformulated during implementation as a result of partner interactions (‘designing as we go’: Binswanger 2000). Different partners do not trade control and benefits of separate parts of the research process, but interact in a shared process of learning and debate. The approach can be described as one of ‘constructivism’, where stakeholders assemble knowledge, as opposed to a more traditional approach of ‘positivism’, where unambiguous goals and a focus on best technical means leads to hypotheses that are tested through repeatable and clearly quantifiable experimentation (Douthwaite & Schulz 2001; Röling & Wagemakers 1998).

Although defined in theory, participatory research is hard to implement in practice. Methodologies are generally rather context-sensitive, with a wide range of factors influencing the ability of partners to participate and interact (Martin & Sherington 1996). On this practical level, therefore, more precision in description of both the conduct and outcome of participatory research is needed in order to provide guidance to others in the implementation of such projects.

The objective of this paper is to describe the evolution of a participatory agroforestry tree domestication research project conducted by farmers, extension workers (from the Ministry of Agriculture) and the International Centre for Research in Agroforestry (ICRAF) in the Meru area of Kenya between 1998 and 2001. Continual interaction and flexibility are particularly important components in agroforestry research because of multiple and sometimes incompatible goals associated with limited inputs of land, nutrients, labour, capital and markets. Our report focuses on a detailed description of the methodological approach taken during the project: a detailed description of results relevant to tree domestication and biodiversity management is given elsewhere (Chapter 2).

Initial plans

The background for the project derived from previous on-farm surveys and stakeholder workshops in the Meru region of Kenya, which suggested the need for farmers to diversify the number of high value trees species grown on their land (Betser et al. 2000; National Agroforestry Research Project 2000; Roothaert 1999). In particular, the project brief was to combat the over-reliance, given biological and economic risks, on the cultivated of the exotic timber tree *Grevillea robusta* in the region, by identifying with farmers, through interviews and on-farm preference trials including growth measurements, three or four priority alternative tree species for cultivation. In addition, farmer preferences for on-farm planting niches for different species was expected to be determined (Table 1).

Ministry of Agriculture (MoA) extension workers had previously established farmer-led farmer groups in the Meru region in a project to prevent soil erosion based on specific limited water catchment areas. Membership of groups was voluntary and free of charge, while the geographic proximity of farmers within groups enabled dialogue among participants and facilitated monitoring of the soil erosion project. We based our research on a subset of participants from three of these groups relatively accessible to the town of Meru (Kigane, Ncoroiboro and Gaukune) and within rather similar agro-ecological zones, based on the following criteria. Local knowledge and possibilities for project interaction are both likely to be determined by wealth and gender. Generally, wealthier farmers and men tend to be over-represented in farm research. Therefore, household data collected by the MoA on farm size, house type and animal stocks were used to stratify farmers by wealth: for each group, four farmers were chosen from high, medium and low economic divisions. In addition, each wealth class within a group contained at least one female-headed household. Participants were chosen within groups by local MoA extension staff and group chairs, based on a desire to participate (Chapter 2). Since farmers around Meru are well known for their tree planting culture, a desire to participate in the project was not considered to be a significant selective bias to understanding tree planting in the region. It was expected that the group structure employed would allow significant sharing of information between participants, although some local knowledge, for example on the medicinal uses of trees, is considered privileged information to traditional healers (ATDAM, the Ameru Traditional Doctors of African Medicine association, personal communication).

Before meeting with farmers to discuss the details of the project, MoA and ICRAF staff determined the trial would consist of two planting rounds, evaluating in total 12 tree species. In an initial planting round, MoA and ICRAF staff determined to provide participating farmers with seven species considered to be of high-priority to farmers according to priority-setting exercises undertaken by Betser et al. (2000) and following the recommendations of other organisations active in agroforestry in the area, including the National Agroforestry Research Project in Embu, ATDAM, the Forest Department office at Meru and the Kenya Forest Seed Centre. Species of indigenous and exotic origin, of various functional uses, different growth rates and suitability for a range of farm niches were chosen. For the second planting round, MoA and ICRAF staff determined that the choice of five species planted should be based on the suggestions of participating farmers. MoA and ICRAF staff restricted planting stock to 12 species because it was felt that farmers could have difficulty in dealing with a larger number of species and, in addition, germplasm access to a wider range of species required a time scale beyond the start of the project. For both planting rounds, a decision was made to provide trees in an ‘all or nothing’ package, since ICRAF staff wanted to obtain preference and measurement data on individual species from a statistically significant number of farmers, and were afraid of loosing poor farmers from the trial due to saturation of their planting opportunities. For the same reason, it was determined that farmers should only receive a very limited number of individuals of each tree species.

Initial project planning meetings between farmer groups, MoA staff and ICRAF were held to discuss the objectives and *modus operandi* of the project. Farmers, who recalled aphid damage eliminating commercial cultivation of a former important species, *Cupressus lusitanica*, at the beginning of the 1990s, confirmed from their own experience the danger of over-reliance on cultivation of any particular tree species. The MoA and ICRAF rationale of species selection for the two planting round was described. Farmers were provided with information on potential use, planting niches and tree management requirements for the first round of species to be planted, if requested, though farmers were left to make their own choices. It was agreed by all partners that the project would last for three years, with MoA and ICRAF staff supplying tree seedlings free of charge and regular follow up surveys before, during and after tree planting. Farmers agreed to contribute land, and labour for planting, tree maintenance and discussions with scientists and other farmers. On the basis of perceived farmer benefits, farmers were invited to participate not only in initial trial execution, but also in further planning, design, monitoring and evaluation of the trial. This was an unfamiliar concept to many farmers, but the responsibility of all partners to input into the further design of the project was made clear from the start.

Implementing the trial

On presenting the seven tree species of the initial planting round to farmers, their species preferences before planting were documented using the Bao game, an application of the matrix ranking method common to participatory research literature (Franzel 2001; Chapter 2). At the same time, the Bao game, farmer group discussions with MoA and ICRAF staff, farm walks and informal meetings were used to select species for the second round of trial planting. Farmers requested some species by name, other species by functional use, such as medicinal, fruit, timber and fodder trees.

Meetings with farmer groups involved a certain degree of 'focussed loitering', where farmers explained general constraints that played an important part in their lives. Although the project was constrained to working with tree species and therefore could not address many of these issues directly, discussion occasionally led to an unexpected potential solution that was tree-based. For example, in response to complaints of crop damage by termites, the use of *Tephrosia vogelii*, a shrub locally used as fish poison, was recommended as an effective and environmentally friendly insecticide.

Before planting the second round of the trial it was already evident that farmers placed very little emphasis on the biological performance of trees on their farms in determining their preferences. It therefore became evident that the on-farm measurements of performance we envisaged were of little value and these were discontinued before the second planting round. Since our initial planting strategy, which was designed to obtain on-farm measurements that were statistically significant, was no longer valid, and because farmers requested more flexibility in determining which of the species presented to them to plant and in what numbers, our rigid approach of 'all or nothing' planting by individual farmers of a few individuals of each species was abandoned for the second round. A policy of 'replacement' was however retained, in which dead or stolen trees already planted were replaced, to ensure that farmers had at least one individual of any species they had requested. During the second planting round, species preferences varied between farmer groups, so that a differentiation in planting activity was observed both within and among groups.

Farmers asked for a third planting round and this was agreed to by MoA and ICRAF staff on the basis that many species requested by farmers in specific functional use groups had not yet been provided. Furthermore, germplasm of a number of rare, endemic species became available only after the first two planting rounds and planting of these species was seen to be important to contribute to the conservation efforts of farmers.

By this stage of the project, several of our starting formulations were no longer relevant. Biological measurements were not undertaken and, although farmers did express preferences for particular species, farmers preferred to plant a wider range of species than we had envisaged. We therefore adapted our research objectives in order to evaluate the saturation point for farmers in planting new tree species (Table 1). Although reports in the literature generally indicate that farmers rely on a number of tree species in agroforestry systems (e.g. Weber et al. 2001), it is however unclear to what extent farmers want to diversify their farms. Due to the greater than anticipated number of species now being dealt with in the trial, an evaluation of biodiversity conservation opportunities through on-farm planting took on a larger focus. This objective developed also through the observation that trial activities influenced management of existing on-farm tree resources of some trial farmers and their neighbours, both of species included in trial planting and others. For example, trial farmers retained naturally occurring wildings of some tested species.

Extending research to a greater number of species entailed considerable extra input from farmers, MoA and ICRAF staff. During group discussions, it was jointly determined to extend planting to fourth and fifth rounds, meaning more work for farmers planting trees and maintaining seedlings through dry periods. Sourcing further germplasm for planting entailed considerable collection and procurement efforts by ICRAF scientists. Most significantly, it was determined that evaluation of species saturation and conservation issues required a baseline of total tree census data to be collected from participating farms, involving considerable effort in data collection by farmers, MoA and ICRAF staff. One farmer decided not to plant trees for the fourth and fifth planting rounds, and another farmer stopped planting after the fourth round, though the latter decided to continue to collaborate on collecting tree census data. Throughout planting, the Bao game continued to be used to stimulate discussion and exchange knowledge on particular species, even though tree preference scores were of less interest under revised objectives than at the beginning of the trial.

The trial at closure, lessons learnt and future plans

After three years the project was formally closed after five planting rounds involving a total of 31 tree species. At the end of the trial, 38 of 40 participating farmers still desired to plant and experiment with additional tree species on their farms. We therefore did not meet our redefined objective of the trial, to assess the saturation point of farmers in planting new tree species. Although further research may define this saturation point, it appears now to be primarily a theoretical issue, since constraints on farmer access to germplasm is likely to be the determining factor (as found in other studies, e.g. DFSC 2003), rather than farmers concerns regarding the number of different species they can manage on their farms as a result of land or labour saturation. At the end of the trial, farmers in one location had begun to develop programmes of joint seed collection and seed exchange to enhance access to germplasm. In another location, a farmer with a private on-farm nursery had extended his inventory to 70 species, a level of diversity previously unseen in the area.

By the end of the trial, as scientists we found it's principle research value in the information provided on farmer's perceptions of tree diversity, rather than on tree species preferences or species saturation levels (Table 1). The process of trial evolution, although unsettling at times, allowed us to understand the decision-making processes of farmers more fully, which should contribute to the design of more productive and sustainable agroforestry systems in the Meru region. If we had chosen to rely on a more detailed positivistic approach to research, we would have obtained a list of three or four priority tree species to cultivate as well as *Grevillea robusta*, but this would have had limited value for meeting the preferences and needs of farmers.

For farmers, the main benefits expressed were the training and information they received in the use and management of tree species, through informal interactions with scientists and other farmers during group discussions, farm walks and use of the Bao game. Farmers particularly benefited through increased interaction with other farmers using the group structure, and appreciated the 'new' knowledge made available to them by MoA and ICRAF staff. Training and increased awareness influenced farmers not only in the management of trial trees, but also in the management of other trees on their farms.

This report has focused on a description of the methodological approach taken during the project. Data on the perception of farmers toward different tree species, diversity management and tree census data, analysed by wealth, gender and location are given elsewhere (Chapter 2). Our research indicated the desire of farmers to plant and experiment with a wide range of tree species. However, in the time-scale of the project, no data could be obtained on long-term retention of planted species on-farm. Since over a three-year period the trial continually evolved, it is likely that changes will continue to occur in the future and these processes of innovation should be a focus of follow-up studies. Despite the evolution of objectives though the trial, the initial assumption of over-reliance on a single tree species, *Grevillea robusta*, remained valid, only the means to address this problem changed.

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Table 1: Summary of the process of a participatory tree domestication project in Meru, Kenya. The table summarises the evolution of the trial through the different stages of implementation described in the text.

Problem statement	Over-reliance by farmers, given biological and economic risks, on a single tree species, *Grevillea robusta*		
	Initial plans	**Implementing the trial**	**The trial at closure**
Type of trial	Tree species selection on-farm	Tree species saturation on-farm	Perceptions of tree diversity on-farm
Activities	• Plant 12 tree species in total during two planting rounds • Interviews (use of Bao game) • On-farm growth measurements • Survey of on-farm planting niches	• Plant sufficient tree species to reach farmer saturation • Interviews (use of Bao game) • On-farm total tree census	• 31 tree species planted in five planting rounds • Interviews (use of Bao game) • On-farm total tree census
Results	Expected results: • Three or four priority species identified • Preferred planting niches of farmers for particular species determined	Expected results: • Tree species saturation point quantified • Conservation opportunities identified	• Tree species saturation point not reached • Farmer's perceptions of tree diversity determined • Training and information provided to farmers • Conservation of species promoted

Chapter 2

Diversity makes a difference: farmers' perception of tree species diversity in Meru district, Kenya

Ard G. Lengkeek[1,2] and Sammy Carsan[2]

[1] Wageningen University and Research centre, Biosystematics Group, Gen. Foulkesweg 37, 6703 BL, Wageningen, The Netherlands
[2] World Agroforestry Centre (ICRAF) PO Box 30677 Nairobi Kenya

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Abstract

In Meru district on the slopes of Mount Kenya, farmers rely heavily on the tree *Grevillea robusta* in agroforestry systems, implying economic and environmental risks. In 1998, Meru farmers, the Ministry of Agriculture and ICRAF started a research project to address this problem of over-reliance. A wide range of participatory research activities was conducted, including a tree species planting trial, species preference ranking exercises, farmer interviews, on-farm tree inventories and lastly focused group discussion on all the activities. Farmers wanted to diversify their agroforestry system to include many species. The most limiting factor for a farmer to plant a preferred species was access to germplasm. Since species preferences were influenced by information, access to germplasm and information exchange should go hand in hand. The uneven distribution and low densities of the species recorded on the farms raised concerns about the long-term viability of populations, and subsequent sustainability of agroforestry systems in general. It is recommended that farmers, researchers and extension workers focus on the domestication of the landscape's diversity as a whole, and not necessarily restrict activities to a few priority tree species. This will help to increase farmers' profits and the conservation of the tree species base on which farmers depend.

Keywords: Agroforestry, biodiversity, diversity management, local knowledge, participatory research, tree domestication

Introduction

Farmers plant trees in pursuit of their livelihood goals of income generation, risk management, household food security and optimum use of available land, labour and capital (Arnold & Dewees 1995). These goals cannot be met by a few species only, hence farmers value many tree species (e.g. Weber et al. 1997; Kindt & Lengkeek 1999; Kindt 2002; Dery et al. 2000; van Duijl 1998). However, farmers are often unable to access (quality) germplasm (DFSC 2003). Due to this limited choice, farmers tend to plant what is available, which may result in an over-reliance on just a few species.

In Meru on the slopes of Mount Kenya, farmers rely heavily on *Grevillea robusta* (Proteaceae). With the disappearance of much of the natural forest (KWS 1999), this inadvertently invites economic and environmental risks. In 1998, Meru farmers, the Meru office of the Ministry of Agriculture (MoA) and ICRAF started a research project to address this problem of over-reliance, initially to find alternatives through on-farm testing of various tree species with farmers. Because of its flexible nature, the project was allowed to evolve from a species preference trial into a diversification trial and diversity study (Chapter 1). The objective was income generation by increasing on-farm tree diversity, at the same time conserving biological diversity and stabilising the agroforestry ecosystem. The prevailing view in ecology is that more diverse ecosystems are more stable (SGRP 2000) and more productive (Tilman et al. 2001). Although species diversity is often equated with species richness, it is a function of the number of species and the evenness in distribution of species abundance (Magurran 1988; Purvis & Hector 2000).

Until recently, trees were mainly grown for on-farm and local use, but awareness of tree growing as an economic enterprise is increasing as Meru farmers look for alternatives to generate income. Due to the deteriorating economic situation in Kenya, including low coffee prices, farmers lack cash. With decreasing forest cover in Kenya, and on Mt Kenya in particular (KWS 1999), the market is increasingly providing incentives for tree growing. In Meru, on-farm timber marketing has mushroomed and the tea factories address their wood shortages by buying large quantities of wood from farms (Holding & Carsan 2001). An important aspect is that buyers are willing to pay premium prices for quality wood. At the same time, the market for fruit remains steady although not large. Farmers sell avocados, macadamia nuts and mangoes. The stimulant Miraa (*Catha edulis*) remains a major cash crop in the higher, drier parts of Meru. The local marketing of tree-based medicinal products and fodder has begun.

Besides providing solutions on how to address the over-reliance on *Grevillea robusta*, this paper describes the results and analyses of farmer perceptions of tree species planting, tree diversification and agroforestry. The objective is to improve tree domestication strategies, to help farmers increase their profits and to help them conserve the species base on which they depend. The process of shaping this research and more detailed concepts of participatory research are the subject of a separate paper (Chapter 1).

Approach and Methodology

Constructivist approach

Scientists can not have perfect knowledge of all the aspects of sociological, economic or ecological systems in complex environments. This research therefore followed a participatory and constructivist approach. Constructivism implies that stakeholders ‘construct’ knowledge as opposed to ‘positivism’ in which hypotheses are posited and tested with repeatable and quantifiable experiments (Douthwaite & Schulz 2001; Röling & Wagemakers 1998). Agroforestry systems have multiple goals, which are often not mutually compatible. Hence assumptions based on unambiguous goals and a focus on ‘best technical means’ or optimum recommendations are to a large extent unrealistic. Our project was structured to learn from the continuous input from farmers, extension workers and scientists, with the purpose of designing a project activity - ‘designing the program as we go’ (Binswanger 2000; Chapter 1). Scientists and extension workers therefore only formulated a starting point, building on earlier on-farm research (Betser et al. 2000).

Selection criteria

Trials were conducted with extant farmer groups that were based on water catchment areas. These farmer groups were farmer-led and, thereby making this the most logical and effective approach. The geographic area of the chosen farmers was limited to ease the logistics of trial management and monitoring, and to increase dialogue among farmers. Furthermore, with the introduction of new tree species, future geneflow problems would be lessened if the trees were close together.

Three groups representing an area of high agricultural potential, at varied distances from the forest, were chosen (Table 1). Farmer groups were also selected from within a relatively similar agro-ecological zone to facilitate comparison of the performance of the tree species, although the groups varied in intensity of cultivation.

The respective chairmen of the farmer groups and the local MoA staff were asked to select the households willing to participate. The criteria given were based on wealth and gender, avoiding over-representation of wealthy and male farmers (resp. Guinand 1996; Friis-Hansen & Sthapit 2000). Preliminary wealth criteria were used to select farmers to get started, more detailed questionnaires were used for the analysis later on. Personal preferences of the chairman as well as the local MoA staff could not be avoided, but were minimised to a certain extent through their mutual responsibility and the set criteria.

Due to these selection criteria, participating farmers were not a random sample of the population. Meru farmers are well known for their ‘tree planting culture’ (MoA 2000a;b), and no farmer refused to join. Nevertheless, it was possible that some farmers were not approached from the start, leading to a bias for increased interest in tree planting or experimentation.

Table 1: Characteristics of farmers and the agro-ecological zones of the study area.

Village	Nkubu	Igoji	Ruiri
Location			
Farmer group	Kigane	Gaukune	Ncoroiboro
District	Meru Central	Meru Central	Meru Central
Zone	Humid	Sub humid	Semi-arid
Land classification °1	Upper Midlands 2	Upper Midlands 2	Upper Midlands 3
Annual rainfall (mm)	500-2200	500-2200	500-1800
Soils	Well-drained, extremely deep clay loam	Well-drained, very deep loam to clay	Well-drained, deep red cracking clay
Distance to the forest	12 km	25 km	0 km
Participating farmers			
Number of farmers	12	12	16 °2
Gender (F – M)	4 – 8	4 – 8	5 – 10 (1 couple)
Wealth °3 (rl-med-w)	5 – 5 – 2	4 – 4 – 4	8 – 4 – 4
Av. Farm size (trial)	1.3 ha	2.2 ha	2.4 ha
Altitude of farms	1497-1674 mas	1353-1586 mas	1524-1761 mas
GPS farms	037 65' E 00 04' S	037 66' E 00 11' S	037 63' E 00 09' N

°1 Land classification according to (Pelley et al. 1985).
°2 More farmers were included because of the drought (Chapter 1).
°3 Wealth classes 'Resource-limited – intermediate – wealthy'.

Wealth ranking of farmers

Farmers differ in many aspects and individuals have different needs and capabilities and therefore may be engaged in different practices and technologies. The wealth classes allowed us to filter out results linked to wealth leading to a better focus on the poorer farmers, our main target group (ICRAF 2000). A large number of wealthier farmers would have resulted in overestimating farmers' possibilities (Guinand 1996).

Ranking individuals into wealth groups can be difficult. Inequality of some sort exists in every human society; the degree of the inequality and the attributes upon which it is based, do, however, vary across societies (Grandin 1988). We tried to find consensus among the three stakeholder groups; farmers, extension workers and scientists. The chairman or chair committee of the farmer group ranked the participants according to their own criteria, as did the extension workers from the local MoA offices working with the farmer groups. The researchers based their list on a questionnaire, using two scientists. The first scientist, the interviewer, grouped the farmers according to his impression of the farmer's wealth, keeping in mind the raw data. The second scientist was independent and was to group the farmers solely on the characteristics from the questionnaire. This resulted in a more objective classification restricted to wealth characteristics. Since the interviewer and independent scientist were both from the area, farmers were grouped using their local knowledge. In this way, an overly strict interpretation of the data was avoided. Data included information on age, education level, housing type, farm size, number and type of livestock, farm production, labour hired, off-farm employment, additional income generation, marital status, number of children residing on the farm, land tenure and any other major possessions. At meetings, the ranked lists of the three groups were merged into a consensus ranking list (Table 1; Appendix 1).

Activities

Farmers were told from the start that the project was going to last three years. A range of activities were carried out on 40 farms to understand farmers' perceptions of tree species diversity:

- species trial;
- farmers' trial species preference exercise;
- interviews on diversity management;
- tree inventories; and
- concluding evaluation.

Farmers were visited before, during and after every trial planting round. Several other visits were made, to conduct the species preference exercises, questionnaires, the tree inventory, and for various other purposes. Group discussions were held prior to every trial planting round. A separate evaluation with each farmer was conducted just before the last planting round. A group evaluation was conducted during the preparatory meeting of the last planting round.

The different types of activities allowed for a triangulation between physical results (tree inventory), farmer statements (preference scores and questionnaires) and from farmers activities (trial planting, maintenance and farm walk observations). For example, Roothaert (1999) concluded in Embu that questionnaires asking farmers about species desired were not always consistent with what farmers really planted and that it is therefore important to actually supply the species and to follow up on the planting. Any contradictory answers or behaviours can be due to the difference between theory and practice, inconsistencies, imperfect communication between the farmer and the scientist, or even indifference if the farmers do not have ownership over the activities.

Farm diversification implies diversifying the number of species as well as the evenness of species, unless specifically mentioned.

Species trial

The trials consisted of 31 species divided over five planting rounds, planting took place every rainy season in March and October. The first round of species was based on the preference list from a Meru farm survey by Betser et al. (2000), complemented with experience from the MoA's Meru office, the Embu National Agroforestry Research Project (NARP 2000), the Ameru Traditional Doctors of African Medicine association (ATDAM), ICRAF, the Meru Forest Department and the Kenya Forest Seed Centre. This planting round consisted of a diverse group of species: those known and unknown to the farmers, indigenous and exotic, with various functional uses, various growth rates and suitability factors for farm niches. The species choices for the second and further planting rounds were increasingly based upon suggestions from the participating farmers.

Trial species were from known provenances ensuring best fit to location (Appendix 3). Seeds were collected from natural populations or seed orchards according to basic seed collection guidelines (Dawson & Were 1997). Additionally, germplasm consisted of three vegetatively propagated species. Seedlings were raised in various nurseries, including an on-farm nursery of a participating farmer.

The uses and possible planting requirements or preferred niche of the species were discussed in group meetings, and specific advice to individual farmers was given when requested. Farmers chose their planting niches as they best knew their farm characteristics, farming plans and tree needs. Researchers and extension workers provided seedlings, follow-up and technical backstopping. Farmers contributed land and labour, as they were to plant and maintain the trees, and spent time discussing and conducting farm walks with us.

Farmers received few (two to three) individual trees per species. Not all farmers planted all species; if a farmer declined a species, it indicated a low preference, and this was the only data we measured. Dead or stolen trees were replaced throughout. The rationale was that the farmer should have at least one tree of a preferred species on the farm; this would help the farmer to relate to the species when discussed. In the three farmer groups, the agro-ecological conditions as well as species preferences were different and thus other species packages were provided.

Farmer preferences of the trial species

Farmer preferences were recorded for all trial species. Preferences were recorded immediately after a planting round in order to capture the initial preferences of the latest species, before they would change due to on-farm performance or farmer familiarity. The rationale was that, especially with unknown species, farmers will judge according to their expected uses of the trees. Subsequent preference exercises revealed changes in time.

Preferences were documented using the Bao game (Box 1). Bao games were repeated to analyse different scores for species and farmer characteristics. Scores were also used to monitor changes over time as the farmers became more familiar with species or species uses, as species performance became clear or with increasing species diversity. Therefore, species having a high overall ranking does not imply that these species are the most appreciated.

Additionally, the Bao game was used for ranking uses of tree species, replacing tree leaves with cards of drawings representing the various tree uses.

Box 1: The Bao game

The Bao game is an application of the ranking method in the participatory research literature (Franzel 2001). Because farmers control the scoring process in the Bao game, they take the exercise more seriously than when responding to questionnaires. The Bao game is a visual tool, respondents can check their score and members of a group can discuss differences in scores among themselves. The Bao game can thus be used for collecting quantitative data on farmers' (qualitative) evaluations accurately. Moreover, the Bao game is an entertaining exercise and a guarantee for lively discussions, often a moment for taking a rest, socialising and an excellent moment for information exchange. During the farm walks, leaves of the trial tree species were collected, and then placed next to the holes on the Bao game board. Farmers then scored their preferences by filling the holes with stones. One stone is the lowest score and five the highest, for unknown species the hole is left empty.

In order to compare differences, scores were adjusted in such a way that the mean for each variable was set at zero. For example, considering gender, separate mean scores were calculated for men and for women. Then, for each gender, the mean score was deducted from the score for each species included in the study. Thus, scores allotted by men and women for each species may be compared to determine their relative level of appreciation. Half a point's difference between variables was considered an indicative difference, with higher scores implying higher appreciation and lower scores less appreciation.

Interviews on diversity management
Farmers were interviewed to obtain a better understanding of their perception of species diversity preferences in open-ended questionnaires. Some questions were phrased in the third person to make them less direct. Questionnaires were formulated during the various interactions with farmers, such as individual discussions, formal group discussions, observations and exchange of views during farm walks and other informal meetings. Discussions encompassed species selection and choices, tree valuation, diversity and other aspects. This process seemed critical, because the issues raised by farmers were not always clearly related to the research questions. Nevertheless, it was important to take the time to digress into these discussions as outsiders may easily overlook issues that play a vital part in farmers' lives. This 'focussed loitering' may initially appear a waste of time but was efficient in the end, as it generated a better final result through providing a better understanding of farmers' perceptions.

The various questionnaires were conducted individually as well as per group (Appendix 11).

Tree inventory
A farm tree inventory was conducted with each participating farmer by recording every woody perennial. We used the same criteria for species inclusion as Beentje (1994); that is, any tree, shrub or liana growing higher than 1.5 metres tall. Trial species were not included in the inventory. The inventory provided information on tree cover and farmer uses, but also provided analytical information on the impact of the trial on the farms' diversity (for more details see Chapter 4 & Appendixes 4 to 10).

The trial and inventory were also compared for species uses. Species were allocated to a 'use group' once two or more farmers had mentioned it; for instance, a timber species. The objective was to understand what the trial added to the existing tree cover; therefore, the analysis of use-group preferences was based on occurrence within the inventory only. For example, two important use groups in the trial were prevention of soil erosion and shade; yet these were not included since farmers hardly mentioned them in the inventory. Ornamentals and boundary markers were major use groups in the inventory and were included, even though these aspects were hardly included in the trial (see Table 5 & 6).

Evaluation
The trial was evaluated with each farmer before the last planting round to permit a discussion on the content of the trial. We prepared questions to guide ourselves through the discussion, though we did not necessarily adhere to them if it meant slowing the pace of the discussion. Farmers were asked to: (i) redefine the objectives, (ii) suggest ways to improve the work, (iii) show existing gaps, and (iv) reveal possible denial of other needs outside the project focus (Appendix 11). We tried to formulate these questions in a way that answers were not necessarily directed to any of the stakeholders involved or not directly to the work conducted, permitting the farmers to openly criticise the project activities.

Analysis

In total 40 farms and households were included in the diversity study, making it more an in-depth qualitative study rather than a quantitative study (Table 2). The intensity of the research activities prevented gathering data from larger numbers of farmers, which would have ensured statistical validity. Therefore, statistical analyses are not included in this study.

Only when the overall project content was discussed activities were restricted to the main participant. For instance, with the preference scores; household members, such as wives, husbands or elder children, also occasionally gave their judgement. In some cases, the main participant and family members jointly did the exercise. This circumstance was unavoidable, and provides a good example of the reality in farming systems. The main farmer is not the only decision-maker; the decision-maker is the person present at the particular moment that farm activities are required, in this case being the Bao game. Therefore, besides influencing the consistency of the data, this situation positively influenced the reality of the data. Gender correction was made for these data.

Table 2: data collected in the tree diversity study in Meru district 1998-2001.

	No. farms	Subject of research	No. data collections	Participant	Differen-tiation [o1]
Species trial	40	Species	5	Farmer	G, F, W
Preferences (Bao)	40	Species & Use	4 [o2]	Farmer	G, F, P, W
Preferences for use groups (Bao)	38 [o3]	Use	1	Main participant	G, F, W
Farm walks	40	Species, Use & Diversity	5 +	Farmer	F, P, W
Inventory	35 [o4]	Species & Use	1 +	Main participant [o5]	F, W [o6]
Questionnaires individual	38 [o3]	Species, Use & Diversity	3	Main participant	G, F, W
Questionnaires group	n.a.	Species, Use & Diversity	6 +	Farmer	F

[o1] Results were differentiated according to Gender, Farmer group, Planting round and Wealth class.

[o2] One preference exercise missed due to practical constraints.

[o3] Two main respondents could not be reached.

[o4] Fewer farms due to practical constraints. In the inventory - trial comparison the five 'trial farms' were separated out.

[o5] Elder family members were regularly consulted for local names or occasionally for species (medicinal) uses.

[o6] Gender differences were not addressed in the inventory since it was not clear which farmer was the main long-term decision-maker.

Results

Species trial and farmer preferences

The clearest result was a large variation in trial species preferences and in allocated use groups among all variables. Arguments for preference alone did not suffice to gain an understanding of farmers' perception; for example, a single mother scored 5 for the 'nut' *Telfairia pedata*, whereas a son of another farmer scored 1, both using the same argument that it is 'food for the kids'.

The overall variation in trial species preferences exceeded the variation within all their allocated use groups. Some trends could be observed in use-group preferences; timber and medicinal species had a high overall ranking and this was also true for fruit with a cash value and to a lesser extent, fodder (Table 3).

Species comparison not only varied according to the (potential) use or performance of the species, but also the farmer's familiarity with the species. If a farmer was not familiar with a species, initial scores may start low, such as with *Warburgia ugandensis*, *Moringa oleifera, Acacia angustissima* or *Carissa spinarum*. If the species showed a satisfying performance, and with farmers' increased knowledge on the potential uses, appreciation increased accordingly. However, this was not true for all species; e.g. with the fruit/nut species, *Telfairia pedata* (climber), *Cyphomandra betacea* or *Casimiroa edulis,* no changes in appreciation were observed (presumably because fruiting had not yet started). For *Leucaena* *trichandra* the expectations were very high because of potential for dairy meal replacement (NARP 1998), but this decreased in time.

Species that were already known were given a score that related to the current knowledge of that species. The introduced *Cordia africana* did not perform as well as expected; the provenance from Nyeri - Mt Kenya was expected to be more drought-resistant, but it was not well adapted to Meru. However, farmers continued to give high scores (Table 3), referring to the usefulness of other *Cordia africana* on the farm, and no reference was made to the under-performing provenance we provided.

A species such as *Azadirachta indica* (neem) is rare in Meru, but its use has been widely advertised. Farmers were very happy to obtain this species and although it did not do well, farmers kept giving this species a high score. On-farm performance did not matter, as the expected future use was too attractive to lower the scores. Only two complaints about slow growth were given, while other farmers told us it did well - the wish seemed to be stronger than the actual growth. If new uses of an already well-known species became clear, such as medicinal and cash values of *Prunus africana*, appreciation also increased. Some value changes cannot be explained (e.g. the timber species, *Markhamia lutea).* Some did very poorly (e.g. the timber species, *Maesopsis eminii),* yet appreciation increased.

The overall variation between individuals exceeded the variation within the various groups, such as gender, wealth or farmer group. Gender differences were not major; only *Ocotea usambarensis* and *Telfairia pedata* showed minor differentiation. More important may be the lack of differentiation; often mentioned is that men like timber and cash better, whereas women like food and firewood. However, timbers such as *Vitex fischeri* (syn. *Vitex keniensis*), *Cordia africana*, *Olea capensis* and *Grevillea robusta* scored equally well, while *Juniperus procera* even scored slightly higher among women. Food and food additives such as *Rosmarinus officinalis, Moringa oleifera* and *Vangueria madagascariensis* showed no gender differentiation either. Other food or fruit trees such as *Casimiroa edulis, Tamarindus indica*, and *Cyphomandra betacea* also have cash value, yet no gender differences were observed. Women even appreciated *Prunus africana,* the species to treat old men's disease (prostate gland; Simons et al. 1998) equally well.

Likewise, no major differences in appreciation were observed between wealth classes. Although results for timbers such as *Ocotea usambarensis* and *Olea capensis* indicated that wealthier farmers may appreciate longer term species more, these results were not supported by scores for the timber species, *Milicia excelsa, Juniperus procera,* and the fruit/medicinal species, *Tamarindus indica* (the latter only fruiting after 11 years, Gunasena & Hughes 2000). Poorer farmer have less access to health care; however, there was no indication that this group favoured medicinal trees, such as *Azadirachta indica, Warburgia ugandensis, Trichilia emetica, Ocotea usambarensis* or *Rauvolfia caffra*, more. Minor wealth differentiation was found: wealthier farmers have access to insecticides, which could be a reason for the insecticide *Tephrosia vogelii* to score low among them. *Casuarina equisetifolia* is an ornamental and may therefore be a luxury good similar to the herb *Rosmarinus officinalis,* and therefore scored higher among the wealthy.

The three farmer groups showed no major differentiation in species preferences. Even though the land is used more intensively in Nkubu, there was no indication that longer term timber species, such as *Cordia africana, Vitex fischeri*, *Ocotea usambarensis, Juniperus procera, Milicia excelsa* or even *Trichilia emetica,* were less appreciated in Igoji and even less appreciated in Ruiri. The species *Olea capensis* clearly did not follow this trend, which may be due to the fact that Nkubu farmers were unfamiliar with this species while it did occur in the other two locations (Appendix 6). Likewise, the fodder species *Sapium ellipticum,* was well known and widespread in Igoji only and was valued for helping the animals through the dry period. In contrast, the food/medicinal/boundary marker species, *Carissa spinarum,* was considered a 'bush plant' in Ruiri and scored low, whereas in both other locations, it was hardly known and obtained a higher score. Nkubu was known for its fodder shortage and its farmers gave high scores to *Leucaena trichandra* but not to the fodder trees, *Leucaena pallida, Acacia angustissima* and *Sapium ellipticum*. No explanation was found for why Igoji had a relatively low appreciation for medicinal species such as *Azadirachta indica* and *Warburgia ugandensis* (Table 3[1]).

All farmers appreciated longer-term species as well, or at least some species. One farmer did not opt for *Milicia excelsa* in the trial, stating that he only wanted fast-growing species. Asked why he gave a maximum score to *Azadirachta indica,* he mentioned that this species was so valuable to him that he was happy to wait.

Interviews on diversity management

Familiarity

Farmers were asked if they were familiar with trial species and whether they already had the species on their farm. Familiarity with a species resulted in a higher appreciation: for 16 species, farmers gave higher scores if they were familiar with the species, compared to farmers who were unfamiliar (Table 4). Only two species were scored higher by farmers unfamiliar with the species, compared to farmers familiar with them. Similarly, having the species on the farm gave a significantly higher appreciation of the species (16) than for those who did not (1).

Familiarity with the species leads to a higher appreciation and this may lead to increased planting of the species. However, whether the species occurred on the farm or not was less clear. For 11 species, farmers gave higher scores if they had the species on their farm compared to those farmers who did not have the species, whereas five species scored higher when the opposite was true. Only for a single species was the maximum score given, based on neither familiarity nor possession of the species - in this case the expectations were high.

Becoming familiar with species characteristics through use raised the appreciation of the species. Regarding two species - a 'new species' and a species with a 'new use' - farmers were asked if they had already used them. In these cases, differences in scores for *Warburgia ugandensis* were 0.5 (4.3 used as medicine and 3.7 not used) and *Tephrosia vogelii* 1.1 (3.5 used as insecticide and 2.4 not used). It is however possible that the farmers who did not use the species were less interested in it from the start, which would have led in any case to a lower score.

[1] Example on how to read table 3: *Warburgia ugandensis* had an average score of 3.8, and ranked 13th based on this average. As the score for planting rounds and groups was adjusted (Box 1); *W. ugandensis* started with lower scores in the first round, increasing gradually towards the 5th round. No gender differences were observed. Igoji scored lower than Nkubu and Ruiri, and intermediate farmers scored lower than the other farmers.

Table 3: Bao scores of the various species in the Meru on farm trials 1999-2001

Species °1	Av.		Planting round °2				Gender		Location °3			Wealth °4		
	score	rank	1	3	4	5	fem	male	Nku	Igo	Rui	Rl	med	w
Number of responses (n)	3111	-	242	626	1003	1240	864	1924	929	955	1227	1308	1011	792
Acacia angustissima	2.7	29		-0.7	0.3	0.4	-0.1	0.0	0.0	0.1	-0.2	-0.1	0.3	-0.4
Azadirachta indica	4.5	1	-0.4	0.1	0.2	0.0	0.1	0.0	0.2	-0.5	0.5	0.1	-0.1	-0.1
Carissa spinarum	2.6	30			-0.3	0.3	0.1	0.0	0.2	0.3	-0.4	0.1	0.1	-0.5
Casimiroa edulis	3.8	12	0.0	0.1	0.0	-0.1	0.0	0.0	0.2	-0.3	0.1	0.1	0.0	0.0
Casuarina equisetifolia	2.8	28			-0.1	0.1	0.2	0.0	-0.4	0.2	0.1	-0.2	0.0	0.4
Cordia africana	4.3	5	-0.2	0.0	0.3	-0.2	0.0	0.0	0.2	-0.2	0.1	0.0	-0.3	0.3
Cyphomandra betacea	3.9	10		0.1	0.2	-0.3	0.2	-0.1	0.0	0.0	-0.1	-0.1	0.0	0.0
Grevillea robusta	4.4	2		0.1	0.2	-0.2	0.0	0.0	-0.1	-0.3	0.3	0.0	0.0	-0.1
Juniperus procera	3.9	9				0.0	0.4	0.0	-0.2	0.3	0.1	0.3	0.0	-0.2
Leucaena trichandra	4.1	8	0.3	0.1	-0.1	-0.3	0.0	0.0	0.5	-0.1	-0.1	0.0	-0.1	0.3
Leucaena pallida	3.1	18		-0.4	0.4	0.1	-0.1	0.0	0.0	0.3	-0.3	-0.1	0.3	-0.3
Lovoa swynnertonii °5	4.3	3				0.0	0.5	-0.1		-0.3		0.1	0.0	0.6
Maesopsis eminii	2.9	25		-0.6	0.2	0.4	0.1	-0.1	-0.4	0.4	-0.2	-0.2	0.2	0.1
Markhamia lutea	3.0	22	-0.4	-0.2	0.6	0.0	0.0	0.0	-0.6	0.2	0.3	0.1	-0.1	0.0
Melia volkensii	2.8	27			-0.4	0.4	0.0	0.0			0.2	-0.2	0.3	0.0
Milicia excelsa	4.3	4			0.3	-0.3	0.0	0.1		-0.2	0.1	0.2	-0.1	0.1
Moringa oleifera	3.0	20			-0.6	0.6	0.2	0.0	0.3	0.1	-0.2	0.0	0.0	0.1
Ocotea usambarensis	4.2	7			-0.1	0.1	-0.4	0.2	-0.3	0.0		-0.2	0.0	0.5
Olea capensis ssp. *macrocarpa*	3.4	15				0.0	-0.1	0.1	-0.9	0.2	0.6	0.0	0.1	0.5
Prunus africana	3.8	11	-0.4	-0.1	0.2	0.3	-0.1	0.1	0.0	0.0	0.1	0.0	0.1	-0.1
Rauvolfia caffra	3.1	17			0.0	0.0	0.0	0.0	0.1	0.3	-0.4	-0.2	0.1	0.1
Rosmarinus officinalis	3.1	19			0.0	0.0	0.1	0.0	-0.7	0.3	0.1	-0.3	0.1	0.8
Sapium ellipticum	3.2	16			-0.1	0.1	0.2	-0.1	-0.9	0.6	-0.2	-0.1	0.1	0.3
Sclerocarya birrea °5	2.4	31				0.0	-0.4	0.2			0.2	0.0	0.7	-0.5
Tamarindus indica	2.9	24		-0.4	0.1	0.3	-0.2	0.0	0.1	-0.2	0.1	0.1	-0.2	-0.1
Telfairia pedata	3.0	21		0.2	-0.1	0.0	0.3	-0.2	0.0	-0.2		0.4	-0.5	0.1
Tephrosia vogelii	3.0	23		0.1	-0.1	0.0	0.1	0.0	0.0	-0.1	0.0	0.2	0.1	-0.6
Trichilia emetica	3.6	14		-0.1	0.1	0.0	-0.2	0.1	0.2	0.3	-0.4	-0.1	0.1	-0.3
Vangueria madagascariensis	2.9	26			0.1	-0.1	0.2	-0.1	0.1	0.0	-0.1	0.2	-0.2	-0.2
Vitex fisheri	4.2	6		0.0	0.2	-0.2	-0.1	0.0	0.0	-0.2	0.1	-0.1	0.0	0.2
Warburgia ugandensis	3.8	13	-1.4	0.3	0.5	0.6	0.0	0.0	0.1	-0.4	0.3	0.2	-0.3	0.0

°1 Species were listed in alphabetical order since the objective remained to understand farmers' diversification efforts and not to focus on a list of 'best' species.

°2 No data available for the second planting round.

°3 Nku stands for the Kigane farmer group in Nkubu; Igo is the Gaukune farmer group in Igoji and Rui the Ncoroiboro farmer group in Ruiri.

°4 Wealth classes are resources limited (rl), intermediate (med) and wealthy (w).

°5 The amount of Bao game data varied because of subsequent planting rounds, and additionally not all species were planted at all locations: *Lovoa swynnertonii* and *Sclerocarya birrea* had too few data to include in the discussions.

Table 4: Farmer familiarity or possession related to species preferences.

Familiarity or possession	Number of species ° receiving higher appreciation.
Familiar with the species	16
Not familiar with the species	2
Species occurs on farm	16
Species is not on farm	1
Familiar and on farm	11
Familiar but not on farm	5
Not familiar and not on farm	1

° A minimum of four negative or positive responses for possession or familiarity was chosen as a lower limit for data inclusion. Data based on 40 farms and 31 species, average number of trial species per farms equals 28.

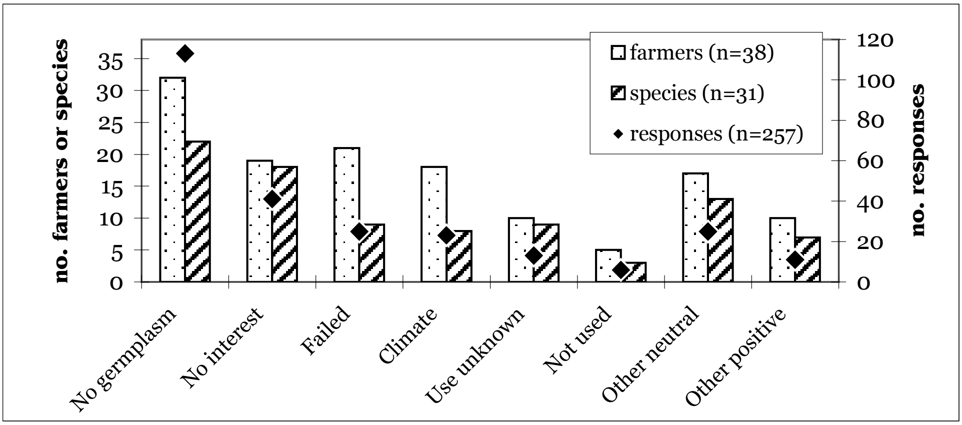

Figure 1: Reasons for Meru farmers for not having a trial species on the farm. 'Failed' means that efforts remained unsuccessful. 'Not used' stands for farmers who were not used to planting that species. 'Other positive' means wanting the species, whereas 'other neutral' stands for other reasons not to plant a species.

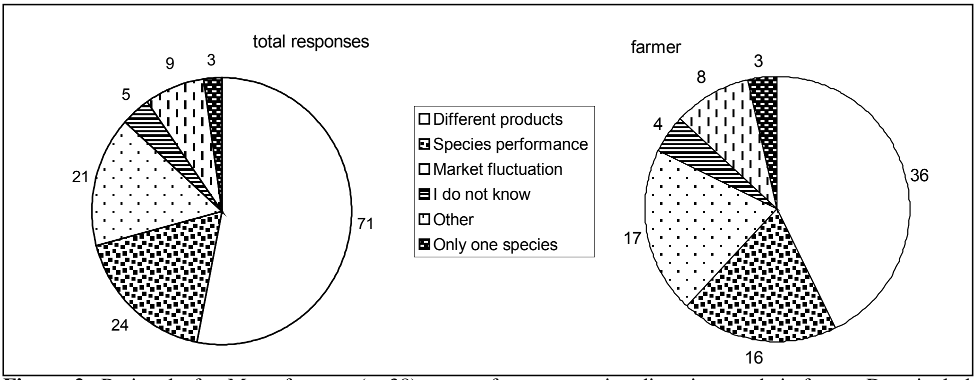

Figure 2: Rationale for Meru farmers (n=38) to opt for tree species diversity on their farms. Data include arguments per farmer and the total number of responses.

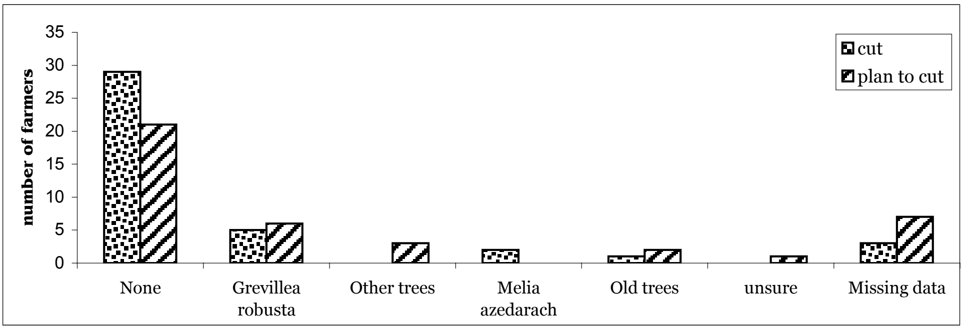

Figure 3: Tree removal by Meru farmers (n=38) caused by the diversification trial.

Reasons for not planting
Several farmers were already familiar with some of the trial species. Farmers had requested certain species, and were therefore asked why they did not already have it on their farm. The most limiting factor for farmers was access to germplasm. This was mentioned by 32 of the 38 farmers, for 22 of the 31 species and in 113 of the total of 257 responses (Figure 1). Responses were checked against the Meru tree inventory of seeding trees (van Oijen 2002; Chapter 4) and in only six of the 113 responses was there doubt about the lack of access as these were common seeding species such as *Cordia africana, Markhamia lutea* and *Prunus africana*.

Experimental attitude
We asked farmers, in the third person to make it less direct, whether, if given a species that would not do well in their location, they think they would plant it even if they knew it was bad. Only seven (of 38) said that they would not try it. The others would try it anyway, giving the following reasons: some mentioned that they liked experimenting, or that the situation may have changed and therefore that the species may do well now after all. Farmers provided examples of the trial to illustrate their point, for instance the success of *Leucaena trichandra* compared with the problems, such as weediness and diseases, that they encountered with *Leucaena leucocephala.* The continuous dieback of *Maesopsis eminii* also showed farmers' persistence with experimenting as they kept on replacing this species, trying all possible farm niches.

Why diversity?
All of the farmers wanted different tree species on their farms; their responses could be summarised as 'the need for different products and services', with six farmers mentioning 'risk management' as well. We then narrowed the question down to the various use groups and asked whether, if one would plant three trees of a timber species, they would plant three of the same or three different timber species. We asked this question to the farmers for three or four use groups, such as timber, medicine, fruit, fodder, firewood and cash.

Almost every farmer (36 of 38) responses recorded dealt with diversification of the product or service (Figure 2): the farmers explained that no timber is the same, that a fire is a product of different species and so on. Other considerations to diversify within a use group were risk management towards 'species performance' (mentioned 24 times in 133 responses) and towards 'market fluctuations' (21 times). Other minor answers were tree characteristics, that the farming system is more stable with a mix of many species, and one farmer mentioned wanting to teach his children about their cultural heritage.

We continued to narrow the choices down, to what if the three species provided an identical product, or identical performance, down to being 'identical in everything'. This process of narrowing down stopped when the question became too theoretical or increasingly irrelevant to the farmer, and responses were made such as 'that is not possible' or 'I want three different species but I cannot explain why'. In only three of the 133 responses did farmers want only one species for a particular use group, two of whom were male farmers discussing firewood.

Maintenance of wildings and replacement
All farmers in Nkubu retained more trees and more species due to the knowledge gained by the project. This practise started between the third and fourth planting round. Species mentioned were *Prunus africana, Cordia africana, Rauvolfia caffra, Trichilia emetica* and even more *Grevillea robusta*. One farmer retained all the trees for the time being. In Igoji, all farmers said they retained more trees and more species, although the consensus was that there were too many *Grevillea robusta* wildings and that they selected according to quality or farm

niche. Species mentioned were *Prunus africana, Rauvolfia caffra, Trichilia emetica, Markhamia lutea, Cordia africana, Erythrina abyssinica* (not in trial), *Vitex fischeri* and even *Tamarindus indica,* although no flowering tamarind was observed during the tree inventory (van Oijen 2002). In Ruiri, farmers explained that no difference in practices had occurred. Because of the drought, they retained almost all species and if they grew in an unsuitable niche the wildings were transplanted.

The majority of farmers had not cut any trees lately (29 of 38) and 21 farmers did not have any plans to cut trees (Figure 3). Only five farmers cut *Grevillea robusta* and another six planned to do so. Other tree removals mentioned included *Melia azedarach* (twice), because through the trials they came to understand that this was ‘local neem’ and they valued *Azadirachta indica* higher. Other trees removed or planned for cutting were old trees.

Use group preferences
Farmers ranked use groups with the Bao game. The clearest result was that farmers wanted species of all use groups. Of the 38 farmers, 11 gave a maximum score to all use groups, another nine farmers only gave a lower score to ornamentals. No major difference in farmer preferences was found, with cash-generating species scoring highest and ornamentals lowest (Table 5). Other uses mentioned were shade (7 times) and windbreak (2).

Scores were differentiated for gender, wealth and farmer groups. No major differences were found; however, wealthy farmers liked ornamentals better (score > 0.5 difference) and resource-limited farmers valued soil conservation or fertility more. Farmer groups did not follow trends related to intensity of cultivation or the distance to forest; for instance, there was no difference between firewood and medicinal species. Remarkable was the high score for ornamentals and low score for cash in Igoji. Frequently mentioned gender preferences for fruit and firewood were not clear, even the difference in timber appreciation was negligible. Women liked ornamentals better than men.

Tree inventory

On 35 of the participating farms, 297 species were recorded, ranging from 28 to 95 species per farm with an average of 53 species per farm. One percent of the trees could not be fully identified at the species level, nevertheless most of their uses were identified. Almost 63,000 trees were recorded in the farmers’ fields, a third of these *Coffea* cultivars. Except for these *Coffea* cultivars and species forming the hedges, *Grevillea robusta* was the most popular species with a density of 50 trees per hectare, followed by *Cordia africana* and *Vitex fischeri* with about ten trees per hectare. The total number of trees per hectare varied considerably per farm: it ranged from approximately 400 to 3700, with an average value for the density based on the farm values of 1300 trees per hectare (also see Chapter 4). Farmers identified many species uses, the most mentioned being firewood; remarkably, farmers attributed medicinal properties to a third of the species (Table 6). There was a large variation within use group abundance among farms (see also van Oijen 2002; Chapter 3).

Wealthier farmers had more species on their farm, which was expected as they generally have more farming land and subsequently most likely have more species. Corrected for farm size, the smaller farms (=mainly poorer farmers) had higher more species (Figure 4).

Table 5: Bao scores for the various uses (n=38).

	No.	Cash	Medi-cine	Soil	Attract Rain	Timber	Fruit	Fodder	Fire-wood	Orna-mental
Average	38	4.9	4.8	4.8	4.7	4.6	4.4	4.4	4.4	3.4
Stand. dev.	n.a.	0.4	0.6	0.5	0.7	0.8	0.9	1.0	0.9	1.3
Female°	11	0.2	0.1	0.1	-0.1	-0.2	-0.1	-0.1	0.2	0.4
Male	26	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.0	-0.1
Resource-ltd	17	0.2	0.2	0.3	0.1	0.0	0.0	-0.1	0.1	-0.3
Intermediate	13	0.0	0.0	-0.2	0.0	0.1	0.1	0.3	0.0	0.1
Wealthy	8	-0.1	-0.2	0.0	0.1	0.1	0.1	0.0	0.1	0.6
Nkubu	10	0.2	0.0	0.2	-0.1	0.0	-0.1	-0.1	0.1	-0.2
Igoji	12	-0.3	0.0	-0.1	0.0	-0.2	0.1	-0.1	-0.1	0.5
Ruiri	16	0.1	0.0	0.0	0.0	0.1	0.0	0.1	0.0	-0.3

Bao scores for gender, wealth class and farmer groups adjusted as described in Box 1.
° One married couple decided jointly so no gender differentiation was made (n=37).

Table 6: Number of species for the various farmer-defined use groups (n=35).

Uses	Inventory (no. species)			Trial (no. species)		Species addition (no. species)			Species increase (%)	
	all farms	av. farm	(range)	all farms	av. farm	all farms	av. farm	(range)	all farms	av. farm
Firewood	121	16	(3-35)	27	25	7	18	(14-22)	6	110
Medicine	97	7	(1-29)	16	15	3	10	(7-14)	3	140
Fodder	87	9	(1-26)	8	8	3	5	(3-6)	3	50
Boundary marker	73	7	(1-24)	3	3	0	2	(0-2)	0	20
Timber	54	8	(2-17)	19	17	4	11	(8-15)	7	140
Fruit & nut	53	10	(4-18)	10	9	3	7	(4-8)	6	70
Ornamental	51	4	(1-16)	2	2	0	1	(0-1)	0	20
Construction	49	5	(1-16)	19	18	6	12	(9-15)	12	250
All species	297	53	(28-95)	31	°28	9	21	(17-25)	3	40

The number of species in the inventory and the trial for all farms and averaged per farm. Species addition represents the number of species –per use group- the trial added to the existing species stock (inventory) on a farm. Similarly, the species increase represents the percentage of species that the trial added to the existing species stock.
° The trial provided 31 species; however, the average number per farm was 28 due to farmer refusal and location-specific ecological differences.

Trial and inventory comparison

The wealth of species recorded in the tree inventory may not seem to correspond with the farmers' wish to diversify. In comparison to the inventory, the trial may not seem a diversification effort; 297 species were recorded and 31 species were planted in the trial, only nine of the trial species had not been present on any farm (Table 6). However, per farm, the number of species the farmers added with the trial to their existing tree species stock was evident: the average number of species per farm was 53 and, on average, 21 species were new. Species addition ranged from 17 to 25 new species per farm (Table 6). There was a major species increase per farm for use groups such as construction, medicine, timber and firewood, and only a minor increase for boundary markers and ornamentals.

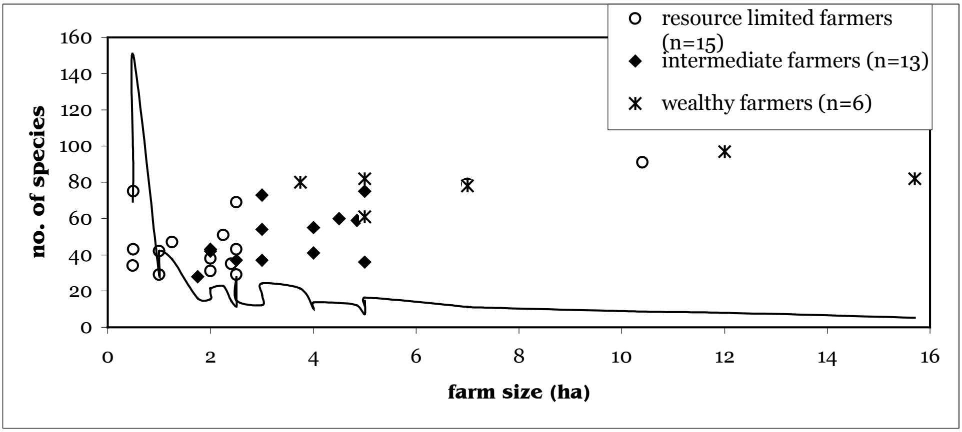

Figure 4: Number of species per resource group plotted against farm size. The line represents the species diversity corrected per farm size (n=34, as one farm size is unknown).

Evaluation

In the individual evaluations, more than half of the farmers (21 out of 38) wanted another tree species planting project; this was especially valid for the intensely cultivated Nkubu farming group (9 of 10 farmers). Half of the farmers (19) mentioned the training as one of the most important aspects gained from the trials. As many as 14 farmers said that they would like to continue having visits; visits can represent access to sources of information, decision power and germplasm, though also for reasons of friendship and status. A further 12 farmers wanted their neighbours - as they formulated it - 'to profit' from the trials, these were mainly from Ruiri, seven of whom requested assistance to set a seed production mechanism in place for that purpose. In the group evaluation it became clear that seed stands were established to remedy the limited number of trees per trial species, theft problems and over-harvesting of some of the medicinal species.

Discussion

Diversification in species and use groups

The trial showed that farmers wanted to experiment with a diverse range of species on their farm. Instead of scaling down to 'best performing' species, farmers kept adding new species - even at the end of the project, a majority of 21 farmers wanted to continue adding species. The trial did not reach the 'farmer saturation point'; with 31 species distributed, our results showed that it was not important to quantify this saturation point. Farmers will rarely be able to obtain germplasm for this many species. Therefore, farmers do not have to think about the number of possible species they can handle, as this is a theoretical problem they will never face. As a result, farmers will always 'want to test more species', despite drought, land and labour constraints.

The Bao game showed that farmers want a diverse range of species and that these were not restricted to use groups. Although multiple uses of species made it difficult to rank according to use group, timber and medicinal species had a high overall ranking. However, these preferences were not confirmed with the use group scores. In both species and use group Bao games the variation among farmers was large and went beyond the wealth and gender criteria.

No major differences between the three locations were found. This uniformity is remarkable; in Nkubu, farmers have less land and the land is of a higher agro-ecological potential, followed by Igoji and then Ruiri. Nevertheless, farm size and farming system intensification level did relate to species preferences and perception of diversity. There was hardly any trend noticeable in terms of species appreciation for small-sized, short-term, or cash-generating species. Although the land may be relatively limited, it is never considered too small for tree planting. All farmers also appreciated longer term species, especially indigenous ones. This substantiates Gupta (1998) findings: that farmers only want fast return species is one of the myths of agroforestry.

Farmers showed great interest in experimenting with (unknown) species. This was confirmed when farmers stated that they would plant a ‘bad’ unknown species if provided. The trial was about experimenting with and not necessarily about keeping these species. The wish to diversify became clear due to trial species being planted and maintained and through responses to the questionnaire and evaluation; however, keeping species may bring another scenario. Nevertheless, the increased maintenance of wildings, especially of the well-known species with ‘new’ uses, showed that farmers did diversify their farm. Furthermore, the 53 species on average per farm showed that farmers are capable of handling a large diversity.

Information and knowledge

Farmers expressed that training was one of the benefits (though it was not an ‘official’ element) of the project. This referred to the continuous information exchange, such as farmer-to-farmer exchanges in group meetings and during the Bao games. Scientists and extension workers ingested and passed on local knowledge and provided the farmers with new knowledge during meetings and through handouts with basic information. The information exchange between farmers, their visitors, extension workers and scientists evolved into a training exercise for all. Lastly, there was a more formal training component with a traditional medicinal practitioner (TMP) of ATDAM to learn more about the medicinal characteristics of tree species.

During group meetings and Bao games, it was clear that farmers were willing to share information with each other. The constraint appeared to be finding the time or place to sit down and discuss (see also den Biggelaar 1996). Another constraint could be modesty regarding the value of their own local knowledge; when an outsider appears with a facilitation role and attaches some degree of importance to local knowledge, it may become more interesting. It became apparent that knowledge was dispersed variably among individuals and sometimes it was surprising how little some farmers knew about local species, such as *Prunus africana, Rauvolfia caffra, Trichilia emetica, Ocotea usambarensis, Tephrosia vogelii*, *Juniperus procera, Carissa spinarum* and *Olea capensis*. This was especially the case for the medicinal uses of species, a knowledge base that had been suppressed in Kenya since the introduction of Christianity, to only recently be rehabilitated (ATDAM personal communications). The lecture from the TMP in farmer meetings elicited a lot of interest and significantly increased farmers’ efforts to tend and maintain trees on their farms. Biodiversity and its use and management rest in cultural diversity; conversely, conserving biodiversity often helps strengthen cultural integrity and values (WRI/IUCN/UNEP 1992).

Farmers have continued to rely on diverse agro-ecosystems to meet their livelihood pursuits for generations. In Meru, this is generally exemplified in both (tree) crops and livestock production enterprises. The reasons for tree diversity are inherent and not readily expressed - it is more a tacit knowledge; that is, knowledge 'by doing' rather than from being aware of the knowledge and being able to formulate it (Nielsen 1998). The farmers seemed to respond to diversity questions with 'surprise' because of what they took to be 'obvious benefits'. When we narrowed the questions down to use groups, some farmers seemed to give more detailed reasons for diversity on the farm (Figure 2). But probing deeper resulted in many farmers losing track of their reasons. Nevertheless, irrespective of the question we would ask, farmers continued to respond that 'different species' was an important factor. Just the same, we believed that some farmers understood the rationale of the questions well. Or as one farmer phrased it:

'You have given me a headache with these questions,
but I am happy as I had never thought about my work in this way.
We have been tree planting for three years
and I have enjoyed playing this game with a cup of tea,
but this was serious'.

Knowledge of species largely determines the farmer's perception. First, with unknown species, the farmers had to rely on the – undoubtedly biased – information provided by researchers. Learning about new uses of well-known species, the bias is almost absent as farmers know the species performance. The preference change here is solely based on whether the farmers the additional uses relevant (see also Table 3 & 4).

Second, the Bao game (Table 3), the knowledge (Table 4) and diversity questions in this study showed that conventional species preference surveys are heavily biased. They presume that the resulting 'priority' species are chosen from a list of species that is based on a certain knowledge level. Firstly, this research being in a limited geographic area already showed that knowledge is localised depending on what species occur in the landscape. Secondly, farmers are willing to expand their knowledge about a wide range of species. This indicates that the usual research scenario in which scientists concentrate on very few species is to an extent a paternalistic misunderstanding of priorities.

Third, farmers explained that the project increased their knowledge about tree species and diversity in general and this led to a change in their practices. Planting trees or any other crop comprises trade-offs between perceived benefits of products or services, from growing another species. This may not necessarily be a case of carefully weighing characteristics of every species, such as production, farm niche, labour needed and risk management, but rather more based on the farmers' tacit knowledge that has evolved over many generations. An increase in their knowledge base helped farmers to further refine their choices (also see Tables 3 & 4; Figure 3).

Conservation

With a decreasing forest cover, a use-based conservation programme is increasingly important (Simons et al. 2000). In Meru, based on the 297 species on the 35 farms sampled, the conservation of species by farmers seems impressive. The major increase in diversity of on-farm tree species achieved through the trial can however only be explained if many species occur on very few farms. Farmers are eager to diversify their farms in terms of evenness: (i) farmers have increasingly cut *Grevillea robusta* and leave wildings of other species, and (ii) farmers have set up seed stands and nurseries to propagate particular trial species.

The conservation value of this research may be limited - the unevenness of distribution and low densities in the agroforestry landscape is a concern for the long term. Many species are recorded in such low densities that their viability is doubtful as low densities increase risks for genetic erosion and (local) species extinction. Extremely low density, where a farmer group only has a single tree of a particular species, was observed in Igoji for 44 species, in Nkubu for 39 species and in Ruiri for 28 species. The consequences of low densities and recommendations on how farmers can be assisted to maintain their species base are published in separate papers (Chapter 3 & 4).

Exotic species may replace indigenous species, thereby hampering conservation efforts. Species can be replaced if exotics appear more useful to the farmer, or if species are weedy. In the three years of research, the risk of decreasing diversity through replacement of 'less useful' species by 'more useful' species (for instance *Melia azedarach* by *Azadirachta indica* in Figure 3) seemed limited. It should however be clear that farmers are the owners and decision makers of their farm and have all the right to replace indigenous species by exotics. With the provision of seedlings, 'weedy' species were excluded and possible weediness of other species was monitored carefully, although we realise that three years is too short for this.

In landscapes heavily influenced by people, species will not decrease uniformly, but will survive in some places and become extinct in others. This will go alongside local knowledge as observed with *Sapium ellipticum* and *Olea capensis*. More information exchange between farmers, nursery managers and TMPs will increase farmers' access to germplasm and their knowledge base. This will allow farmers to use and conserve more species.

Resource-limited farmers contribute relatively more to the conservation of species, since smaller farms contain more species (see also Figure 4; Kindt 2002). As mentioned in the Convention on Biological Diversity (2003), poor people depend most on biological diversity and they are the ones who suffer first in cases of biodiversity loss. A focus on the poorer farmers would therefore be most efficient in promoting the sustainable use and conservation of tree species diversity.

Access to germplasm and species choice

Farmers can only plant what is available. Limited access to species hamper farmers from making optimal decisions and to act accordingly to optimise their livelihood goals. Moreover, farmers seemed frustrated by their lack of access to germplasm (Figure 1), as was reinforced by the loud cheer following the researcher's suggestion to ask a local forest department to dig out root suckers from *Ocotea usambarensis*, a much desired species that is hard to obtain. The level of natural rejuvenation for many species was high, but not for all species (van Oijen 2002; Chapter 4).

Many species are available in the landscape (see also Table 6). However, due to the low numbers of trees per species, the unevenness of distribution among and within farmer groups, farmers have problems in accessing germplasm. Cross checking the number of seeding trees in the respective farmer groups showed that 'no seeds available' is a valid excuse. Farmers, extension workers and scientists active in tree domestication could, therefore, focus on improving access to germplasm of a wider range of species.

Seed distribution mechanisms are needed to support farmers' in their use and conservation efforts. Increased interaction among farmers, through local networks, is an option to improve access to germplasm by sharing and collective seed collection. Although farmers only need small quantities of germplasm, they may need information on basic seed collection principles, particularly guidance is needed for populations that have been reduced to a few individuals, so a reduction in genetic diversity among trees is possible within populations.

For species that are difficult to access in the landscape, Nathan's (2000) suggestion of having tree seeds sold in small bags similar to vegetable seeds could be a good option. These need to address the agro-ecological zones of the species to: (i) ensure adaptation of populations to avoid failure, and/or (ii) preserve the genetic integrity of indigenous tree populations.

However, not everyone wants to raise trees from seed - only 15 of the 40 farmers ever raised tree seedlings. Therefore, nursery managers are an important group to include in diversification efforts. They can be trained in seed collection and are suited to the introduction of quality germplasm of rare and new species.

The various activities conducted permitted a triangulation between physical results (tree inventory), farmer statements (preference scores and questionnaires) and from farmers activities (trial planting, maintenance and farm walk observations). It was expected that these would not be consistent with one another. For instance in 18 cases, farmers had shown no interest in the species prior to the trial (Figure 1); this however included two farmers who gave maximum scores for *Azadirachta indica* for all Bao games. Farmers appreciated many species, but their overall criteria for liking or disliking particular species were not very clear. Often a reasonable explanation could be found but this was regularly contradicted. This research indicated that species being highly appreciated at a certain point could just as well have been another species, depending on the time of interview, the location, but most important on the individual farmer. Indeed, the preference exercises with a random set of farmers from Betser et al. (2000) on Mt Kenya and Meru resulted in another preference list, whereas the data on tree cover turned out to be very similar (Betser unpublished data). One conclusion could therefore be to address access to germplasm of a wide range of species and good information simultaneously. Another conclusion is that species preference exercises should be interpreted with caution.

Conclusion and recommendations

The research and extension activities of this project helped to gain a better understanding of the farmers' perspective on tree species, tree diversity and agroforestry in general. Farmers clearly expressed the wish to diversify their agroforestry systems in terms of species, use groups and evenness of distribution.

Three main constraints were identified: access to germplasm, information and unevenness of species distribution. The most limiting factor for a farmer to plant a preferred species is access to germplasm. Species preferences by farmers are largely determined by knowledge, and therefore access to germplasm and information exchange should go hand in hand. More species on offer with better information attached is important in the design of seed and seedling supply systems for farmers.

Information about species uses and diversification can be obtained through increased interaction among farmers, as a vast knowledge base already exists within the farming community. An option is to facilitate (existing) farmer groups to share information as well as germplasm. The results showed that information and access should not be restricted to rare or exotic species only. The groups can include (on-farm) nursery managers to share information and access germplasm at the same time. Another option is to include traditional medicinal practitioners for more specialised knowledge. All these forums can also be used to provide additional information from outside the communities.

The unevenness in species distribution and low densities of many species in the landscape raise concerns about the viability of populations, and subsequently the sustainability of agroforestry systems in general. It also causes limited access to germplasm for farmers within and between locations and increases chances of losing knowledge.

Use-based conservation appears to be an effective method to conserve species and local knowledge. The full potential can be met through the above-mentioned germplasm-information strategy. This will increase farmers' options to conserve species to a large extent, as: (i) farmers have not yet reached their species saturation point by far, and (ii) farmers want to diversify their farm in terms of evenness of distribution. A focus on the poorer farmers would be very efficient.

The knowledge gained by this research will be used to further improve domestication strategies. A focus on domestication the landscape's diversity instead of only on a few priority species should be given greater emphasis. Results show how farmers, extension workers and scientists learned to understand the possibilities, usefulness and constraints of increasing diversity. This diversity will make agroforestry practices more sustainable and productive as well as helping to conserve local biodiversity. Supporting farmers in their choices will assist them in their livelihood strategy.

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Chapter 3

Tree Species Diversity on Farms in Cameroonian, Kenyan and Ugandan Landscapes

Roeland Kindt [12], Ard G Lengkeek [13], Anthony J Simons [1],Patrick Van Damme [2], Jean-Marc Boffa [4], Ann Degrande [5], Jean-Gaël Jourget [6], Charlie Mbosso [5], Danielle CC van Oijen [3] and John C Weber [6]

[1] ICRAF, the World Agroforestry Centre, PO Box 30677, Nairobi, Kenya.
[2] Ghent University, Laboratory of Tropical and Subtropical Agriculture and Ethnobotany, Coupure Links 653, B-9000 Gent, Belgium
[3] Wageningen University and Research centre, Biosystematics Group, Gen. Foulkesweg 37, 6703 BL, Wageningen, The Netherlands
[4] ICRAF, PO Box 1752, Kampala, Uganda
[5] ICRAF, PO Box 2067, Yaoundé, Cameroon
[6] Dicles, 42380 Perigneux, France
[7] ICRAF, Apartado Postal 1558, Lima 12, Peru

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Abstract
Agroforestry is aimed at diversifying and sustaining agricultural landscapes for increased social, economic and environmental benefits. We calculated species accumulation curves (documenting the relationship between sample scale and species richness) for all species and species belonging to the dominant on-farm niches and functions of trees on-farm in each of 4 landscapes of tropical Africa. Important differences could be observed between functions and niches, which allow one to target diversification efforts to groups of species of lower diversity. Ecological research demonstrated that diversification of a group of low diversity will have larger effect on ecosystem functioning than the same level of diversification of a group of higher diversity. Targeting diversification towards groups of low diversity could also be more relevant to limit risks of non-production. Species were not distributed at random over villages, which allows for increases in their richness by distributing species more randomly in the landscape. Distance to forest, wealth, farm size and family size were positively linked with species richness within a use-group in a minimum of 3 landscapes each. In western and central Kenya, >70% of trees were planted, whereas in Cameroon and central Uganda <50% of trees were planted. Exotic species had higher abundance than their species proportion. Population sizes of indigenous species were, therefore, small so that village- and/or landscape level genetic diversity management efforts may be necessary to ensure that tree populations are sustained.

Keywords: agroecosystem; conservation; diversification; diversity; domestication; farms; forest; metapopulation; species accumulation; tree

Introduction

Ecological experiments and models have shown that diversification of species composition could lead to enhancements of the stability and productivity of ecosystems (e.g. Chapin et al. 2000; Cottingham et al. 2001; Loreau et al. 2001; Norberg et al. 2001; Tilman et al. 2001). Increasing the stability and productivity of agroecosystems by diversifying the composition of tree species on farms is one of the objectives of the International Centre for Research in Agroforestry (ICRAF 2000). The studies presented here were aimed at exploring tree species diversity in four African agroecosystems, so that their diversification could be planned. We expect that diversification of sections of landscapes that have lower diversity at present will have larger effects on ecosystem function.

The species-area relationship shows that more species will be encountered when a larger area is sampled (Arrhenius 1921). The existence of species-accumulation patterns implies that statistics on species richness are meaningless without referring to the sample size used to obtain them. In this study, scaling patterns of tree-species richness were investigated within managed landscapes. Within each landscape, diversity was compared among groups that combined all trees of a particular establishment pattern (*i.e.* niches) and groups that combined all trees with a similar product or service (*i.e.* use-groups). The relationship between species diversity on farm and farm characteristics such as distance to forest ecosystems, gender of the household head and wealth was investigated to assist in planning future diversification efforts. This study focused on tree species diversity in agroforestry systems, so surveys were conducted only on farms. Landscape diversity, which would include diversity in the forested areas near the farms, was not completely sampled.

The primary objective of the surveys was to explore options for diversification of agroecosystems – not to investigate the design of ecological approaches to conservation of indigenous or endemic tree species. Integrating indigenous tree species in agroecosystems is one condition for their long-term conservation within these systems. However, further research on aspects of individual species – such as their reproductive ecology, genetic diversity, and landscape-level metapopulation dynamics – should be investigated to address their long-term conservation (Hanski 1999; Young et al. 2000; Palmer et al. 2001).

Methods

Study areas

Complete tree inventories were made on farms in four landscapes in Cameroon, Uganda, western Kenya, and central Kenya. Farms, defined as all land managed by a household, were sampled in a random or stratified random manner within villages. Villages were sampled in a stratified random manner based on their distance from forests. This sampling strategy separated the effects on tree diversity due to villages and to household characteristics within the villages.

Cameroon
The study area is located between 10°N and 6°S, and 30°W and 35°E and is characterized by altitudes of less than 1000 m above sea level. Annual rainfall ranges between 1400 and 4000 mm with bimodal distribution and the main daily temperature varies between 24 and 27°C. The soils are mainly ferric acrisols.

Information was available from 39 farms, located in two villages. One village was located in a humid forest zone (2°55' N; 11°21' E), the other in a degraded humid forest zone (4°06' N; 11°24' E). Households were sampled based on a participatory wealth-ranking exercise (Degrande et al. personal observations).

Central Uganda: Mabira
The study area was located near the Mabira Forest Reserve, in the Mukono District between the major towns of Kampala (45 km) and Jinja (20 km), at 1070-1340 m above sea level. This area is in East and Central African Bimodal Highlands, characterized by altitudes greater than 1000 m above sea level, with two pronounced rainy seasons, and total annual rainfall exceeding 1000 mm (Hoekstra 1988).

The surveys collected information from 105 farms and 15 villages that were arranged in five equidistant, radiating axes that started from the Mabira Forest Reserve (axes at angles of about 72°). Along each axis, 3 villages were selected at different distances from the Mabira Forest Reserve: one village less than 1 km from the forest, a second 5-7 km from the forest, and a third 12-19 km from the forest. Within each village, a randomly-stratified sample was taken based on the gender of the head of the household and wealth (Boffa et al. personal observations).

Western Kenya: Vihiga and Kakamega
The study area is located in the East and Central African Bimodal Highlands. The area is inhabited predominantly by the Luhya (Luyia) ethnic group and belongs to agroecological zone Upper Midlands 1 (Tea-Coffee Zone), a zone with permanent cropping possibilities consisting of two or three variable seasons. In the zone, altitude ranges 1500-1800 m above sea level, annual mean temperature ranges 18.1-20.4 °C, and annual rainfall ranges 1600-2000 mm (Jaetzhold & Schmidt 1983).

Surveys were conducted on 201 farms located in four villages. Each village was located in a different stratum as identified by Bradley et al. (1985) through interpretation of low-level aerial photographs. Strata mainly differed in farm sizes and arrangement of woody biomass in the landscape. The selection of villages coincided with distance (2.5, 15, 25 and 32 km) from the species-rich Kakamega Forest National Reserve. Selection of farms within villages was random.

Central Kenya: Meru
The study area is located in Meru district, adjacent to Mount Kenya National Park / National Forest, which was inscribed on the IUCN World Heritage List in 1997. The Natural Forest (70,520 ha) is located between 1600 and 3100 m above sea level. This study area belongs to the East and Central African Bimodal Highlands, as the previous two study sites.

Surveys were conducted on 35 farms in 3 villages. Surveys followed the framework of participatory on-farm species screening trials that were implemented earlier. For the trials, three groups were selected within similar agro-ecological zones (Upper Midlands 2 and 3: Coffee and Marginal Coffee Zones), and based on different distances from the forest (0, 12 and 25 km). Farmers, who were willing to participate in tree planting trials, were selected for the surveys according to wealth and gender (Chapter 2).

Information recorded on tree species

Complete tree inventories were done through participatory interviews conducted during walks on all sections of selected farms. Species were identified in the field where possible, while local names, herbarium specimens, and repeated field visits were used to identity species that were not identified during the first inventory. However, the botanical identity could not be established for all species. The number of botanical families, therefore, may be underestimated. The percentage of indigenous species could be overerestimated if several unidentified specimens were actually the same local species. Nevertheless, since most species were identified (85% in western Kenya, 90% in Meru, 93% in Uganda, and 100% in Cameroon) the general trends reported below should hold true.

To better describe the distribution of species within each landscape, the number of trees within predefined on-farm niches was counted for each species, with the exception of cocoa (*Theobroma cacao*) in Cameroon (this was an oversight – although cocoa gardens were distinguished as a particular niche, cocoa should also have been inventoried). Related to the focus on agroecosystem productivity, species were grouped according to their uses documented by ethnobotanical surveys that complemented the biodiversity surveys. Informants explained the products and services that each species provided on their farms. Analyses were made for the main niches and use-groups (Table 1).

Species accumulation

Species accumulation curves show the trend in which additional species are encountered when a larger area is sampled. The exact average species richness for random accumulations of sites (farms in this case) can be calculated using an approach based on the hypergeometric distribution rather than the less accurate and more lengthy Monte-Carlo procedure of calculating the average species richness of various random site sequences (Kindt 2001a). Where species *i* occurs on f_i of F_{tot} sites, the expected average species richness after *N* random site additions for S_{tot} species equals

$$\hat{S}_N = \sum_{i=1}^{S_{tot}} \left(1 - \prod_{a=1}^{N} \frac{F_{tot} - f_i - a + 1}{F_{tot} - a + 1}\right) = \sum_{i=1}^{S_{tot}} \left(1 - \binom{F_{tot} - f_i}{N} \Big/ \binom{F_{tot}}{N}\right).$$

Species accumulation curves were calculated with a program that calculates $\hat{S}_N$ over the entire range of accumulated sites from a site × species matrix.

Results

Overall species diversity in the landscapes

Fig. 1 and Fig. 2 show the relationship between the number of farms and average species richness in the four landscapes. Species richness accumulated in a downward convex manner in the log(sample size)-log(richness) space, so that the same difference in sample size at larger sample sizes corresponds to smaller increases in richness. This nonlinear pattern in log-log space implies that a two-parameter model for species richness, such as $S = cA^z$ (Arrhenius 1921), will not accurately describe species accumulation. The figures further indicate that the landscapes mainly differed in alpha diversity (the average number of species on one farm), whereas the shapes of the species accumulation curves were relatively similar within the four landscapes.

Average species richness on a farm ranged from 16.6 in western Kenya to 53.2 in Meru (Table 1). Total species richness was lowest in Cameroon) and highest in Meru (Table 1). Since the sample sizes in the landscapes were not the same, comparisons between surveys are only meaningful after species richness is *rarefied* to the same sample size (*e.g.* Sanders 1968; Hurlbert 1971; Magurran 1988; Hayek & Buzas 1997; Legendre & Legendre 1998; Gotelli & Colwell 2001). After adjusting for the same number of farms (n=35 corresponding to the sample size for Meru), western Kenya had the lowest richness (96.5) and Meru the highest richness (294).

Although diversity if often equated with species richness, diversity is a function of the number of species and the evenness in distribution of species' abundances (Magurran 1988; Purvis & Hector 2000). Although the frequency (abundance/total abundance) of the dominant species (*i.e.* the Berger-Parker diversity index) does not provide a complete characterization of the evenness of a particular system, it is a practical statistic for diversification planning (Kindt et al. 2001). Systems that are perfectly evenly distributed have no dominant species as each species has a frequency equal to the reciprocal of the total species richness.

Comparisons between total species richness and the frequency of the dominant species show that each landscape contained a dominant species (Table 1). The dominant species had the highest frequency in Meru (*Coffea* cultivars with 32%) and the lowest frequency in Mabira (*Markhamia lutea* with 13%). The dominant species *Eucalyptus saligna* and *Persea americana* had frequencies of 17% in western Kenya and 14% in Cameroon respectively.

Table 1 shows the large number of botanical families represented in the surveys, ranging from 42 in Cameroon to 64 in Meru. Total species richness was mainly composed of indigenous species, since only 13% (Cameroon) to 28% (Meru) of species were exotic (Table 1). Exotic species, however, constituted a proportionally larger percentage of the total abundance, ranging from 30% (Cameroon) to 62% (Meru). The two Kenyan landscapes differed from the others in having a higher percentage of planted trees (71% and 80%, versus 48% and 37%). Most of the exotic trees were planted, but also some indigenous trees were planted (*e.g.* in Cameroon, only 60% of planted trees were exotic).

The 1997 IUCN Red List of Threatened Plants (Walter & Gillett 1998 at http://www.unep-wcmc.org) was consulted to check the IUCN threat category of the species encountered in the four landscapes. Of the 237 species included in the list for Kenya, one rare species (*Euphorbia friesiorum*) and three vulnerable species (*Milletia tanaensis, Prunus africana* and *Vitex fischeri* syn. *Vitex keniensis*) were encountered in Meru. *Vitex fischeri* was also encountered in western Kenya. None of the 15 species listed for Uganda nor the 87 species listed for Cameroon were encountered (not sure if *Prunus africana* was included).

The spatial distribution of species was investigated using two methods: a null model that simulated a random distribution of farms in the landscape (Kindt 2001c), and Redundancy Analysis (Legendre & Legendre 1998; Makarenkov & Legendre 1999; Legendre & Gallagher 2001). Results indicated significant aggregation of species within villages and significant differences in species composition among villages in all four landscapes (Kindt et al. personal observations).

Table 1: Diversity characteristics on farms surveyed in four African landscapes. Characteristics are tabled for the entire landscape (all) and for representative niche-groups and use-groups. Characteristics include the percent of farms; alpha diversity (average farm richness); total number of species; percent of exotic species; total number of families; abundance on farms where the group is present; percent abundance of dominant species (dom.) and exotic species; and percent abundance of all planted species and planted exotic species.

Landscape surveyed	Group (all, niche or use)	% farms	Alpha diversity	Species total (S_T)	% exotic species	Family total	Abundance per farm	% abundance dom.	% abundance exotics	% abundance planted	% abundance planted exotics
Cameroon	All	100.0	29.5	119	12.6	42	171.8	13.8	29.9	48.2	28.2
(*n*=39)	Cocoa	92.3	24.9	116	11.2	41	147.8	13.8	26.3	46.7	24.8
	Homegarden	53.8	3.1	23	47.8	18	18.1	21.6	78.4	90.0	74.5
	Foodcrop	41.0	3.2	56	16.1	31	36.9	15.6	35.2	51.8	34.6
	Fallow	23.1	2.7	52	19.2	30	45.4	12.5	23.2	25.4	20.3
	Firewood	100.0	21.7	109	9.2	39	128.7	18.0	33.6	46.8	31.7
	Fruit	100.0	8.1	30	36.7	18	84.8	27.6	59.0	90.6	56.1
	Medicine (human)	100.0	13.6	84	9.5	37	88.3	16.0	30.8	54.6	29.8
	Construction	97.4	10.5	76	3.9	35	46.3	18.4	1.2	12.1	1.2
	Spices	97.4	2.0	18	11.1	12	9.8	55.0	0.5	33.8	0.3
	Tools	84.6	3.1	40	12.5	23	14.9	19.1	10.0	15.7	10.0
	Soil fertility	76.9	1.4	28	7.1	16	13.2	44.7	4.3	18.4	4.0
	Stimuli	64.1	1.0	5	0.0	4	5.6	82.3	0.0	90.1	0.0
	Gums	51.3	0.7	11	18.2	10	14.0	45.0	22.9	55.7	16.1
	Drugs	30.8	0.6	13	0.0	10	10.0	45.0	0.0	46.7	0.0
	Fodder / animal medicine	30.8	0.5	15	26.7	13	12.8	27.9	53.2	64.9	48.1
	Shade	25.6	0.8	19	10.5	15	16.8	16.7	23.8	37.5	23.8
	Vegetables	23.1	0.2	3	0.0	3	3.2	89.7	0.0	0.0	0.0
Mabira	All	100.0	27.9	249	23.3	62	210.7	12.6	31.7	37.4	22.6
(*n*=105)	Cropland	99.0	20.1	202	21.3	55	122.3	13.3	29.0	31.6	18.1
	External boundary	85.7	4.6	100	21.0	35	37.6	25.7	40.0	64.0	33.8
	Homestead	81.9	5.3	120	36.7	41	21.7	15.7	56.8	70.7	49.4
	Fallow	21.9	2.5	94	14.9	37	88.5	8.0	11.4	8.1	5.3
	Internal boundary	13.3	0.6	46	15.2	25	28.9	38.0	44.9	56.3	42.0
	Firewood	100.0	15.1	187	17.6	46	118.3	15.5	20.3	24.1	11.4
	Fruit	100.0	5.5	24	58.3	17	31.4	28.2	95.2	61.2	59.1
	Medicine	92.4	3.6	79	24.1	29	25.2	27.8	27.5	24.4	19.1
	Construction	89.5	2.4	70	9.5	30	41.7	59.5	15.9	25.2	10.9
	Timber	89.5	3.8	71	19.7	27	33.2	18.5	4.4	22.1	3.6
	Shade	80.0	3.0	93	33.3	36	24.5	32.0	16.9	46.7	10.3
	Boundary demarcation	78.1	1.4	19	36.8	12	32.3	43.2	51.0	67.9	42.9
	Soil fertility	60.0	1.0	32	21.9	12	17.5	22.2	28.7	55.4	27.4
	Leaves for cleaning utensils	41.0	0.4	1	0.0	1	4.2	100.0	0.0	1.1	0.0
	Charcoal	36.2	1.1	58	12.1	22	24.7	20.7	7.0	8.5	4.8
	Fodder	33.3	0.6	16	31.3	6	19.5	55.3	28.2	72.4	24.0
	Ornamental	24.8	0.4	31	48.4	18	4.3	20.7	47.8	78.8	45.1
	Stakes	24.8	0.3	6	16.7	3	46.1	93.4	93.6	91.0	89.2
Western	All	100.0	16.6	175	22.9	49	508.1	16.9	72.3	80.2	62.6
Kenya	Cropland	98.5	6.5	105	27.6	37	107.1	56.9	71.8	87.9	67.2
(*n*=201)	External boundary	95.0	4.6	64	31.3	31	211.8	30.8	70.8	87.9	63.8
	Homestead	89.6	5.0	107	29.0	34	24.6	22.6	73.4	67.5	57.1
	Woodlot	74.6	2.9	72	29.2	32	152.2	65.1	79.6	72.2	68.0
	Internal boundary	36.3	0.9	43	25.6	26	65.5	16.4	54.8	90.8	48.4
	Fallow	20.9	1.3	81	27.2	35	113.8	41.5	55.3	14.7	9.1
	Crop contours	11.9	0.2	23	43.5	12	34.6	19.5	63.0	46.7	41.7
	Firewood	100.0	15.2	156	25.6	45	476.7	18.0	75.9	79.4	65.7
	Fruit	100.0	4.7	25	60.0	14	46.1	72.6	99.2	21.8	21.5
	Boundary demarcation	98.0	2.8	34	38.2	20	217.6	30.9	73.1	92.6	66.3
	Construction	98.0	1.9	20	50.0	11	111.6	78.4	80.3	82.9	79.3
	Furniture	97.5	3.9	49	28.6	23	142.2	61.9	92.9	93.3	90.3
	Shade	82.6	3.0	84	34.5	29	28.7	13.0	55.6	58.2	38.7
	Soil fertility	67.7	1.0	27	44.4	18	87.8	52.8	63.7	89.7	63.6
	Medicine	55.7	1.2	58	12.1	22	23.3	66.4	10.5	19.6	10.4
	Ornamental	47.8	1.0	53	35.8	23	55.0	50.9	56.2	94.8	52.3
	Charcoal	39.8	0.6	27	37.0	13	42.6	49.6	57.5	60.2	54.1
	Beverage	30.8	0.4	4	75.0	4	309.4	80.3	80.3	100.0	80.3
	Fodder	23.4	0.3	7	57.1	4	9.7	42.1	44.3	54.6	41.6

Meru	All	100.0	53.2	294	27.9	64	1798.5	32.0	61.8	71.1	59.4
(*n*=35)	Cropland	100.0	17.9	136	26.5	49	160.6	17.2	49.7	61.1	36.3
	External boundary	100.0	26.6	198	20.7	54	692.2	10.0	47.7	60.4	37.2
	Homegarden/homestead	94.3	8.7	107	53.3	42	28.3	20.2	63.7	77.4	59.6
	Coffee garden	91.4	10.7	100	20.0	44	677.9	71.1	94.8	93.4	92.1
	Internal boundary	88.6	8.2	114	34.2	41	186.4	15.4	76.9	80.9	71.0
	Fallow	68.6	6.7	117	20.5	45	114.1	13.8	40.0	29.9	24.4
	Crop boundary	54.3	1.9	36	36.1	20	17.9	19.1	72.7	72.4	64.2
	Woodlot	45.7	5.3	103	23.3	46	93.0	11.3	31.9	51.1	27.3
	Firewood	100.0	16.1	121	23.1	45	534.1	35.1	70.1	67.4	59.0
	Fodder	100.0	9.1	87	17.2	39	263.7	28.3	48.3	51.5	38.1
	Fruits or nuts	100.0	9.8	53	49.1	28	106.2	13.9	71.9	46.0	40.0
	Timber	100.0	8.1	54	24.1	29	191.3	45.7	65.7	62.8	51.3
	Boundary demarcation	97.1	7.2	73	26.0	47	508.4	26.6	51.4	81.0	55.5
	Cash	97.1	2.6	8	50.0	6	637.2	93.3	94.7	99.8	94.5
	Medicine	97.1	7.1	96	14.6	40	200.6	14.7	23.0	45.3	17.1
	Construction	91.4	4.2	49	26.5	27	126.2	28.5	63.1	55.9	47.3
	Ornamental	82.9	3.6	51	70.6	24	46.1	34.1	86.9	98.2	88.5
	Plant support	62.9	1.2	16	12.5	11	122.7	40.9	37.1	91.3	37.1
	Animal traps	51.4	0.9	15	0.0	2	15.0	34.1	0.0	13.7	0.0
	Charcoal	45.7	1.1	20	10.0	14	27.8	24.0	6.1	9.4	4.3
	Tool handles	45.7	0.6	9	0.0	8	25.2	42.9	0.0	34.7	0.0
	Shade	42.9	0.6	13	53.8	11	7.9	49.6	79.8	65.5	53.8

Species diversity in various sections of the landscape

Similar analyses, described above for all trees, were performed for trees that occurred in various sections of the landscape, which are referred to below as on-farm niches. The results allow ranking niches from less to more diverse.

Similar to the analysis of all trees, species accumulation patterns were downwards convex (Fig. 1). For some niches, such as internal boundaries in Mabira and crop boundaries in Meru, curvature was minimal. The richest niches irrespective of sample size were the cocoa gardens in Cameroon, cropland in Mabira, external boundaries in Meru, and homesteads and cropland in western Kenya. Lower richness in some niches was linked to lower frequency of these niches in the landscape – for example, homegardens only occurred on 54% of farms in Cameroon and woodlots only on 46% of farms in Meru (Table 1). In general, niches with higher alpha diversity also had higher total richness. However, some accumulation curves intersected, for example homegardens and fallows in Cameroon, external boundaries, woodlots and fallows in western Kenya, and fallows and coffee fields in Meru. These cases indicate strong sample-size influences on species richness.

Table 1 demonstrates that species were not evenly distributed in any niche. Coffee fields in Meru were most strongly dominated as *Coffea* cultivars had 71% of group abundance. Fallows in Mabira were least dominated as *Persea americana* only had a frequency of 8% in that niche. A niche with larger total species richness does not necessarily have a smaller proportion of the dominant species. For example, fallows in Cameroon and Mabira had the smallest frequency for the dominant species, but these were not the niches with the largest total richness. Where rank-orders for total richness and evenness are not the same, systems cannot be ranked from less to more diverse (Kindt et al. 2001).

Table 1 shows that niches differed in the percentage of exotic species they contained. Homegardens and homesteads contained the largest percentage of exotic species in Cameroon, Mabira, and Meru. In Cameroon and Mabira, homegardens and homesteads also formed the niche with largest percentage of exotic and planted trees. The homestead area is the space around houses that can be distinguished from other niches such as cropland or boundaries, but it is not necessarily dense enough to be a homegarden. However, a fixed criterion to discriminate between homegardens or homesteads was not used.

Tests on the spatial distribution of species indicated that species were aggregated in some niches (*e.g.* cocoa gardens in Cameroon, cropland in Mabira and western Kenya), but not all niches (*e.g.* homegardens in Cameroon, fallows in western Kenya) (Kindt et al. personal observations).

Species diversity distributed over uses

The total number of use-groups distinguished were 17 in Cameroon, 51 in Mabira, 60 in western Kenya, and 62 in Meru (Appendix 9, medicinal uses combined). Many species had several uses, therefore the sum of total richness of individual use-groups exceeds overall richness.

Fig. 2 shows that although in general the use-groups with larger alpha diversity also had higher total richness, more intersections among accumulation curves were observed than for niches. This indicated stronger differences among farms in species composition within use groups than within niches. Fruit had high alpha diversity and low beta diversity (*i.e.* a less steep species accumulation curve) in the four landscapes. Unlike the downwards convex pattern observed for all niches, some use-groups had a downwards concave pattern at larger sample size – examples include vegetables in Cameroon, stakes in Mabira, beverage and fodder in western Kenya, and cash-generating trees in Meru.

Within the four landscapes, firewood was the use-group with largest alpha diversity and total richness, which indicates that firewood was the primary or secondary function of many species. Use-groups with more specific requirements had low total species richness: examples were species with hairy leaves that are used to clean utensils (Mabira), species providing leafy vegetables (Cameroon) and species used for beverages (western Kenya). For the more general use-groups like shade, ornamental planting, boundary demarcation, and soil fertility improvement, total richness was never below 10 species.

As for niches, a use-group that had lower richness than another use-group did not necessarily have lower evenness than that use-group (Table 1). It is therefore impossible to rank most use-groups in terms of diversity. Some use-groups, however, can be distinguished with lower diversity than the other groups in the same landscape: vegetables and stimuli in Cameroon, leaves for cleaning utensils and stakes in Mabira, beverage in western Kenya, and cash in Meru.

Table 1 shows that use-groups of larger total richness were rarely dominated by few botanical families, except for animal traps in Meru composed of only 2 families (15 species). In some use-groups, nearly half or more than half of the species were exotic. These included fruit and ornamental in Mabira; cash, fruit (or nut), and ornamental in Meru; and fruit, construction, and beverage in western Kenya. When considering the abundance of trees, rather than the number of species, even more use-groups were dominated by exotic species. In many use-groups, more than half of the trees was planted. In general, groups with more planted trees contained more exotic species.

As for niches, species were aggregated and species composition differed significantly for some, but not all, use-groups (Kindt et al. personal observations).

Relationships between farm diversity and farm characteristics

The hypothesis that species diversity varied among use-groups and among farms was investigated by stepwise multiple regression analysis (Anderson & Legendre 1999; Mathsoft 1999). Details of the methods and tabulated results are not presented. If the hypothesis is correct, domestication efforts could meaningfully focus on use-groups and/or types of farms of lower diversity.

Use-group and farm characteristics explained 57% – 81% of variation of farm richness. Although partial regression coefficients indicated that the variation explained by farm characteristics was very low (< 5%), the regression coefficients for many farm characteristics were statistically significant. The following characteristics had a positive influence on species richness: wealth in all four landscapes; farm size in three landscapes where it was measured (not measured in Mabira): and distance from the forest and family size in three landscapes (not in Meru). Other characteristics of farms showed less consistent patterns across the four landscapes. For example, male-headed farms had more species in western Kenya but fewer species in Cameroon. Some characteristics were only measured in one landscape. For example, in Cameroon households that were indigenous to the village had more species on their farms, compared with households that had immigrated from other villages; and in Mabira, farmers that had been identified as forest users had more trees and more species on their farms, compared with farmers that were not identified as forest users.

Discussion

Are tree populations large enough on farms?

A large number of tree species were found on farms in the four African landscapes included in this study. Although most species were indigenous, there were many trees of exotic species. In both Kenyan landscapes, for example, the percentage of indigenous species was larger than the percentage of exotic species, but a larger percentage of individual trees was exotic. This pattern indicates that, although farmers were protecting and actively planting trees of some indigenous species on their farms, they were planting a larger percentage of exotic species. Further research is required to determine if this reflects (a) differences in value derived from exotic versus indigenous species; and/or (b) higher levels of natural regeneration of indigenous species, compared with exotic species (Chapter 4).

Farmers do not manage species – they manage individual trees or populations of trees. The fact that the census number of many indigenous species was rather low stresses the importance of evaluating effective population sizes of tree species: in Cameroon, Mabira, western Kenya and Meru, respectively, 39%, 53%, 63% and 47% of indigenous species had fewer than 10 tree individuals in the landscape survey. In addition, most species in western Kenya were aggregated within farms and within villages (Kindt et al. personal observations). If farmers plan to manage trees for sustainable production, then the effective population size should be maintained at least at 50 trees to ensure that most genetic diversity is maintained over time (O' Neill et al. 2001).

It is difficult to assess, however, whether current abundance and distribution of indigenous tree species within a matrix of farmland and natural ecosystems leads to adequate effective population sizes because information on the reproductive ecology of many tropical tree species is very scant (Alvarez-Buylla et al. 1996; Boshier 2000). Metapopulation models that simulated spatially-realistic geneflow suffered from lack of information on geneflow, current levels of genetic diversity and species distribution in other sections of the landscape (Kindt 2001b; Kindt et al. personal observations). More species-specific information is thus required to assess how many species are composed of "sink populations" only. For example, only nine trees of the vulnerable *Milletia tanaensis* were recorded in two villages in the Meru landscape. However, it is not known if these trees were connected by geneflow with trees in other sections of the landscape. The three other species listed in the IUCN Red List, *Euphorbia friesiorum, Prunus africana* and *Vitex fischeri*, were very abundant in Meru (289, 404 and 597 trees, respectively), but there was no information about the source and historical bottlenecks in these populations (see also Chapter 7).

Species that grow in low densities do not necessarily have high risk of genetic erosion – most canopy trees of tropical rain forests have densities lower than one tree ha^{-1} (Chase et al. 1996). Hamrick and Nason (2000) mention that pollen flow can be quite extensive (>25%) over distances of one kilometer. Young and Boyle (2000) indicate that pollen flow can be high in fragmented populations, provided vectors can pass non-forest habitat. Young and Merriam (1994) and White et al. (2002) showed that fragmentation could actually lead to an increase in pollination distances. Chase et al. (1996) found that isolated trees could act as stepping stones for geneflow among populations. Stacy et al. (1996) studied the combined effects of subpopulation size and species aggregation, and reported that plants in small clusters received more pollen from outside than plants occurring in larger clusters or in more even distributions. Young and Boyle (2000) indicated the potential danger of outbreeding depression where fragmentation had lead to breakdown of local populations while geneflow between populations was maintained. Overharvesting of trees reduces census numbers and may lead to lowering of genetic diversity and inbreeding depression (Murawski et al. 1994; Dayandandan et al. 1999).

Cain et al. (2000) pointed out that the patchy nature of many landscapes makes long distance seed dispersal of many spatially isolated species a necessary, although unusual, event. Reay and Norton (1999) and Galindo-González et al. (2000) reported that dispersal can occur in restoration sites and pastures. However, Hanski (1999) mentions that a significant amount of habitat is often unoccupied, indicating limitations in movement of many species. Dalling et al. (1998) and Hubbell et al. (1999) report that dispersal limitations in tropical forests result in their higher species richness. Cordeiro and Howe (2001) found that recruitment of animal-dispersed trees in small forest fragments (< 9 ha) was about 1/3 the value observed in fragments that were three times larger, whereas recruitment of wind- and gravity dispersed trees was unaffected by fragment size. As most tropical trees bear fruit adapted for animal dispersal, these authors, therefore, expect tree recruitment limitations for most species following forest fragmentation. Aldrich and Hamrick (1998) indicated further complexities as they found that 68% of seedlings in forest remnants originated from remnant adults in surrounding pastures, creating a genetic bottleneck.

Specific species and landscapes need to be evaluated to determine if current pollen and seed dispersal limitations exist and if they lead to genetic erosion. In case substantial genetic erosion is recorded or expected under current tree management practices, farmers could co-ordinate germplasm exchange within and among farming communities, or obtain more diverse germplasm if available from forests, plantations or germplasm production stands (Kindt & Lengkeek 1999, O' Neill et al. 2001).

Do African farmers want tree diversity?

The fact that farmers prefer certain species and only maintain other species in low abundance does not necessarily mean that they are unwilling to foster diversity. In western Kenya, in a follow-up survey to the tree inventories, farmers were requested to rank species by preference, and also asked which species they desired on their farms (Kindt et al. personal observations). In the survey, although exotic species often were preferred for particular use-groups (e.g. *Eucalyptus saligna* for construction and firewood, *Persea americana* for fruit), farmers expressed the desire to maintain a variety of indigenous species on their farms for these uses. In addition, some indigenous species were preferred for other uses (e.g. *Sesbania sesban* for soil fertility improvement, *Warburgia ugandensis* for medicine). Therefore, although many indigenous species regenerated naturally and were not highly preferred in western Kenya, farmers desired their presence.

The various explanations that farmers provided for preferring diversity within a use-group included statements about the advantage of complementary characteristics that were not easily provided by a single species. Examples were the need for strong poles and flexible branches for construction, higher efficacy of medicines when used in mixtures, fast versus more robust growth for boundary marking or timber, and year-round supply of fruit, firewood, and charcoal. Moreover, surveys did not indicate a saturation point for desired diversity, as farmers with high richness on their farms also desired high richness. In addition, farmers preferred to obtain several tree products and services from their own farm, rather than concentrating on one species.

Limitations in local knowledge about alternative species was an important factor that prevented farmers from increasing diversity on farms. Although many farmers were experimenting with new species on their farms, wider distribution of information could result in more rapid diversification. Lengkeek et al. (personal observations) also noted that farmers that had experience with the performance of many species opted for more diversity. Experiments that introduced new species to farmers resulted in substitution of the dominant species *Grevillea robusta* by other species. The fact that forest users in Mabira maintained higher species richness and abundance on their farms also indicates that knowledge about species' uses could facilitate wider cultivation of these species (Boffa et al. personal observations).

Whereas farmers wanted diversity mainly for differentiation among and within products and services, ecological research has demonstrated that there is a conditional positive relationship between ecosystem diversity, and ecosystem stability and productivity, although it is often difficult to distinguish between effects due to species' identities and species diversity *per se* in these studies (Cottingham et al. 2001; Kindt et al. 2001; Loreau & Hector 2001; Loreau et al. 2001; Tilman et al. 2001; Cardinale et al. 2002). The positive relationship is based on heterogeneity and complementarity in species' and environmental characteristics – for homogenous environments, one species will be more productive than species' mixtures. Variation in species' traits provided by mixtures could lead to increments in productivity and stability. Diversification could also reduce risks in an uncertain market environment, or if there are potential pest and disease problems with a particular species. Diversifying species does not necessarily reduce their threat where new species are also hosts (Schroth et al. 2000) – species-rich mixtures that provide low variation in species' traits will have smaller benefits on their functioning. Future research could focus on identifying species that perform well in mixtures by providing (1) the variation in products and services desired by farmers, and (2) the variation in species' traits that complement the environmental heterogeneity.

Distribution of species within landscapes

Results indicated the presence of spatial patterns in the distribution of diversity of many use-groups or niches. In many cases, a more random distribution of species – and of their uses – would result in higher average richness of villages. Such results indicate the potential for diversification of the landscape without introducing new species. For example, species that are dominant in one village and not in another could be prime species to introduce in neighboring villages where they have low abundance, since such species would already have demonstrated their fitness in the landscape. Landscape sections with low evenness could also be targeted by future interventions that seek to diversify agroecosystems. Species diversity and composition also differed among various types of farmers, so that species could be introduced from one type of farmer to another.

Species accumulation curves provide information about the possibility of enhancing diversity by modifying the distribution of species that are already present in the landscape. A wider distribution of species that currently have lower frequencies would substantially increase the alpha diversity, especially in landscapes where alpha diversity is low and beta diversity is high. In contrast, landscapes with high alpha and low beta diversity have a more limited scope for diversification with species that are already present.

Future research with farmers should focus on the reasons why some species currently occur in low frequencies in a landscape. Some possible reasons include: the species have limited fitness for a particular use; few farmers need the specific products of the species; a few trees produce sufficient product for several households; few farmers know how to use the species; and/or farmers do not have access to germplasm of the particular species. It is obvious that efforts to increase the frequency of species should consider farmers' perceptions and limitations. In addition, space limitations on individual farms and within villages could make it impossible to maintain large effective population sizes for each species, which in turn would limit the species richness that could be sustainably managed within the village. Possibly, neighboring farmers could agree on common species to manage on their farms to allow large enough effective population sizes (O' Neill et al. 2001).

Biodiversity conservation in African agroecosystems

In general, results demonstrate that farmers cultivate substantial diversity of trees on farms, especially when scaled-up from the individual farm to the village and larger spatial areas. It is unrealistic to expect that farmers will conserve all indigenous species that were historically present in their landscapes, but we believe that a substantial percentage of indigenous tree species can be conserved by farmers while also contributing to their well being. Especially in areas where forests are under threat of fragmentation and extinction, conservation-through-use efforts may offer the most realistic conservation approach for many tree species.

Although this research focused on agro-ecosystems, there is clearly a need to protect remaining forest ecosystems in the landscapes. Although only three species from the IUCN Red List were encountered in the surveys, more species could be threatened as deforestation progresses. Some of these species may not be useful to farmers or not suited to their agro-ecosystems, and could only be conserved in forests. The relative importance of various evolutionary forces may be different in agroecosystems and conservation-through-use may therefore not be equivalent to *in situ* conservation (nor as *ex situ* conservation for that matter). In fragmented landscapes, farms may provide corridors that provide a necessary link for conservation of tree species in otherwise isolated forest fragments – trees may be needed both in agroecosystems and in remaining forest ecosystems to enable the survival of the species.

Where forests are fragmented or gone entirely in a landscape, trees in agroforestry systems may offer suitable habitats for other organisms. Safford and Jones (1998) for example reported that restoration of native vegetation is not always the most effective conservation method for animal species, but that certain exotic species can be essential. On the other hand, some agri-environmental schemes may not be effective in conserving plant and animal species Kleijn et al. (2001). Investigations of bird species' composition on farms and in the Mabira forest showed significant differences in their composition (Boffa et al. personal observations). Some farmers in the western Kenya survey explained that they established some fruit trees to feed bird species as they felt it was their human duty to do so. Similar to the need to investigate whether tree species are "living dead," case-specific studies are needed to investigate whether associated species are or could be conserved in mixed landscapes.

Studies suggest that, under a limited set of conditions, people will conserve natural habitats if they benefit financially from community-based enterprises that depend on the habitats (Salafsky et al. 2001). There was a weak association between enterprise success and conservation success, but a strong association between local involvement in the enterprise and conservation success. Conflicts may exist between conservation of local biodiversity and livelihood strategies of local people. Therefore, enterprises that are not linked to biodiversity, that are easier to be implemented and more profitable may actually be more effective.

Studies in sub-Saharan Africa demonstrate that biodiversity conservation and human needs may indeed result in conflicts since biodiversity and human population density are positively correlated at present (Balmford et al. 2001; Huston et al. 2001). McNeely and Scherr (2001) point out that, since 1.1 billion people live in the 25 global biodiversity hotspots identified by Myers et al. (2001), a new type of agriculture is needed that leads to increased food security and conservation gains. Their report provides examples of innovative landscape management strategies that successfully combined both objectives by applying eco-agriculture strategies. Some of their strategies include enhancing wildlife habitat on farms and corridors that link uncultivated spaces in the landscape, establishing protected areas near farming areas, and mimicking natural habitats by integrating productive perennial plants). Some farmers surveyed in the four landscapes managed their ecosystems in ways similar to these eco-agricultural strategies, especially the last one. We are cautiously optimistic, therefore, that farmers will conserve some of their landscape's biodiversity. This is a hypothesis, however, that needs to be tested through whole-landscape research, which includes the metapopulation dynamics of flora and fauna in the landscape.

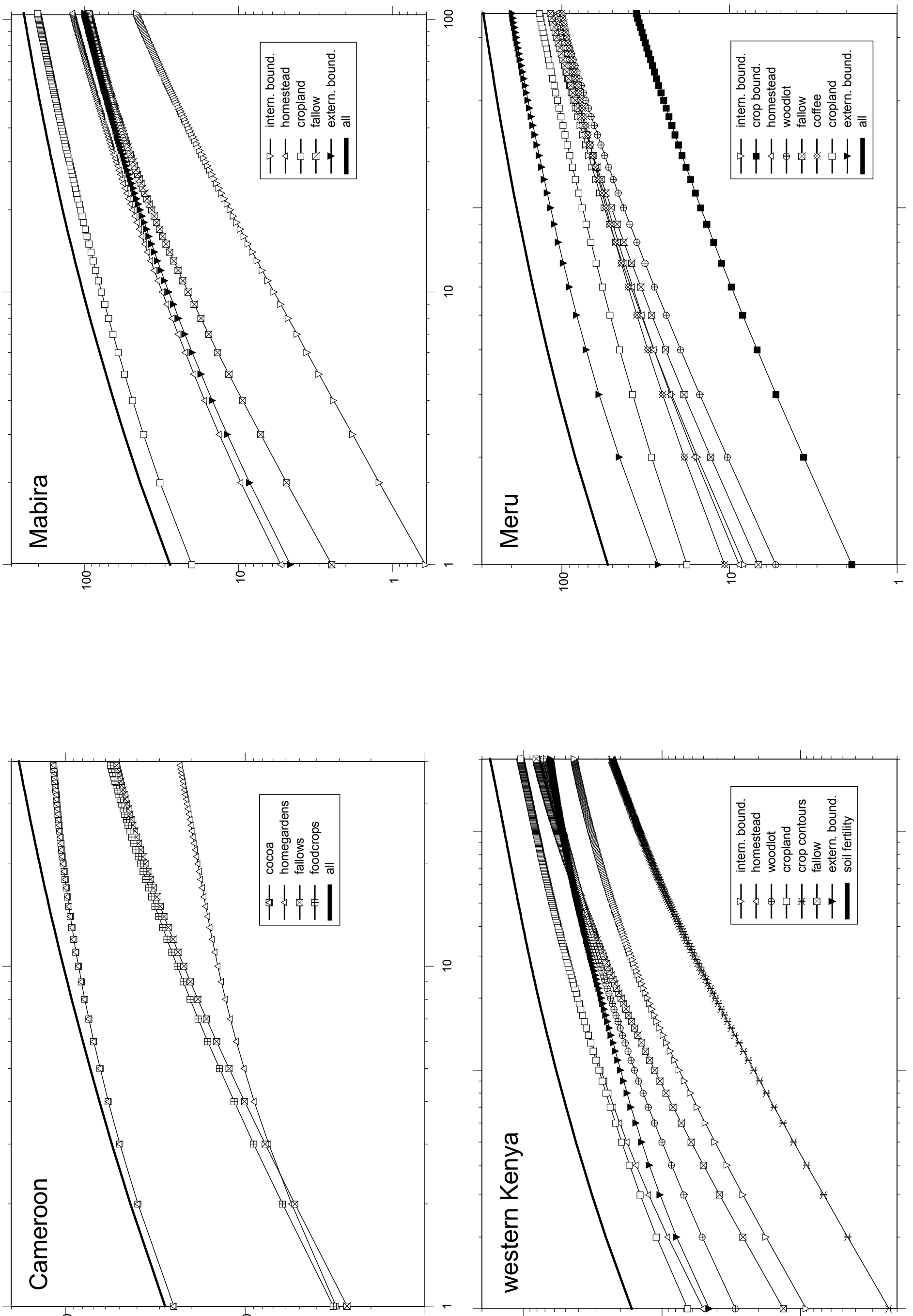

Fig. 1. Species accumulation curves for trees in various on-farm niches in four African landscapes. Horizontal axis: number of farms, vertical axis: number of species.

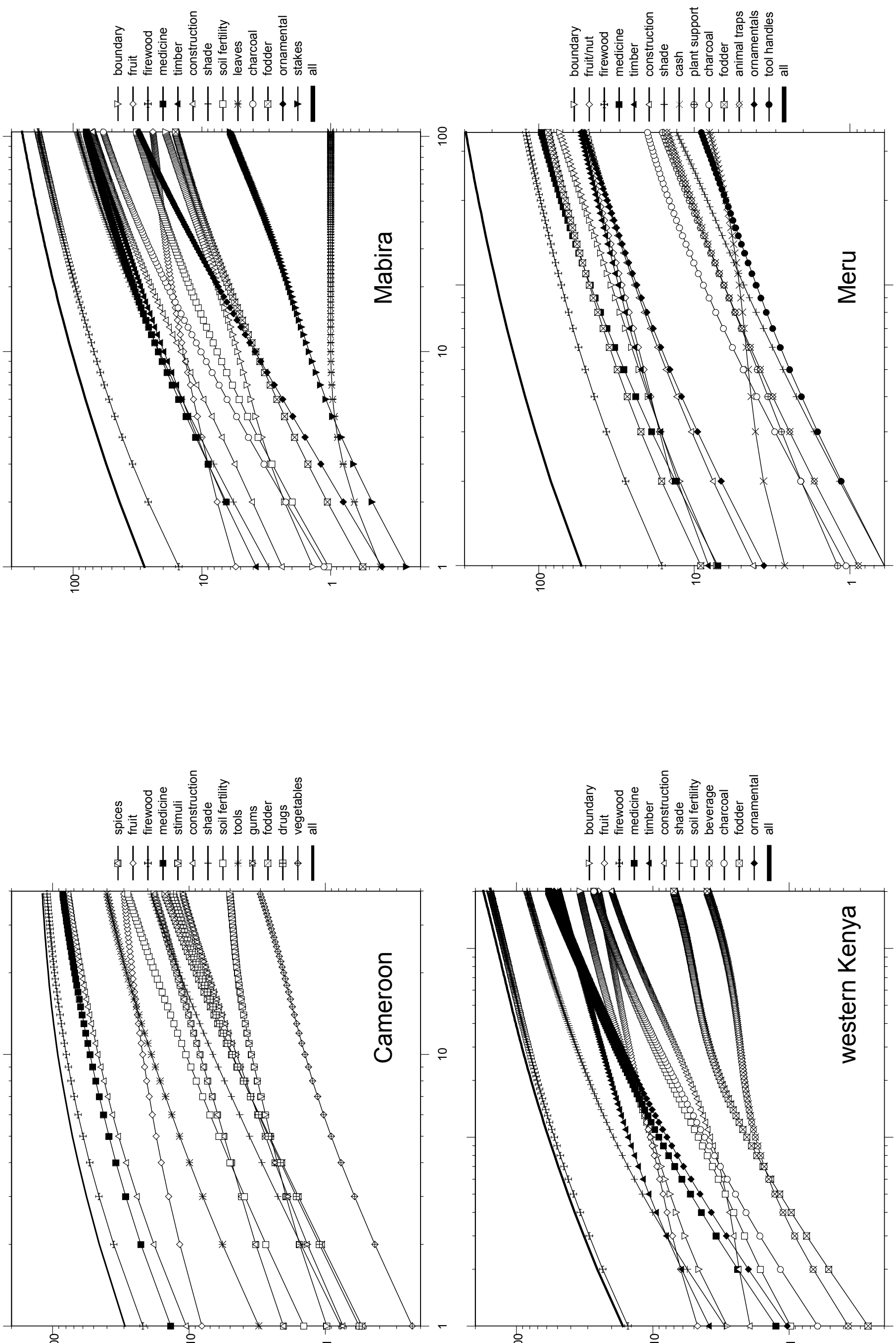

Fig. 2. Species accumulation curves for trees in various use-groups in four African landscapes. Horizontal axis: number of farms, vertical axis: number of species.

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Chapter 4

Tree density and germplasm source in agroforestry ecosystems in Meru, Mt Kenya

AG Lengkeek [12], R Kindt [1], LJG van der Maesen [2], AJ Simons [1] and DCC van Oijen [2]

[1] World Agroforestry Centre (ICRAF) PO Box 30677 Nairobi Kenya
[2] Wageningen University and Research centre, Biosystematics Group, Gen. Foulkesweg 37, 6703 BL, Wageningen, The Netherlands

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Abstract

Farmers use and conserve a large variety of tree species. In Meru, a tree census on 35 farms covering 60 hectares was conducted. This study included farmer interviews and biological measurements, with about 63,000 trees and 297 species being recorded. This paper discusses tree densities per species and germplasm sources for trees and species. The low densities and limited influx of germplasm from outside the farming community for some species, may result in an increased vulnerability to inbreeding and genetic erosion. This paper aims to provide some baseline data for understanding genetic resource management in agroforestry systems. It also provides suggestions for interventions to lower the vulnerability for species in Meru. Farmers need to have increased access to germplasm to diversify their farms in terms of species evenness, by substituting trees of more common species with trees of rarer species, or by increasing trees of rarer species.

Keywords: conservation, gene migration, genetic erosion, inbreeding, tree domestication

Introduction

Farmers plant trees in pursuit of their livelihood goals of income generation, risk management, household food security and optimum use of available land, labour and capital (Arnold & Dewees 1995). Farmers use and conserve species to obtain many products such as food, wood, medicine and fodder, and for numerous services. Trees also play a crucial role in the cultural life of people. The many products, services and roles these trees provide cannot be delivered by a few species only. As a result, farmers have a wide variety of tree species on their farms. Farmers benefit from using all these species and thereby conserve the biological diversity on their farms. This conservation through use is increasingly important as the natural tropical forests are disappearing fast (Simons et al. 2000). Putting greater tree diversity into use is a method to increase farmer benefits and to conserve biological diversity on farm (Kindt & Lengkeek 1999).

Farmers need biodiversity, including intra-specific diversity, for the productivity and sustainability of their agroforestry ecosystem. A broad genetic base provides the species with an adaptive capacity to respond to environmental fluctuations and changing farmer practices and markets. It ensures the vitality and long-term survival of the species in question and can be important for the vitality and sustainability of the entire agroforestry ecosystem (SGRP 2000).

Critically low densities may hamper adequate gene migration within species populations. Low densities may result in pollination problems, such as: (i) no pollination, (ii) increased selfing, resulting in inbreeding, or (iii) biparental inbreeding. There are, however, no baseline data available on what should be the ‘minimum’ tree densities to maintain the genetic base. Some species specific information is available: Murawski et al. (1994) indicated that a reduction in population density of *Shorea megistophylla* following selective logging can significantly elevate the proportion of seeds produced through inbreeding. Whereas Cascante et al. (2002) found that in fragmented forest seeds from isolated trees of *Samanea saman* had less genetic diversity and were less likely to germinate, and the seedlings that did grow had smaller leaves. Regardless of this little information available, it should be clear that the lower the tree density of a species, the more chance for genetic erosion.

Geneflow materialises through seed transfer and pollen dispersal. Hamrick and Nason (2000) cite various studies to indicate that pollen dispersal is responsible for much higher levels of gene migration in natural populations. This may be different on the farm, since farmers actively collect their germplasm. Although there is some evidence for large-distance movement of seed along human migration patterns, most germplasm is obtained from local sources (Kindt 2002; Lengkeek & Carsan 1999; Brodie et al. 1997).

The hypothesis is that, due to critically low densities and limited influx of seed from outside the farming community, a percentage of the species will be vulnerable to inbreeding and genetic erosion in the landscape. This paper aims to provide some baseline data for farmers, conservationists and agroforesters to understand the genetic resource management of the tree component in agroforestry systems. These data may help to address this vulnerability, with the objective of securing farmer benefits and conserving the biological diversity.

Material and methods

In Meru district on the slopes of Mt Kenya, 35 farmers were questioned about all the trees currently on their farm. A tree census was conducted during the first half of 2001. The census team consisted of the farmer, an extension worker from the Meru office of the Ministry of Agriculture (MoA), a researcher from the International Centre for Research in Agroforestry (ICRAF), and an extra taxonomist (from ICRAF) often also accompanied the team.

Farms

Three farmer communities participated in the study, representing a large area of high agricultural potential based on Mount Kenya (Table 1). Participating farmers were representative of Meru farmers, but were likely to be biased because of a higher interest in tree planting trials (Chapter 1 & 2). The farmers had already been involved in ICRAF's tree domestication trials for two to three years. One reason for selecting them, rather than working from a random sample, was that farmers had to spend a significant amount of time explaining different aspects of all their individual trees, which ranged from 3 hours to 2 days per farm. We therefore felt that the research benefits would not compensate the inputs a random set of farmers had to make. Secondly, we knew that a random sample would not be able to provide as detailed information on, for instance, cultural and medicinal uses of species, while a good and trusting relationship already existed with the trial farmers. Comparing our data with an earlier survey of randomly selected farmers to assess tree cover in Meru (Betser et al. 2000) showed great similarity, and therefore this data set can be seen as representative of the Meru farms.

Table 1: Characteristics of the agro-ecological zones of the study area

Farming community	Gaukune	Kigane	Ncoroiboro
Village name	Igoji	Nkubu	Ruiri
District	Central Meru	Central Meru	Central Meru
Zone	Sub humid	Humid	Semi arid
Land classification°	Upper Midlands 2	Upper Midlands 2	Upper Midlands 3
Annual rainfall (mm)	500-2200	500-2200	500-1800
Av. farm size (census)	2.2 ha	1.3 ha	2.4 ha
Soils	Well drained, very deep loam to clay	Well drained, extremely deep loam clay	Well drained, deep red cracking clay with humic topsoil
Distance of the community to the forest	25 Km	12 Km	0 Km
Altitude farms (MAS)	1353-1586	1497-1674	1524-1761
GPS farms	037 66' E 00 11' S	037 65' E 00 04' S	037 63' E 00 09' N

°Land classification according to (Pelley et al. 1985)

Data

All trees were measured and farmer information was recorded through open-ended questionnaires. Data per tree included the species identification (by the farmer, extension worker and researcher), species origin - native range - (from the farmer, literature) source of germplasm and type of germplasm used (both from farmer interviews), reproductive capacity (from farmer interviews, visual recording by extension worker and researcher), age (from farmer interviews, visual measurements by extension worker), tree biomass (from diameter and visual measurements by researcher, using classes of tree shapes). Hedges with uniform vegetation were documented through multiplying representative 5 metres parts (from measurements by extension worker and researcher). Data per species included interviews about the species' uses (from farmer interviews). Data per farm included GPS coordinates (taken by researcher) and farm size (from farmer interviews, MoA data).

Definitions of 'trees' were similar to Beentje's (1994) criteria for species inclusion and comprised all woody perennials growing to over 1.5 meters tall, but also included exotics. Because of the long-term cultivation of the sampled agroforests, (only Ncoroiboro was recently (50 years ago) brought under cultivation (MoA 2001a)), it was not possible to ascertain whether indigenous species have occurred in the various farming communities. Species origin could therefore not be classified as endemic per farming community, but was classified as 'indigenous' if occurring in the UM2 and UM3 zones (see Table 1) in Meru district; hence, the rationale of the term indigenous instead of endemic in further analysis. Cultivars, for instance of *Coffea*, were not classified as indigenous (Maes 1993). The natural vegetation of the UM2 and UM3 zones was checked using farmer information and from literature such as Beentje (1994), Agnew and Agnew (1994) and Bussmann (1994). For Ncoroiboro, a census of the nearby forest (Sjöberg & Swenson 1990) also assisted in identifying the original natural vegetation.

Analysis

Densities were calculated by dividing the total number of trees over the total number of hectares. Densities were compared between indigenous and exotic species and between the three communities. The origins of germplasm (categorised as from the own farm, from the same community or from outside the community) and types in which the germplasm was obtained (categorised as natural regeneration (wildings), transplanted wildings, forest remnants, cuttings or seedlings obtained from nurseries, the latter produced on or off of the farm) were compared between indigenous and exotic species

The analysis was conducted for two categories: all tree species and indigenous species. The rationale behind this was that from a farmer's point of view, access to quality germplasm of all species is important (Chapter 2; DFSC 2003). However, the origin of the tree species is often seen as being less important; therefore, for short-term production purposes, genetic losses of exotic species can be just as harmful to the farmer. From a biological point of view, the conservation value of exotic tree species is less important than that of indigenous species.

The trees contributing offspring to the next generation determine the size of the genepool. As a result, non-seeding trees are not part of the effective population. However, this showed that the potential effective population size could be larger than the current one. To address this, the potential effective population size was analysed as well.

The analysis was split up between the different farming communities. The tree cover could not be analysed as a meta population because of the geographical distance between the communities, and because the agro-ecological characteristics and farmer practices differed. Detecting possible differences between the farming communities was not an objective.

Results

Taking stock of species and trees

A total of 64 plant families was recorded. Major families were Rubiaceae (with 22 species), Euphorbiaceae (21) and the subfamily Papilionoideae (19). As many as 18 families were represented by a single species only. Family richness ranged from 16 to 44 families per farm with an average of 28 families (see Table 2). A total of 297 species were recorded, ranging from 28 to 97 species per farm with an average of 54 species per farm. Not all species could be fully identified: 23 species were identified to the genus level, 13 species were identified by local name(s) only, six species remained unidentified ornamentals (most likely exotics) and another 12 species could not be identified (data not shown).

In total, almost 63,000 trees were recorded, 1/3 of these *Coffea* cultivars. The number of trees per hectare varied considerably, ranging from 419 to 3,645, with a standard deviation of almost 800. The density based on the farm averages was 1,291 trees per hectare. About 61% of the species were indigenous whereas 29% were of exotic origin, and 10% remained uncertain (Table 2). Nevertheless, there were more exotic trees on the Meru farms - 2/3 of the individual trees were exotic. The five most commonly occurring species were all exotic and formed 54% of the total number of trees on the farms (data not shown). Excluding *Coffea* cultivars, however, would result in almost an equal number of indigenous and exotic trees.

The results of the farming communities were consistent: the number of plant families ranged from 47 to 52, covering 73 to 81% of the total family diversity (see Table 3). The number of species per farming community ranged from 171 to 178, covering 58 to 60% of the total tree species diversity. Due to larger farm size, the total number of trees in Ncoroiboro was larger; however, the number of trees per hectare was lower.

Table 2: Number of families, species, trees and trees per hectare by origin on 35 Meru farms

	Total	Indigenous (%)	Exotic (%)	Unknown (%)	Av. per farm (st dev)	Min. per farm	Max. per farm
Family	64	-	-	-	28 (6.8)	16	44
Species	297	61	29	10	54 (20)	28	97
Trees	62,946	32	67	1	1,798 (1,402)	294	5,718
Trees, excl. coffee	42,135	47	51	2	1204 (1130)	240	4,535
Density	°1,048	32	67	1	°1,291 (775)	419	3,645
Density, excl. coffee	702	47	51	2	868 (625)	229	2,456

°Density for the total area versus the density based on farm averages.

Table 3: Number of families, species and trees per farming community in Meru

Community	No. families	%	No. species	%	No. trees	ha	No. trees / ha
Gaukune	47	73	178	60	17,000	14	1200
Kigane	52	81	171	58	17,000	16	1100
Ncoroiboro	52	81	173	58	29,000	31	900
Total	64	100	297	100	63,000	60	1000

No differences among communities between the number of species and families (P=0.94, P=0.89). There were significant differences in the proportions of indigenous/exotic trees between communities, with a greater balance in Kigane, and even more indigenous trees if *Coffea* cultivars were excluded, in both cases (chi-square tests, P<0.001).

Densities

Figure 2 shows the densities of species by plotting the number of species against the numbers of trees for that species per hectare. Included are densities of all species as well as indigenous species alone for the total number of trees and for seeding trees. The graph only shows data from Gaukune, but other farming communities show similar profiles. Data presented in figure 2, for instance, display the number of species with a density of more than one tree per hectare: these included 67 species, which was 38% of the total amount of species recorded. For seeding trees, the numbers were, 34 (19%) for all species. For indigenous species only this density included 43 species (39%) and for seeding trees 22 species (20%). Averaged over all farmer communities, 76% of both all and indigenous species had less than a single seeding tree per hectare, representing 132 and 82 species for all and indigenous species, respectively.

Table 4 shows the percentage of species that had fewer seeding trees per hectare for various arbitrarily chosen tree densities. For example, averaged over the three communities, 97% of the indigenous species had less than 10 trees per hectare whereas 44% had less than a single tree per 10 hectares. Although the three farming communities came from different agro-ecological zones and had different farming practices and species compositions, the results were consistent (Chi-square test, P=0.38 for all species; P=0.09 for indigenous species). For all and indigenous species only, approximately 20% of the species had no seeding trees.

Allowing trees to set seed would increase the density of seeding trees for many species. There is a potential for increasing the cover of seeding trees, for instance through a change in management (e.g. no pruning) or ageing. For example, 76% of the indigenous species had less than one seeding tree per hectare; however the total for this density (including all non-seeding trees) is 60%. Figure 3 plots the overall tree density and the density of seeding trees against this potential. The results shown are for one species per hectare and one species per 4 hectares; other densities show similar patterns. Age was the most limiting factor; nevertheless, mortality, weeding and harvesting may remove many more seedlings and therefore the full potential of extra trees joining the genepool is unlikely to be met.

Germplasm source

Farmers were questioned about the type and the source of germplasm of every single tree. Trees from indigenous species were more often wildings and rarely came from distant sources (see Table 5).

The ‘unknown’ source consisted of 95% wildings and 4% forest remnants for all species, and for indigenous species, the unknown source consisted of 94% wildings and 6% forest remnants. The data show that trees of unknown sources most likely originate from the farm itself or from the local area. Wildings were most likely progeny of trees located on the farm or from other local trees; even if wildings were recorded under a seeding tree, they were classified as ‘unknown’. Nevertheless, there is a chance that some of the trees of some species in Ncoroiboro derived from the adjacent forest (see also table 1). Forest remnants are part of the founder population on the farm; these trees comprise the on-farm source itself. These results correspond with other findings that most trees are derived from the close vicinity (Kindt 2002; Lengkeek & Carsan 1999; Brodie et al. 1997). Nurseries were an important mechanism for the influx of germplasm from distant sources. The vast majority of trees from distant sources were seedlings produced off the farm and these seedlings were derived from nurseries.

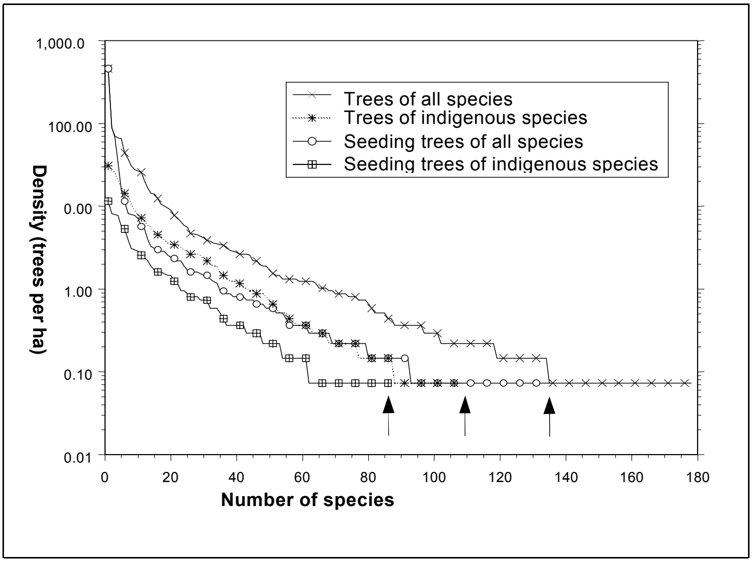

Figure 2: Tree densities per species in Gaukune, Mt Kenya

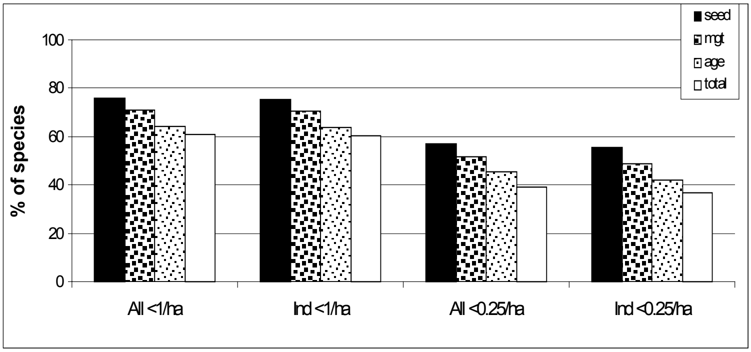

Figure 3: Percentages of species that have fewer trees or fewer seeding trees per given densities, and the potential of management or ageing to increase the percentage of seeding trees per species. Densities include 1 tree per hectare and 1 tree per 4 hectares for all and indigenous (Ind) species. All data are averaged per species and per farming community. 'Total' represents the overall tree cover, whereas 'seed' represents seeding trees only. In between there are the potentials 'age' and 'mgt' representing the percentage of trees that may seed through ageing or a change in management practices.

Table 4: Percentage of species that have fewer seeding trees per hectare averaged over three villages for various densities

Density (trees / ha)	<10	<5	<2.5	<1	<0.5	<0.25	<0.1	No seed°
All species (%)	95	91	85	76	66	57	45	21
Indigenous species (%)	97	93	87	76	65	56	44	20

° 'No seed' represents the percentage of species that have no seeding trees.
No differences between villages for all trees and indigenous trees (Chi-square test, P=0.38, P=0.09 resp.)

Table 5 also shows that only a limited number of species had one or more individual trees within their current population deriving from a distant source. On average, 29% of all species included trees from a distant source; for indigenous species, only 14% of the species included trees from a distant source.

Source of germplasm according to density

Table 6 combines densities (see Table 4) and the influx of external germplasm per species (see Table 5) for two arbitrarily chosen densities; i.e., a single species per hectare and per four hectares. For all species it shows that, for both densities, about 20% of the species included one or more trees from a distant source in the current population. For indigenous species, and both densities, 8% of the species included trees from a distant source.
Although the objective was not to detect differences between farmer communities, the variation increased here, which may subsequently increase the error margin. Nonetheless, no differences were found and other densities (data not shown) gave comparable results.

Table 5: Source of germplasm (GP) per species and source and main type of GP per seeding tree

Source of GP	Species (source in %) All	Species (source in %) Indigenous	Trees (source in %) All	Trees (source in %) Indigenous	Main type of GP per source	Trees (type in %) All	Trees (type in %) Indigenous
On-farm	25	20	15	14	Cutting	41	81
					Transplanted wilding	32	5
					Seedling on farm	24	15
Local	40	27	36	22	Cutting	59	64
					Seedling off farm	31	34
Distant	29	14	9	3	Seedling off farm	83	98
					Cutting	10	-
Unknown	77	91	40	60	Wilding	95	94
					Forest remnant	4	6
Total	100	100	100	100	Wildling	38	56
					Cutting	28	26
					Seedling off farm	19	11

Percentage of species with germplasm from a particular source averaged over the three farmer communities, focusing on 'all' and 'indigenous' species. Per individual tree, data represent all seeding trees (n = 42,135, this excludes *Coffea* cultivars,) and indigenous seeding trees (n = 19,861) at 35 Meru farms. All *Coffea* cultivars originate from distant sources and from seedlings produced off the farmers' farm. The trees sourced as 'local' originate from within the farmer community whereas distant sources come from outside the community.
Significant difference between all and indigenous species in sources (Chi-square=8.39, P=0.038).

Table 6: Percentage of species with less than a seeding tree per one and four hectares, receiving germplasm (GP) from a distant source.

	All species					Indigenous species				
	No. of species	% of species		% of species with GP from a distant source		No. of species	% of species		% of species with GP from a distant source	
		1/ha	0.25/ha	1/ha	0.25/ha		1/ha	0.25/ha	1/ha	0.25/ha
Gaukune	178	81	62	15	16	109	80	57	7	8
Kigane	171	75	56	16	16	107	76	53	4	4
Ncoroiboro	173	71	54	32	29	111	71	56	14	13
Av.	174	76	57	21	20	109	76	55	8	8

No difference between the communities between indigenous and all species (Chi-square test, P=0.95, P=0.755, P=0.50 and P=0.47 resp.)

Discussion

The number of individual trees per species per hectare was low for many species - more than half of the species had only one tree or less per 4 hectares. Although a change of management or ageing could increase the density of many species, this potential would make a minor difference (see figure 2 & 3). Secondly influx of germplasm from a distant source for species with low densities only occurred for a few species, and rarely for indigenous species (see Table 6). No baseline data were available to provide information on the densities and geneflow needed for species populations to prevent inbreeding and genetic erosion. This baseline data were certainly not available for all 297 species involved, besides these would be dependant on too many other factors such as farmer decisions, incompatibility mechanisms, climatic conditions, pollinator populations, pollination processes, flowering patterns, possible subpopulation divergence, spatial structure of the tree populations and their various interactions, to name but a few. Nevertheless, species with very low tree densities are more vulnerable for inbreeding and genetic erosion than species with high tree densities, irrespective of the processes by which tree densities are determined.

Two additional factors further lowered the ‘effective’ density of seeding trees. In Meru, there are two clear and distinct rainy seasons, the long and the short rains (Pelley et al. 1985); therefore, it is likely that most trees flower and set seeds at the same time. The extensive farmer interviews and interviews with seed collectors from the Kenyan Forest Seed Centre (KFSC) confirmed this. Nevertheless, asynchronous flowering cannot be excluded. Furthermore, not all recorded species were monoecious or hermaphrodite. It was however not possible to determine the sex of all individuals as the trees were not all flowering during the survey due to the time of year or due to management practices (e.g. hedges). Therefore, dioecious species were not treated as such.

‘Tree domestication on the landscape level’ is a concept recently developed at ICRAF (Simons et al. 2000; Kindt 2002; this thesis). In contrast to the domestication of agroforestry species aimed at using the diversity present in individual species –(for instance, selection), domestication of the landscape proposes using the diversity of the tree component in agroecosystems. The data on densities and germplasm sources provide some baseline data that increase our understanding of the genetic resource management of tree and species diversity in the landscape. Furthermore, these baseline data may help farmers to address possible problems of inbreeding and genetic erosion.

Farmers’ options

Farmers have four possible interventions available to them regarding domestication of the tree component of agroforestry ecosystems; these are ‘replacement’, ‘addition’, ‘modifications in tree management’ and ‘substitution’ (Simons et al. 2000).

1. Replacement of a tree by a tree of the same species would not increase the size of the genepool of the rarer species. If the germplasm is obtained from a distant source it may increase genetic diversity since small amounts of germplasm from the meta population can already prevent genetic drift in subpopulations (Wright 1931; Newman & Tallmon 2001). The number of species receiving germplasm from distant sources was, however, very limited, especially for indigenous species (see Table 5 & 6). Additionally, the influx of germplasm from a distant source is not always effective, particularly not when species have low densities. If no gene exchange occurs between the local trees and trees derived from distant sources, there will be no difference in vulnerability. For instance, genetic erosion will be independent of the source if a farming community only has a single tree of

the species, as was observed in Gaukune for 44 species, 39 in Kigane and 28 in Ncoroiboro. The effect of the influx of germplasm from distant sources on lowering the vulnerability of genetic erosion is limited.

2. The addition of new trees is not effective either. Using the densities in Table 4 as an example, we can understand the effect of increasing tree densities in Meru. By defining – for example - a single tree per hectare as ‘critically low’, 76% of all species will have had a ‘critically low’ density. Doubling the tree cover on farm, which is similar to setting the density at 0.5 trees per hectare, 66% of the species would have a ‘critically low’ density. Doubling the tree cover once more – to 0.25 trees per hectare- the percentage of species with ‘critically low’ densities decreased to 57%. Similar results were found for indigenous species (see Table 4). Obviously, data on critically low densities are unknown and speculative, and doubling the current tree cover in Meru is next to impossible due to the high tree density already in place. This unrealistic ‘doubling’ would, however, decrease the number of species vulnerable to genetic erosion with 10% only, other, more realistic levels of tree addition would hardly make a difference. This example therefore shows that relatively independent of how the density is defined as ‘critically low’, the addition of new trees is not the most effective option.
3. A change in tree management, such as pruning, would not increase the effective population size substantially either. Only a limited number of trees would be able to seed in a different management regime (see Figure 3). Another management option farmers have is to change the location of the species in the landscape. For instance, farmers may choose to conserve their species by aggregating the species instead of segregating. However, the rule of thumb for species is 50 individuals for short-term productivity and long-term survival (FAO 1993). Averaged over the three farming communities, only 25% of the species had more than 50 individual trees per community (data not shown). Therefore, aggregation of the current tree population per species does not seem to be enough. Aggregation will result in small-sized populations with an increased geneflow within the small population, leading to more genetic drift, and more incompatibility problems, and local species extinction, similar to the problems of fragmented forests (Young & Boyle 2000; Hall et al. 1996) or island populations (Hubbell 2001). Even if aggregation was possible, 50 trees of a species on one farm does not correspond with the farmer’s wish for risk management (Chapter 2). It should however be clear that the densities recorded did not imply that trees are distributed randomly over the sampled area, as farmer preferences and niche occurrence vary from farm to farm.
4. The best option seems to be a diversification in terms of species evenness of the agroforestry ecosystem through substitution; i.e., fewer trees of a few major species and more trees of the rarer species. Solely increasing the rarer species will give the same results, though this is more a ‘relative substitution’ than an increase as such.

Species substitution

Almost 300 species were recorded and it is unlikely that all farmers can or want to conserve all these species. In the case these species were evenly distributed over the almost 63,000 trees, then the density of each species would be: 3.53 trees/ha. In the current situation, almost 90% (Table 4) of species has a lower density. Substitution of trees of dominant species with trees of less dominant species will increase the densities of rarer species. However, to obtain the completely even distribution of 3.53 trees on average for each species, then over 46,000 (73%) of the 63,000 trees would need to be substituted. In no natural or agroforest ecosystem, perfect evenness of species is observed. A more realistic approach to model evenness is to use the broken-stick distribution (Hubbell 2001). In that case, over 32,000 trees would still need to be substituted. It may therefore not be realistic to expect farmers to make all these substitutions. A more practical goal could be substitute some of the trees of the dominant species with some trees of rare species, but only targeting a subset of the rare species. One hypothetical suggestion could be that farmers substitute 1/3 of the trees of the 10 most dominant trees (over 13,000 individuals) with 50 rare species. The result would be that the density of these 50 rare species is increased by 4.43 trees/ha. Farmers' perceptions about individual species must be considered when planning such substitutions.

Interviews with the Meru farmers showed that they are eager to diversify to a large extent, in terms of species and evenness of distribution (Chapter 2). Especially where farmers have made deliberate management decisions to establish some species in high abundance and other species in low abundance - for instance based on their livelihood options - we may expect that farmers would not be interested in substituting most of their dominant species. It is, however, not sure if the current dominant species are also the most preferred species; Farmers have no choice but to plant or maintain what is available. Therefore there is a risk that well-preferred species may even become locally extinct, instead of the less preferred species that may have a better availability or regeneration capacity.

A large natural regeneration rate was observed; for indigenous species, 56% of the tree cover was derived from wildings and 91% of the indigenous species had one or more wildings and forest remnants in the population (see Table 5). For all species, 38% of the trees were wildings and 77% of the species had one or more wildings or remnants in the population. This regeneration capacity of species is however not sufficient to address the farmers' needs in search of preferred germplasm (Chapter 2). Therefore, to enable farmers to continue to use and conserve a reasonable subset of species, access to germplasm needs to be improved (see also Chapter 2 & 5; DFSC 2003). Additionally, farmers may need to increase their efforts to obtain germplasm.

Farmers should be guided in their use and conservation efforts to increase tree densities of the rarer species, however, because: (i) populations have been reduced to few individuals, so it is likely that there has been or will be a reduction in diversity among trees within populations, and (ii) the germplasm of the current populations mainly comes from local sources and, therefore, probably has limited genetic diversity. As a result, species may have difficulties in re-establishing to larger population sizes from these small populations because of mating incompatibility. If by chance some of the genotypes have higher selfing compatibility rates, than the population could be re-established, but it would have a higher inbreeding coefficient. On the other hand, it is possible that selfing capacity tends to indicate selection against inbreeding depression. Since data on tree densities are unknown and dependant on many factors, it is however not clear to what level substitution must occur.

Some less preferred species will always have marginal numbers. Survival may occur in hedges and fallows, and indeed hedges often comprised the most diverse niches in Meru (e.g. Kindt 2002; van Oijen 2002). Hedges were also classified as niches for biodiversity conservation in comparable farming systems in western Kenya (Backes 2001). This may change, however, because invasive weeds such as *Tithonia diversifolia* and *Lantana camara* increasingly inhabit hedges, which does not help biodiversity conservation.

Vegetative propagation

About 28% of all trees were propagated vegetatively (see Table 5). Species that are solely reproduced vegetatively are also vulnerable for clone losses without the influx of new or the reintroduction of old clones. A certain number of individual clones are propagated more successfully and simple models show that after some generations only a few clones may dominate the area (Lengkeek unpublished data). In short: with sexual reproduction one loses genes, and with vegetative propagation one loses clones. Note that the 20% of non-seeding trees (Table 4) were not able to seed due to age (56%), so these were not solely dependent on vegetative propagation. Only 11% of the vegetatively propagated trees were not able to seed.

Indigenous and exotic species

The analysis was split between all species and indigenous species only because farmers need access to quality germplasm of all species. From a biological perspective, indigenous species are perhaps the most threatened group of species and merit more immediate attention for conservation. However, results on densities of all or indigenous species only were similar (see Table 4). Therefore, conservation from both the farmers' and biological perspective coincided and diversification in terms of species evenness sufficed to lower the vulnerability to genetic erosion.

The source of the germplasm differed between all species and indigenous species (see Table 5). Indigenous trees were markedly less often sourced from outside the community than exotic trees, both in terms of total amounts of germplasm and the proportion of species. Because minor gene migration per species from outside may already prevent narrowing of the genetic base (Wright 1931; Newman & Tallmon 2001), this indicates that indigenous species are relatively more vulnerable to inbreeding and genetic erosion. Therefore, if farmers would be aware of the advantages of the source of germplasm, it would benefit the genetic sustainability of indigenous species in particular.

Some factors may influence the vulnerability of indigenous species as compared to exotics. Indigenous species may receive geneflow from neighbouring forests, by pollen as well as by seed. In Uganda, Gerrits (1999) found increased densities of wildings of timber species closer to the forests. However, there is a rapid destruction of forests on Mt Kenya and surrounding areas, especially in the vicinity of settlements (Francis Ndiege, Meru forest officer personal communication; KWS 1999). Seed sources for indigenous species used by the KFSC also suffer from illegal logging (Joseph Ahenda personal communication). Similar to exotic species, the populations of indigenous species on farm will increasingly have to survive on their own. From a conservation point of view, on-farm populations are increasingly important. For exotics, there are generally more formal pathways for obtaining good quality exotic material for reintroduction.

Furthermore, exotics are more likely to be under cultivation in an area for a shorter period of time than indigenous species. Their long-term cultivation with possible bottlenecks may therefore be of less importance. On the other hand, exotics often get introduced in low numbers only, resulting in a narrow genetic base of the founder population.

Conclusions & recommendations

It would be speculative to give a percentage of species that are vulnerable to inbreeding and genetic erosion since no data on species densities are known and the vulnerability is a product of many other factors as well. However, it is fair to conclude that with more than half of the species having less than an individual tree per four hectares, the recorded tree densities of many species are low on Meru farms. Secondly, the influx of germplasm from a distant source is minimal, especially for indigenous species.

These two factors lead to a vulnerability for inbreeding and genetic erosion for some species in agroforestry ecosystems. This may cause short-term productivity and long-term stability loss. The best option to prevent this is to diversify the farm in terms of species evenness through an increased number of trees of rarer species, or through a substitution of the more common species. Farmers and researchers active in tree domestication could focus on improving access to quality germplasm of a wider range of species, instead of only concentrating the frequently mentioned domestication activities on a few successful or high potential priority species.

Due to the wide range of variables that may impact on tree genetic diversity levels on-farm, studies that mathematically simulate (Kindt 2002) or directly measure variation are useful. Direct measurements are however currently limited and have generally involved informal comparisons of native populations with exotic stands (for example, Chamberlain 1998; Muluvi et al. 1999). Rarely have studies directly compared the diversity of natural and on-farm populations within the native range of a tree species (*Prunus africana*; Muchugi 2001). Currently, farm and forest stands of the important and heavily exploited timber tree *Vitex fischeri* (syn. *Vitex keniensis*) from central Kenya are being tested as a model for genetic erosion concerns on the farm by one of the authors (AGL), by employing molecular genetic markers. These molecular genetic data, although restricted to individual species, can be used to increase the understanding of the genetic resource management of agroforestry systems.

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Chapter 5

A wealth of knowledge
How farmers in Meru, central Kenya, manage their tree nurseries

Ard G. Lengkeek[12], Sammy Carsan[1] and Hannah Jaenicke[13]

[1] World Agroforestry Centre (ICRAF) PO Box 30677 Nairobi, Kenya
[2] Wageningen University, Biosystematics Group. PO Box 8010, 6700 ED Wageningen, The Netherlands
[3] Forestry Research Programme. Park House, Bradbourne Lane, Aylesford ME20 6SN, United Kingdom

Abstract
With disappearing forests farmers are increasingly dependent on growing their own trees. To be successful, these trees should be available, healthy and of high genetic quality. We surveyed the knowledge and approaches of a sample farming population in Meru, Central Kenya. In particular, we looked into on-farm nursery practices with a focus on nursery management options, propagation and germplasm management, depending on the farmers' wealth characteristics. Results showed some differences between wealth categories, but most pronounced was an enormous variation in approaches and knowledge among farmers. A lot of information is already available but it is scattered and incomplete. Improved information exchange would help to diffuse what already exists. The most serious gap in farmers' knowledge appeared to be in their use of a limited number of mother trees to raise the nursery population. Farmers also mentioned water shortage and access to germplasm as main constraints. We recommend exploring possibilities to help develop nursery associations where information exchange could boost the quality and quantity of nursery production. Improved access to germplasm and training in water use and seed collection are other recommendations.

Keywords: nursery management, on farm nurseries, propagation methods, tree genetics, wealth ranking

Introduction

A successful approach to combat rural poverty is through increased involvement of the poor farming community in decision making about their natural resource management options (Izac & Sanchez 2001). Part of such a decision making framework is the combination of natural resources management concerns with quality germplasm. The use of healthy improved or genetically diverse germplasm can be expected to contribute to the ecological stability of an environment.

Traditionally, farmers have used a large variety of plants and their products. Many of these plants grew in their natural environments, e.g. the forests, and did not require intensive management *per se*. In landscapes with diminishing natural ecosystems and diminishing indigenous plant populations, farmers are forced to grow the plants they need for food, fodder, medicine, timber and other products or services on their farms (Kindt & Lengkeek 1999). Such efforts are successful if germplasm of these plants is available and of high genetic quality (Simons 1996; 1997). However, studies by AFSICH (1993), Roothaert and Tuwei (1994), Kindt (1997), Koffa and Roshetko (1999), O'Connor (1997) and Holding and Omondi (1998) revealed that the majority of the new planting stock on farms originated from farmers' own farms and that (quality) germplasm of many species was not available. There were also indications that active mother tree selection was rare and that the number of mother trees was too limited to avoid the risk of inbreeding.

Many farmers in tropical countries raise tree seedlings for their own needs rather than for sale. Often however, their technical knowledge is insufficient to produce healthy plants, and scarce resources, such as water, are often wasted when seedlings do not survive field planting (Jones 1993). In particular seed pre-treatment and irrigation methods, pest and disease control, and simple management techniques such as appropriate shading are in many cases not sufficiently mastered, especially for slow growing, and difficult-to-raise species. Vegetative propagation methods are important for the successful production of improved fruit species, but although these methods are known by a relatively large percentage of rural people, however, only few can apply the technique to a satisfactory level (Tchoundjeu et al. 1997).

Surveying the current knowledge of a sample farming population in Meru, Central Kenya, we have attempted to determine the opportunities and gaps existing for successful diversification of the agricultural landscape and for alleviating the vulnerability of the farming poor to environmental and economic risks. In particular, we were interested in mapping the understanding and approaches of farmers to tree propagation and germplasm management.

The objective of this paper is to characterise the current situation regarding on-farm nurseries, with some regard to wealth category, and devise possible interventions. Genetic consequences are reported in detail elsewhere (Chapter 6).

Materials and Methods

The survey was conducted in December 1998. In total 25 on-farm nurseries were surveyed. The aim was to target a subset of farmers from most administrative divisions in Meru Central, including neighbouring divisions of Meru North (fig. 1). Nursery operators were interviewed in nine divisions. The selection of informants was carried out in collaboration with the Forest Department and the Ministry of Agriculture. These partners provided baseline information on the farmer contacts and logistics of the area and also facilitated introductions to farmers, which helped to avoid unnecessary suspicion towards the researchers. Additional nurseries were identified by asking interviewees and their neighbours for further addresses, and identifying nurseries through all possible means.

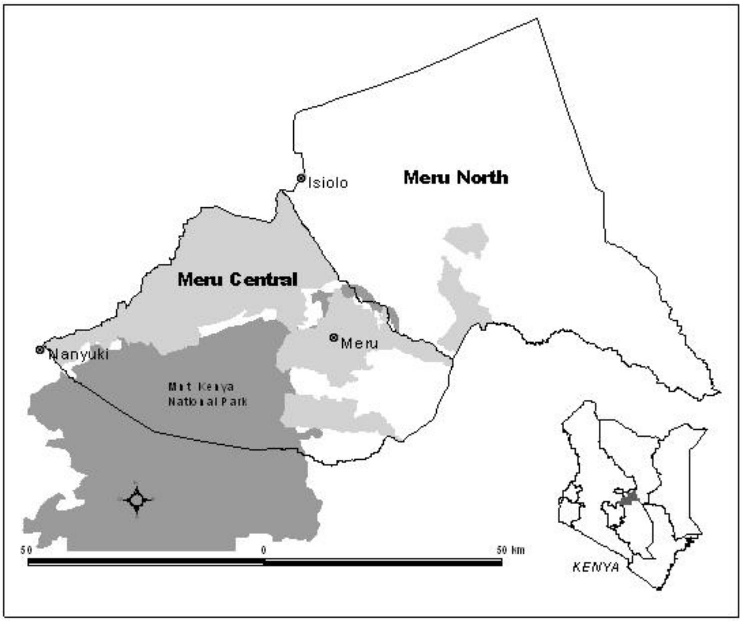

Figure 1: Map of Kenya showing Mt Kenya, Meru Central and Meru North.

Individual on-farm nursery operators were targeted over other nursery enterprises, such as forest department nurseries, women groups, town vendors and NGO nurseries, because research showed that most germplasm distribution is via farmer-to-farmer exchange (Kindt 1997). Farmers were assigned into three wealth categories (see below).

Data collection included the stock of trees and species, nursery constraints and nursery management options, such as soil, containers, shade and propagation methods. The results are discussed per wealth category. More extensive questions were asked to the farmers on a limited number of species. In order to keep the interview short and the interference to the farmers minimal, details of only two species per nursery were collected. A criterion for choosing these two 'main' species was that this had to be the most important species for that particular nursery (determined by the farmer). Although 25 nursery operators were interviewed the data set contains 44 cases, because six nurseries had only one or only one important species. For most species-specific questions there were no differences by wealth category, therefore it was decided not to split the data by the wealth categories for this section.

The interviews had a semi formal character: a questionnaire was used, some open-ended questions were asked, but questions were not restricted to a prepared list. Vernacular names of species were recorded for identification and translation where species were not identified on location. Most interviews were held in the local language, Ki-Meru.

Being fact-finding research, data collection concentrated on a wide range of nursery practises to provide a broader understanding of issues, instead of concentrating on extensive data collection on a limited number of issues, allowing statistical validity. This resulted in a more in depth qualitative study rather than a quantitative study. Most pronounced details of this study allowed extension with more nurseries, but this is part of a separate, more quantitative, paper (Chapter 6). Data were analysed using comparative statistics in MS Excel and MS Access.

Socio-economic characteristics of nursery managers

Nursery managers are not a homogenous group but differ in many aspects, such as education, gender and wealth. Different individuals have different needs and capabilities and therefore may be engaged in different practices and technologies. In this study, we tried to group nursery managers with similar wealth to better understand the effects on nursery practices, for instance, on which and how many species to raise (Guinand 1996). This allowed the researcher to increase understanding for whom a new technology or management practice may be beneficial.

The nursery managers we interviewed were not necessarily a representative sample of the farming population in Meru. On the contrary the education level of nursery managers was relatively high compared with the expected averages. Also, older age groups were over-represented. We gathered household characteristics for nursery managers only as these are our target group. We are presenting the indicative results as trends only.

Wealth ranking

Ranking the nursery managers into wealth categories is a difficult exercise. Grandin (1988) writes: 'Inequality of some sort exists in every human society; the degree of the inequality and the attributes upon which it is based do, however, vary. Every human society defines certain differences between its members as being of great importance and values certain characteristics above others.' Indeed in Maseno (Western Kenya), farmers were ranked according to a list of criteria and were also asked to group themselves into classes (J. de Wolf & R. Rommelse pers. comm. 1998). These scientists were, however, not able to find a relation between their grouping of various wealth criteria, and the grouping that the farmers did themselves. Guinand (1996) describes a thorough wealth ranking exercise, by both farmers and researchers. However as the nursery managers in our survey were located over a widespread area, they were strangers to each other and would not have been able to classify each other in that way. A combination of two methods was used to arrive at useful wealth categories for the sample farmers.

The first method was to group the nursery managers according to their characteristics by an independent person. This gave an objective classification by restricted wealth characteristics only. The following variables were used for the analysis: education level, type of house, farm size, off-farm employment, the use of labour, and various types of livestock (pure breed cows, cows of mixed breed, local cows, sheep and goats).

Second, one interviewer, from the district, grouped the nursery managers according to his subjective, local knowledge, keeping in mind the raw data. This method avoided an overly strict interpretation of the data in the absence of secondary data on, for example, land quality.

Both methods showed significant overlap and resulted in three evenly distributed wealth categories. There were eight 'poor', eight 'intermediate' and nine 'rich' nursery managers.

Taking stock

The total number of seedlings present in the 25 nurseries was almost 3.3 million, ranging from 15 to ca 1.5 million seedlings per nursery. The average number of seedlings raised in the nurseries exceeded 130,000. The distribution was skewed - 25% quartile 500, median 5000 and 75% quartile 10,000 seedlings - as there were three nurseries that had a very large numbers of seedlings (Figure 2).

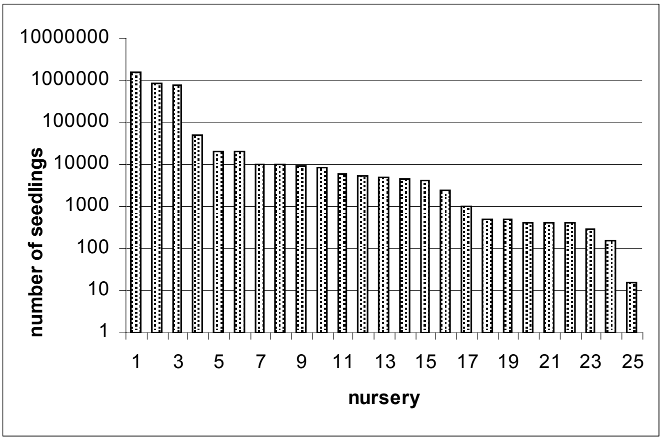

Figure 2. Number of seedlings present per nursery in Meru (log scale).

The 25 on-farm nurseries raised in total 49 tree species (Table 1). The number of species per nursery ranged from one to 28, with an average of six. This distribution was skewed, as more than half of the nurseries (15) raised no more than five species, eight nurseries raised six to ten species and two nurseries more than ten species.

The most popular species in the on-farm nurseries was *Grevillea robusta*, raised in 17 of the 25 sampled nurseries. The hedge species *Cupressus lusitanica* (cypress) and *Dovyalis caffra* (kei apple) were found in 11 nurseries each. The most popular indigenous species was *Vitex fischeri* (Meru oak), which was raised in five nurseries.

Grouping the species by their functional use showed that the 'top ten' contain five (exotic) fruit tree species – *Macadamia tetraphylla* (eight nurseries), *Mangifera indica* (7), *Citrus limon* (6), *Persea americana* (6) and *Psidium guajava* (5), and four timber/firewood species – *Grevillea robusta* (17), *Cupressus lusitanica* (11), *Eucalyptus* spp. (5) and *Vitex fischeri* (6).

In absolute numbers timber/firewood species occurred slightly more often (38 times) than fruit species (32 times). The majority (17 of 25) of farmers raised species of various functional uses.

Only two nurseries raised one of the species most under pressure as mentioned in the KWS (1999) report, *Hagenia abyssinica* and *Juniperus procera* (Table 1). Other major indigenous forest species found in nurseries were *Vitex fischeri* (five nurseries) and the cash crop *Catha edulis* (two nurseries).

Species diversity per resource category

Both poor and rich nursery managers had on average seven species and the total species diversity was 30 to 32 species (Table 2). Diversity indices could not be used here because of the small sample sizes. The intermediate nursery managers had fewer species and fewer seedlings than either the rich or poor farmers.

Both poor and rich nursery managers had about the same ratio of exotic to indigenous species, 19 : 12 and 19 : 9, respectively – again the intermediate nursery managers had less diversity with 14 exotic and only two indigenous species. *Coffea* sp. *Acacia* sp., *Terminalia* sp. and *Ficus* sp. were excluded from this comparison since their origin was unknown.

A total of 24 species, including 16 indigenous species, were only raised in one of the 25 nurseries respectively. It was mostly the poor nursery managers who raised these ‘single’ species (Table 2) emphasising their contribution to the conservation of biological diversity. Exotic tree species rarely have a conservation value outside their natural distribution.

However, this does not imply that the poorer nursery managers mainly grew rare species. On the contrary, the poorer nursery managers raised the three most popular species more often than their wealthier colleagues (Table 2). As was seen in Table 1, these three species occurred in 17 (68 %), 11 (44 %) and 11 (44%) of the 25 nurseries, respectively.

Constraints

Farmers identified a lack of water and appropriate germplasm as major problems in nursery management. Access to germplasm was listed as a bigger constraint by poor nursery managers than by the two other wealth categories (Table 3). Furthermore, poor nursery managers had more problems accessing tools and bags.

Because the poor are usually the most vulnerable to environmental stress, including the loss of biological diversity (Izac & Sanchez 2001), we assessed access to germplasm by wealth category. The results seem to indicate that the richer managers were more persistent in finding the species they wanted, whereas the poorer managers looked for alternatives (Table 3).

Table 1: Tree species and their occurrence in 25 on-farm nurseries in Meru.

Species name	No.	Species name	No.	Species name	No.
Grevillea robusta	17	*Annona senegalensis*	2	*Hagenia abyssinica*	1
Cupressus lusitanica	11	*Catha edulis*	2	*Juniperus procera*	1
Dovyalis caffra	11	*Cordia africana*	2	*Lippia kituiensis*	1
Macadamia tetraphylla	8	*Cyphomandra betacea*	2	*Malus* sp.	1
Mangifera indica	7	*Eriobotrya japonica*	2	*Morus mesozygia*	1
Citrus limon	6	*Ficus benjamina*	2	*Pinus* sp.	1
Persea americana	6	*Leucaena leucocephala*	2	*Prunus* sp. (fruit)	1
Eucalyptus sp.	5	*Podocarpus* sp.	2	*Rapanea melanoploeos*	1
Psidium guajava	5	*Abies homolepis*	1	*Sapium ellipticum*	1
Vitex fischeri	5	*Azadirachta indica*	1	*Schinus molle*	1
Callistemon citrinus	4	*Calliandra calothyrsus*	1	*Solanum aculeastrum*	1
Casuarina cunn.	4	*Citrus sinensis*	1	*Spathodea campanulata*	1
Coffea sp.	4	*Croton megalocarpus*	1	*Vangueria madagascariensis*	1
Passiflora sp.	4	*Delonix regia*	1	Carkia °	1
Carica papaya	3	*Dombeya torrida*	1	Mububao °	1
Sesbania sp.	3	*Ficus* sp.	1	Orida °	1
Terminalia sp.	3				

° identified by local name only

Table 2: Species diversity, abundance and origin per wealth category in Meru.

	"Poor"	"Intermediate"	"Rich"
Nurseries sampled	8	8	9
Average number of species	7	3	7
Total species diversity	32	17	30
Average seedling number	110,000	4,400	260,000
Number of species occurring in only one nursery			
Indigenous	10	0	3
Exotic	5	3	3
Number of nurseries with major species			
Grevillea robusta	8	3	6
Dovyalis caffra	5	3	3
Cupressus lusitanica	7	2	2

Table 3. Constraints to successful nursery operations and flexibility in sourcing germplasm if desired germplasm is not available by Meru nursery managers.

Wealth category	"Poor"	"Inter-mediate"	"Rich"	Total
Nursery constraints				
Water	4	6	5	15
Pests and diseases	2	3	4	9
Polytubes	5	1	3	9
Tools	6	2	1	9
Soil	1	1	3	5
Access to germplasm	7	3	3	13
Action taken when no immediate access to desired germplasm (more than one answer possible)				
No answer	1	0	1	2
Does not plant	0	1	0	1
Looks for alternative	4	3	2	9
Searches for species	3	4	6	13

Nursery management options

The following section presents results concerning technical inputs and management practices.

Substrate

Good plant development depends to a large part on the growing medium used (Jaenicke 1999). Therefore, soils used in nurseries should be selected for their physical, chemical and nutritional properties. In total 18 nursery operators (78 %) obtained their potting soil from their farms (Table 4). When collection was on farm, the preference was usually topsoil, which was collected from a fertile area of the farm. Two coffee farmers used as preferred source the coffee benches, under which rich humus accumulates from the coffee husks (included in the 'on farm' group).

Four farmers also obtained their substrate from the forest and the forest department (when nursery size was large). Forest soil used to be recommended for potting in the nursery, however, few farmers are able to obtain it due to location and costs of transport (Kenya/Japan Social Forestry Project 1991).

In areas of intensive agriculture in particular, as in the tea/coffee/dairy land use zones, farmers complained of diminishing availability of fertile topsoil (see Table 3 for constraints). Indeed, the average size of containers used was 15 x 5 cm, which translates into approximately 500 grams of soil. This meant that 50 tonnes of soil is required to raise 100,000 seedlings. However, this may be supplemented when other ingredients like manure are incorporated into the potting mix.

Many farmers added supplements to their potting substrate (Table 4). When comparing wealth categories, it was noted that all rich farmers used some form of additive, whereas the options were much more restricted for the poor farmers, who used manure, sand and inorganic fertilizer from the coffee production as additives. Three farmers in the poor and intermediate wealth categories did not add anything to their substrate.

Container use

Farmers have the option of raising bare-rooted seedlings of some tree species in Swaziland beds which do not need costly containers. However, most farmers in the sample preferred to use containers. Surprisingly, none of the resource-poor nursery operators raised barerooted seedlings, although they were more imaginative with alternative containers. The most common containers were polythene bags (polytubes), followed by milk cartons and other pots, mainly from "Kimbo" fat (Table 4).

Barerooted seedlings appeared to be preferred in certain species, mainly *Carica papaya, Coffea* sp., *Cupressus lusitanica*, *Dovyalis caffra*, *Eucalyptus* sp. and *Grevillea robusta.* An alternative to the commonly used Swaziland bed is to raise many seedlings in one larger container. This was observed with *Dovyalis caffra* and *Grevillea robusta.*

Shade Use

All interviewed nurseries used locally available material for shading, particularly on germinating seedlings. Most frequently used was tree shade (13 nurseries) and grass on the seedlings (9), sometimes combined with the use of other materials (Table 4).

Vegetative Propagation

Propagation through cuttings and grafting were the main methods used. Cuttings were known to 19 farmers and practised by 14, while grafting and budding techniques were known to 20 and practised by 17 farmers (Table 4). We have no reliable data on the grafting success in these nurseries. Cuttings were mainly used to propagate ornamental species like *Hibiscus rosa-sinensis* and *Bougainvillea* sp., while grafts were made for *Mangifera indica*, *Persea americana*, *Citrus* sp. and *Macadamia tetraphylla.* The farmers in the intermediate resource category used a wider variety of propagation methods than their colleagues in the other categories.

Table 4: Soil sources, substrate additives, container use, shading and vegetative propagation methods known and practised by nursery operators in Meru.

Wealth category	"Poor"	"Inter-mediate"	"Rich"
Soil source			
Farm	6	6	6
Valley bottom	1	0	0
Forest	1	1	2
Fallow land	0	0	1
No answer	0	0	1
Container use			
No container	0	2	1
None + polytubes	0	0	1
Polytubes	3	6	7
Milk cartons only	2	0	0
Polytubes and milk cartons	2	0	0
Polytubes + "Kimbo" pots	1	0	0
Shade			
Under tree (+grass +pine leaf)	5	4	4
Grass (+branches +bamboo)	3	2	4
Banana leaves	0	1	0
Polythene	0	0	1
No shade	0	1	0
Substrate additives			
Inorganic fertilizer	2	0	5
Manure	3	5	8
Charcoal	0	1	0
Compost	0	1	0
Sand	1	2	4
Sawdust	0	0	1
Murram °	0	0	1
Nothing	3	3	0
Vegetative propagation - known (practised)			
None	0	1 (1)	0
Air layering	2 (2)	1 (1)	4 (2)
Cuttings	8 (7)	5 (3)	6 (4)
Grafting/budding	7 (5)	4 (4)	9 (8)
Root cuttings	0	1 (1)	1 (1)
Suckers	0	1 (1)	0

Double mention of ingredient use possible. °Murram is a local 'gravel' used for country roads.

Species-specific information

This section contains results from the more extensive questions on only one or two species per nursery. Since there were no clear differences by wealth category, data in this section are presented for the total sample of 44 cases of 'main species' from the 25 nurseries.

Propagation methods

Although farmers were aware of a wide variety of propagation methods, their main method remained sowing. Most farmers had precise species-specific knowledge of propagation methods. In 34 cases this was seed propagation. These species included: *Carica papaya* (two nurseries), *Citrus limon* (1), *Coffea* sp. (3), *Cupressus lusitanica* (4), *Dovyalis caffra* (3), *Eucalyptus* sp. (2), *Grevillea robusta* (14), *Leucaena leucocephala* (1), *Macadamia tetraphylla* (1), *Sesbania* sp. (1) and *Vitex fischeri* (2).

In nine cases the species were propagated vegetatively, these species included: *Catha edulis* (1), *Citrus limon* (1), *Macadamia tetraphylla* (1), *Mangifera indica* (5) and *Persea americana* (1). Note that all of the vegetative propagated trees – apart from *Catha edulis* – were exotic fruit trees.

One farmer dug out *Podocarpus* sp. wildings from the forest.

Although vegetative propagation was carried out in only nine cases, there were over 500,000 propagules found in the nurseries. The 34 cases of seed propagation yielded a total of slightly more than 1 million seedlings. This result emphasises the higher multiplication rate of vegetative propagation in Meru nurseries.

Questions about the reasons for preferring seed over vegetative propagation did not result in clear answers. Many respondents stated that seeds were the only material available, or that this method was more successful and easier than vegetative propagation.

Value of germplasm

Prices of the plants differed depending on the method of production (Figure 3). Vegetatively propagated (e.g. grafted) plants cost on average 70 Kenyan shillings (KES), ranging from ten to 120 KES. Seed-propagated plants cost on average 6.5 KES, ranging from one to 40 KES. The cheapest seedling was a *Grevillea robusta* for one KES, the cheapest vegetatively propagated tree was a *Citrus limon* (ten KES), the most expensive seedling was also a *Citrus limon* but now for 40 KES and the most expensive vegetatively propagated tree was a *Mangifera indica* for 120 KES. A total of 12 nurseries did not raise trees for sale but produced for own consumption only.

The source of germplasm

Farmers were well aware of the germplasm source they used: all remembered where they, their family members or hired labourers had collected germplasm. In only four cases the nursery operator did not collect germplasm but obtained it from official or commercial sources. Farmers mainly obtained germplasm from their own farm (20 of 44 cases) or from neighbouring farms (13 cases) (Figure 4). In seven cases the farmer collected germplasm from another village. In only five cases were seeds bought at market. Official seed distributors, such as the Kenya Forest Seed Centre, Kenya Agricultural Research Institute or the Coffee

Research Foundation, were also used (five cases). Forest (4), other nurseries (3) and communal land (3) were infrequently used as a source of germplasm.

In 13 of the 44 cases germplasm was collected from several sources. The most common combination was collecting from the own and the neighbouring farms (8). The most important source remained their own or the neighbour's farm, in 25 of the 44 cases (57 %) germplasm was collected from one of these two sources.

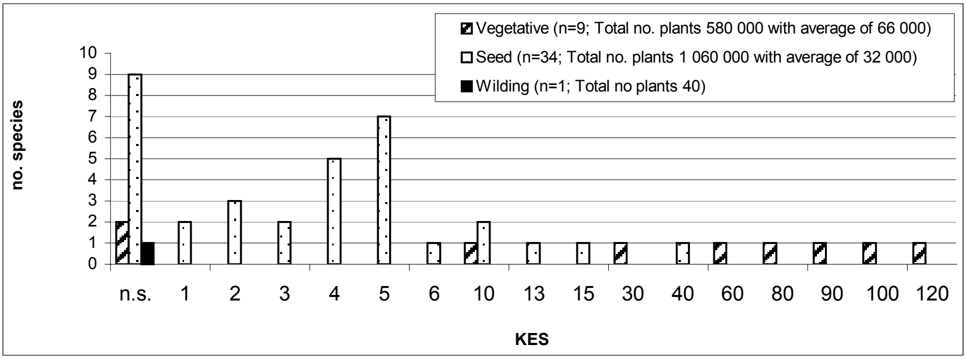

Figure 3: Number of plants and prices in Kenyan shillings (KES) per plant in Meru nurseries. (10 KES = 0.13 USD, Dec 1998). 'n.s' stands for 'not for sale'

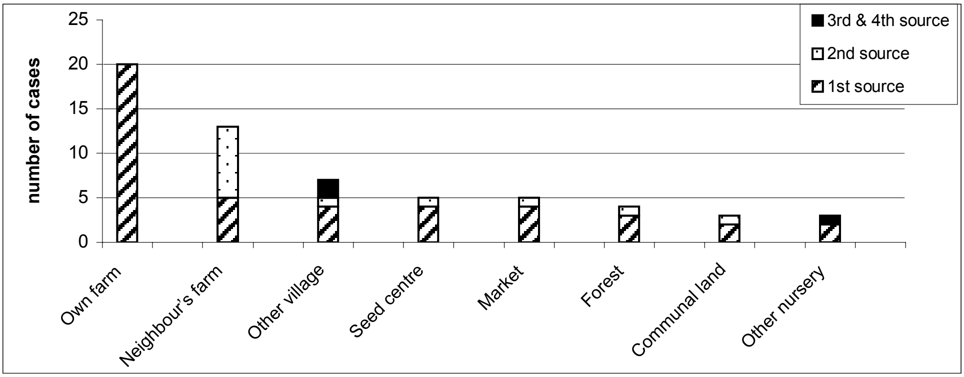

Figure 4: Source of germplasm for Meru nursery managers.

Germplasm pathways

Germplasm movement from source to planting site affects its spread and the size of the genepool. Factors that can influence germplasm movement, such as distance to the tarmac road and the forest are discussed below. The hypothesis was tested whether farmers made more efforts to collect more expensive propagules than cheap ones. If true, such behaviour could influence the distance propagules were transported and subsequently the transfer and spread of germplasm. Other factors influencing the movement of germplasm, such as type and location of market and the rarity of the purchased germplasm, were not addressed in the current survey.

The three nurseries located closest to the tarmac road, that is less than eight minutes away, obtained their germplasm from other villages as (one of) their source(s). Only three of the remaining 19 farmers collected tree germplasm from another village as well, but no other indications for differences in access to roads were found.

The four farmers that collected germplasm from the forest were at a similar distance, (110 minutes walking time) from the forest, compared with those farmers not collecting germplasm from the forest (100 minutes walking time).

The sources from where germplasm was collected were grouped in two: (i) a source located close by which in this case easy and cheap access, such as ‘own farm’ or ‘neighbour’s farm’; and (ii) a source far away, which takes generally more effort, such as another village, another nursery, the forest or from an official supplier. Communal land and market were not included, as it could not be determined in the current survey how far they were located from the farm (nursery). There was, however, no indication that the distance of the germplasm source affected the price of nursery plants.

Vegetative material was collected from nearby in six of nine cases, seed in 19 of 34 cases. Farmers looked for vegetative material from a far away source in three of nine cases, and for seed in 13 of 34 cases, roughly the same quota (33%-38%) for both propagule types.

Source or mother tree selection

Although farmers were well aware of the germplasm source they used, and additionally most farmers also collected the germplasm themselves, they had difficulties in answering the question about their reason for choosing a particular source. Part of this difficulty is attributed to a perceived irrelevance of the question (why chose when a source is right there?) and part to the Ki-Meru language which apparently has no words for such links. Therefore although the following results seem quite straight forward, caution must be taken in drawing conclusions (Figure 5).

In eight of 44 cases (18 %) no particular reason was given. In seven cases the source was the only one available (for mature seed or accessibility).

The question was easier to answer when the farmers looked for special varieties, or when no seed were readily available. In eight cases the farmers wanted a particular variety or provenance and therefore searched for that germplasm. In seven cases there was an active selection of the mother trees for performance. This was mainly for fruit trees (12 of the 15 cases) where fruit quality and quantity criteria predominated. Other criteria mentioned were resistance to pests, crown shape, and leaf shape. In three cases the farmers actively selected timber trees.

In the six cases where farmers bought germplasm they were interested in the species itself and trusted the quality assurance of the seller.

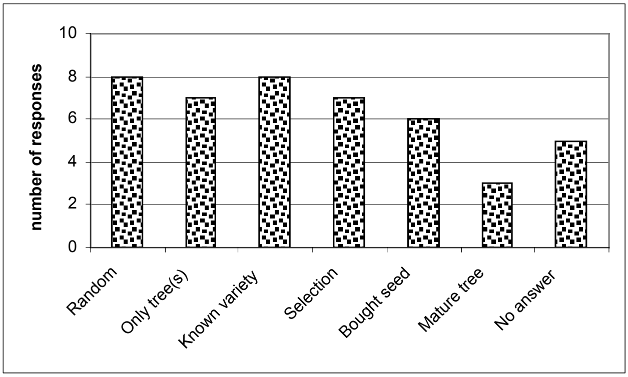

Figure 5: Reasons for the selection of mother tree(s) for the main species (n = 44).

Table 5: Number of mother trees used for seedling production in Meru nurseries (two reasons given).

Reason	number of cases	average number of mother trees used	range of mother trees used	Standard deviation
By choice (selection)	25	4.4	1 - 10	4.2
To satisfy need (availability)	9	8.1	1 - 20	8.2
Total	34	5.9	1 - 20	6.2

Number of mother trees

In order to avoid deterioration of the genetic quality and productivity of outbreeding tree species, a minimum number of 30 mother trees from which seed are collected is advisable (Dawson & Were 1997). In our survey, farmers harvested seed from between one to 20 mother trees, with an average value of 5.9 (Table 5). In 11 cases (of 44) farmers harvested from only one single mother tree.

Splitting the data in 'need' and 'choice' confirmed that without a practical need, farmers harvested from fewer trees. This has implications on the risk for genetic erosion for the different species.

Improved species

All 25 farmers were willing to spend money on improved varieties. In particular, they were interested in *Mangifera indica* (mentioned five times), and 16 other species.

Most farmers (15) would like fruit trees to be improved, 11 farmers named wood and timber species, and six liked 'exotics' to be improved. One farmer thought that all trees should be improved, another mentioned bee forage trees, and another wanted this to be led by the market. There was not much interest in 'improved' indigenous species, only two of the 25 farmers showed specific interest.

Discussion

The survey provided a wide range of information about germplasm and nursery management of tree seed and seedlings in Meru Central District during December 1998. The results showed that on-farm nursery operators knew and used a wide variety of approaches. Being an in-dept qualitative research, the amount allowed no statistical analyses. However the large amount of variables analysed all give the same result; there is variation throughout.

Although initially nurseries were identified through partners in the Forestry Department and Ministry of Agriculture, continuous interaction with farmers in the area revealed that there were large numbers of very small (10-50 seedlings) nurseries on farms, often not recognized as 'a nursery' by the farmers themselves. Therefore we have reason to believe that the larger nurseries are over-represented in our survey, as these nurseries are normally better known to a wider audience. In addition, they have a more commercial aspect and advertise themselves more often through signboards. The impact of (small) tree nurseries on the overall seedling provision might be underestimated in our survey.

Wealth differences

Grouping the farmers into three wealth categories allowed us to correlate knowledge and inputs to assets, and to compare the entrepreneurship of farmers from different backgrounds.

The most pronounced difference was the large variation in approaches and knowledge. Table 6 summarises some of the variables. Although access to quality germplasm was a larger problem for the poor farmers, they contributed more to the use and conservation of tree species for the community by raising species that other operators did not. Our hypothesis that poorer nursery managers are more dependent on biodiversity and therefore would raise more species could not be confirmed through this survey (Table 2). In our survey both 'rich' and 'poor' farmers raised larger numbers of trees than the 'intermediate' farmers.

In general, we found the poor nursery managers more entrepreneurial than their wealthier counterparts. Despite their financial situation, the poorer nursery managers found their way to the market or official seed supplier more often than medium or rich nursery managers (six, two, two respectively).

Table 6: Main differences in germplasm and nursery management by poor, intermediate and rich on-farm nursery operators in Meru.

Wealth category	'Poor'	'Intermediate'	'Rich'
Total number of species	30	17	32
Average number of species per nursery	7	3	7
Number of species raised in only one of 25 sampled nurseries	15	3	6
Cases of seed collected (own or neighbouring farm)	10	10	13
Cases of seed bought (market or seed centre)	6	2	2
Problem with access to germplasm	7	3	3
Use of inorganic fertilizer or manure	5	5	13
Prevailing containers	Variety of containers	Polytubes	Polytubes

The basic technologies used did not vary throughout the category for most variables. Poorer operators had less access to good soil and other substrates or fertilizers, although rich managers mentioned access to soil as a constraint. We explain this with their larger output of potted seedlings (each in containers of at least 300 ml). Technical knowledge, such as about vegetative propagation, was comparable between the wealth categories. All farmers used inputs such as polytubes to a similar extent, however, the poorer farmers again showed ingenuity by substituting with milk cartons and fat containers.

Poor nursery managers were also the most willing to pay money for germplasm. They also sold their seedlings cheaper than intermediate and rich farmers which might be attributed to a lack of market power and market intelligence.

Germplasm

The nursery managers considered germplasm collection (both seed and vegetative material) as an important activity. They were very well aware of their sources, and usually germplasm collection was the managers' own responsibility. We found high variation in aspects such as germplasm sales prices and sources, even though the main sources were own or neighbouring farm. The lack of germplasm was considered a major constraint and this also had an effect on the choice (Figure 5) and number of mother trees (Table 5).

The farmers' selection criteria were difficult to assess. Despite various ways of formulating the question, many farmers found the logic of collecting seed from more trees than obviously necessary difficult to follow. Statements such as 'the only tree(s) available' for a common species like *Grevillea robusta* illustrate the difficulty the question posed. Most farmers collected seed from available trees and collected from any one tree as much as they needed or could access. Older and/or bigger trees were often preferred for various reasons, one of the more prominent ones being that seeds from a mature tree are more viable than the seeds from a young tree.

One farmer surprised us by having developed a sophisticated selection programme for *Cupressus lusitanica*. He regularly visited forests to look at felled trees to check if they had holes. By doing so he claimed to be able to select non-hollow standing trees in the forest on outside appearance. Other criteria he used were selection for a straight stem, preferred tree structure and stunted growth rate. He selected as much seed to fulfil his seed needs, in this case from ten trees.

Vegetatively propagated trees were more expensive than seedlings (Figure 3) and we expected that farmers would make greater efforts to collect the desired germplasm, such as sourcing it from further away or from registered mother orchards. However, we could not confirm this within the current sample. Vegetative propagation material, such as scions or cuttings, was usually collected from similar sources as seed. It was usually not bought at the market or obtained from official suppliers, although this would have been possible, for example through the state prisons, who have a large collection of fruit tree species and cultivars (J. Griesbach pers. comm.). Although to propagate a registered or known variety, material from only one tree might be sufficient, for the purpose of improving material from the wild through selection and cloning, grafting or cutting material ought to be collected from a number of sources.

In general, for a wide variety of reasons, the nursery operators preferred seed propagation.

All farmers expressed interest in at least one improved species, showing that there was a demand for (genetic) quality germplasm. The species mentioned most often was *Mangifera indica*. This shows a likely lack of information rather than technical skills. In Kenya, projects have been running for many years introducing improved cultivars for several (exotic and indigenous) fruit species, but the uptake by individual small-scale farmers has been low, most probably because these farmers do not have the information about and access to the few central mother orchards that sell scions of improved cultivars (J. Griesbach pers. comm.).

The connection between quality germplasm and selection or number of mother trees was not known. Farmers acknowledged the need for better germplasm, but many did not apply this in practice. Farmers were not aware that ‘to improve a species in order to have an improved variety available’ really meant improving the genetic makeup of the species itself; that is by breeding or selection. Grafted trees were always called ‘improved trees’, regardless of whether the scion had originated from an improved or wild stock. As many grafted trees start flowering and bearing earlier, this could have contributed to this assumption.

Inexpensive training courses, including farmer to farmer exchange, could be developed to broaden the understanding of these difficult issues and help nursery operators to identify quality germplasm sources.

Inbreeding and genetic erosion

Our survey indicates a dangerous risk for genetic erosion through current nursery practices. The very small number of mother trees used for seed collection (on average 5.9) was much lower than the recommended number of 30 to adequately capture genetic variation (Dawson & Were 1997). By narrowing the genetic base of a population, its adaptive capacity for changing user requirements and environment decreases.

Our study provides further worrying evidence. (i) Most germplasm (57 %) was collected from the own or neighbouring farms (Figure 5), emphasising a danger of inbreeding in future generations. (ii) The number of flowering trees around was on average more than enough for an effective population size to prevent genetic erosion (data not shown). However, seed sourcing from a single solitary tree was no exception. Therefore, in specific cases the risk for inbreeding – even through self-pollination – becomes real. (iii) The few cases of selection were applied without considering the necessary genetic implications. Depending on the heritability of the selected traits, selection may give an initial positive response due to selection of superior genotypes, but this positive effect could be lost in subsequent generations due to a narrowing of the genetic base.

The effect on the imperfect nursery practices on the genetic base of the species is determined by the proportion of the size of the nursery lot compared to the size of existing genepool. The genetic constitution of planted nursery lot may have an influence on the genepool of the tree populations in place but with a large genepool in place it can also ‘drown in the genepool’? Common species may therefore be less vulnerable than the rarer species.

Ultimately, the risk for inbreeding in any species depends on its biological characteristics as well as on propagation practices: a prolific seeder is more vulnerable for genetic erosion, also because nursery managers prefer to obtain the necessary quantity from fewer trees (Table 5). However, apart from the sheer number of seeds produced, many other factors play a role as well, such as the selfing rate, the life span of the tree, its pollinator, seed dispersal, duration of the flowering period, replacement rate and the natural rejuvenation capacity.

Conservation through use

Farmers identified a lack of appropriate germplasm as a major problem in nursery management. In Murang'a, on the other side of Mt Kenya, Roothaert and Tuwei (1994) reported similar results. A successful concept to conserve species or the diversity within species is 'use it or loose it' (Kindt & Lengkeek 1999; IPGRI 1999). A risk to biological diversity exists if germplasm can no longer by found locally and becomes forgotten by farmers. In our survey most farmers reported to actively search for a 'lost' species or variety, however, we do not know for how long they will continue, and whether the next generation will still know these species. We also do not know how soon the tree species or varieties in Meru might get lost and how easily it would be to reintroduce them (Richards & Ruivenkamp 1997). Since more than a third of the 25 farmers looked for alternatives or replacements with matching functions when they could not source a desired species or variety, the risk of genetic loss is real. Access to germplasm is an important issue for the farmers and they do want to diversify (Chapter 2). In the increasingly densely populated areas of Meru the future of trees will be on farm (Simons et al. 2000). However, a serious challenge in species conservation is posed by the fact that new genes are not introduced. In this survey, in 25 of the 44 cases (57 %) the germplasm was obtained from the own and/or neighbours farm, compared to 48% recorded in Western Kenya (Kindt 1997). Access and successful farmer to farmer exchange of germplasm is the key factor in minimising the loss of indigenous biological diversity.

Conclusion

One of the objectives of this survey was to document the variation in knowledge and practises in nursery management within Meru Central District. Clearly, results were consistent; there was an enormous range in almost all variables. This variation was also found within wealth categories. Although nursery operators are generally well aware of appropriate nursery practices, there was a serious knowledge gap regarding the number of mother trees.

In order to improve the current nursery practices in Meru Central District, emphasis ought to be put into fostering information exchange between nursery operators. This will be an important step in addressing improvement of the technical nursery management and the marketing of high quality seedlings. All nursery operators we interviewed had something unique to contribute to the overall knowledge base. The knowledge of the nursery managers was often more adapted to the local situation than the knowledge brought forward by outside researchers. We suggest exploring possibilities for the development of nursery associations for information exchange both on technical as well as marketing issues.

In addition, technical input in two main areas will improve nursery practices: (1) Germplasm handling, including seed collection. (2) Improved access to germplasm, through, for instance, information about seed availability or setting up seed orchards for species perceived as important by the communities. All wealth categories could benefit from these activities. More emphasis on the poor nursery managers, who in our survey already produced more diverse nursery populations, would certainly contribute to the use and conservation of a variety of tree species.

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Chapter 6

Genetic bottlenecks in agroforestry systems: results of tree nursery surveys in East Africa

Ard G. Lengkeek[12], Hannah Jaenicke[1] and Ian K. Dawson[1]

[1] World Agroforestry Centre (ICRAF), PO Box 30677, Nairobi, Kenya
[2] Wageningen University and Research centre, Biosystematics Group, Gen. Foulkesweg 37, 6703 BL, Wageningen, The Netherlands

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Abstract

Seedlings sourced through tree nurseries are expected to form an important component of future tree cover on farms. As such, the genetic composition of seedlings provided is expected to impact on the productivity and longer-term sustainability of agroforestry ecosystems. Here, by surveying current practices of nursery managers in five areas from Kenya, Tanzania and Uganda, we quantified parameters associated with the collection, production and distribution of tree germplasm in East Africa. Enormous variation was observed for seed-propagated nursery species, with current seed collection practice a clear limiting bottleneck in delivering genetic diversity to farmers. For the 143 cases analysed, on average seed from only 6.4 maternal parents was collected to establish nursery seedling lots, while 22% of nursery lots were established from single maternal parents. On average, each sampled maternal parent provided sufficient progeny to supply all the seedlings received by an individual nursery client. Therefore, the potential impact of non-randomisation within the nursery of progeny from different maternal parents on farm and landscape genetic diversity levels is great. Pair-wise analysis of transformed data suggested differences between some areas relating to the number of clients supplied by nurseries. Interventions likely to promote genetic diversity through altered nursery practices, in particular increased maternal parent sampling and germplasm exchange, are discussed.

Key words: genetic resource management, tree nursery practices

Introduction

Farmers plant trees in pursuit of their livelihood goals of income generation, household food security and risk management, endeavouring to optimally use available land, labour and capital (Arnold & Dewees 1995). In areas where natural forest cover is contracting, farmers are increasingly dependent on the productivity and sustainability of agroforestry ecosystems (Kindt & Lengkeek 1999; Simons et al. 2000). These systems depend on the vitality of their individual species, an essential component of which is determined by genetic processes (SGRP 2000). 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 (Simons et al. 1994; Simons 1996; Brodie et al. 1997; Boshier 2000). Among other factors, inbreeding depression may result in losses in vigour, productivity, survival and seed set (Charlesworth & Charlesworth 1987; Mouna 1989; Griffin 1990; Turnbull 1996), leading to significant long-term viability concerns. Intraspecific genetic resource management (GRM) therefore plays an important part in determining the ecological stability of farming systems based on agroforestry.

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 (Kindt 1997; Weber 1997; Holding & Omondi 1998; Chapter 5). In a limited survey conducted on tree nurseries found on farms around Meru in Central Kenya, results from Chapter 5 suggested genetic issues to be of particular concern during nursery management. In the limited number of cases where data were available, they found that germplasm collected on average from 5.9 trees was used to raise nursery lots, with a range of between one and 20 trees collected. Of particular concern, in more than one third of the cases examined seed was harvested from a single tree. Furthermore, after initial farm introductions, most germplasm for subsequent planting rounds was harvested from trees on the same farm or, less frequently, from neighbouring farms. Data therefore indicated the potential for a narrowing of genetic variation through tree nurseries, suggesting that intraspecific tree diversity in on-farm stands may often be initially limited and further reduced in subsequent generations.

Here, we addressed genetic concerns raised by the preliminary observations in Chapter 5 in a wider geographic range of East Africa where natural forest cover is contracting (FAO 2001). Included were tree nurseries from Tanzania and Uganda as well as Kenya. Our objectives were to assess genetic issues associated with tree nurseries in more detail and to determine if common issues applied across the region. We hoped to draw general conclusions regarding possible interventions at the nursery level for tree GRM in East Africa.

Materials and Methods

Five areas in East Africa where changes in tree cover are currently underway were chosen for nursery survey. Important considerations in selecting areas for inclusion in the survey were the presence of logistical support, on-going agroforestry research and geographic spread, the last in consideration of an assessment of inter-area variation. Chosen areas were (i) Meru District, near Mount Kenya, Kenya, where data were collected from the same on-farm nurseries assessed in Chapter 5, (ii) Nairobi, Kenya, where urban and peri-urban nurseries were sampled in and around Nairobi and Kiambu (Basweti et al. 2001), (iii) Kabale District, Uganda, where nurseries were sampled across the district, including within the buffer zone of Bwindi Impenetrable Forest, (iv) Mabira, Mukono District, Uganda, including on-farm nurseries in the buffer zone to the Mabira Forest Reserve; and (v) Arusha, Tanzania, where peri-urban and rural nurseries around Arusha were assessed.

For all areas except Arusha, survey involved visits to individual nurseries followed by interview of nursery managers. Selection of nurseries within areas was generally undertaken in collaboration with government departments of forestry and agriculture, as well as with early survey interviewees. Nurseries operated by government departments were generally excluded, with emphasis rather placed on private nursery operators. The date of nursery visits varied between December 1998 and April 2001, depending on area. The month of survey was chosen to coincide with rainfall patterns such that nursery stocks were expected to be at a maximum level during data collection. At Arusha, data were not collected by nursery visits. Rather, data were collected from nursery managers during a training course on nursery management held in Arusha in July 2000, organised by the Regional Land Management Unit of the Swedish International Development Cooperation Agency (see Lengkeek & Saruni 2000).

Interview of each nursery manager, normally conducted in the local language, focused on a limited number of tree species. For each nursery, data were generally collected on the two seed-propagated tree species present that were considered by the interviewee to be of most importance for the nursery. Occasionally, more species were included, particularly if the number of known nurseries available for survey in an area was limited. In each case, the interviewee was asked to provide data on three measurements relating to the collection, production and distribution of germplasm that are key to understanding nursery GRM. These were (i) the number of maternal parents sampled to establish a given nursery population (or lot) (N_m), (ii) the quantity of seedlings in that nursery lot (N_s); and (iii) the projected number of clients (farmers and other users) for the nursery lot (N_c). Nursery managers that only raised trees for their own use were counted as single clients. Different from the first two values, N_c is an estimate based on the experience of a nursery manager over previous years. On some occasions, nursery managers were not able to estimate N_c. In other cases, N_m was unknown because seed had not been collected directly but obtained from other sources such as non-governmental projects and seed dealers, or managers could not recall how many trees had been sampled. Included in our analysis were only those cases where N_m was available.

In order to provide some verification of interviewee responses, N_s was counted directly by the interviewer in a number of cases from each area (except Arusha). Observation generally confirmed the previously given estimates of nursery managers. In some cases, where values for the three measurements appeared inconsistent with each other or unrealistic for a given species (for example, if $N_c > N_s$), data were excluded from our analysis.

Results

Data for the region

In total, data on 143 cases were analysedfor the East Africa region. Cases came from 71 nurseries and represented a total of 43 species, of which 15 species (35%) were indigenous to the region (according to regional Flora), although indigenous species represented only 27 cases (19%). The five species most frequently included were all exotic: *Grevillea robusta*, *Calliandra calothyrsus*, *Dovyalis caffra*, *Senna siamea* and *Cupressus lusitanica*, with 34, 10, eight, seven and seven cases, respectively (individual values not shown in Table 1), making a total of 66 cases. Twenty-two species (51%) were included once only in the analysis.

The mean number of maternal parents collected for nursery lot establishment (mean N_m) for all 143 cases was 6.4. In 31 cases (22%), nursery lots were established from seed collected from single trees, of which 6 cases (4%) represented indigenous species. For the five species most frequently included, *G. robusta*, *C. calothyrsus*, *D. caffra*, *S. siamea* and *C. lusitanica*, mean N_m values were 8.6, 4.7, 21.6, 8.0 and 3.1, respectively (overall mean = 8.9; values not shown in Table 1). For the 22 species included only once in analysis, mean N_m was 5.9. Considering exotic and indigenous categories, mean N_m values were 6.8 (N = 116) and 4.5 (N = 27), respectively. Figure 1 illustrates the relationship between cases and N_m. In only 18 cases (13%) was $N_m > 10$, while in only two cases was $N_m > 30$. Data suggested a relationship between the frequency of species occurrence and N_m (Fig. 1c). Overall, the five most common species appeared skewed to higher N_m values compared to species included only once in analysis.

Averaging across all 143 cases, approximately 1,400 seedlings were raised in each nursery lot (mean N_s), with 28 clients receiving seedlings from each lot (mean N_c) (Table 1; the latter figure based on the 113 of 143 cases for which client data were available). A mean of approximately 370 seedlings was raised per maternal parent sampled for nursery lot establishment (N_s/N_m; N = 143) and each client received on average 125 seedlings from a nursery lot (N_s/N_c; N = 113) (values not shown in Table 1). Considering cases individually, in 106 cases (N = 113) the mean number of seedlings received by clients was $\geq N_m$. In 96 and 74 cases respectively, the mean number of seedlings received by clients was $\geq 2\ N_m$ and $\geq 5\ N_m$ (data not shown in Table 1). Therefore, assuming randomisation of progeny from separate maternal parents in the nursery, it appears likely that individual clients will generally receive seedlings from most of the initially collected maternal parents. However, since the mean number of seedlings raised per maternal parent sampled for nursery lot establishment is large ($\cong$ 370), the potential impact of progeny array non-randomisation is great (that is, on average, one maternal parent provides sufficient progeny to provide all the nursery seedlings received by an individual client).

Variation among areas

Of the five areas assessed, the greatest number of cases analysed were collected from Arusha, followed in descending order by Nairobi, Mabira, Meru and finally Kabale (Table 1). The mean number of cases analysed per nursery differed somewhat between areas, ranging from 2.9 at Mabira to < 1.5 at Nairobi and Meru. The number of species represented in analysis varied from seven at Meru to 16 at Nairobi and Arusha, likely due in part to the greater overall number of cases analysed in the last two areas. As a proportion of all species analysed, indigenous species ranged from a maximum of six of 14 species at Mabira to a minimum of one of seven species at Meru and three of 16 species at Arusha. As a proportion of cases, indigenous species ranged from a maximum of 10 of 26 cases at Mabira to two of 17 cases at Meru and five of 54 cases at Arusha. Whilst these differences likely reflect in part the greater mean number of cases analysed per nursery at Mabira, since this provides greater opportunity for sampling species of lower overall importance, it appears likely data also reflect genuine differences between areas for indigenous and exotic species.

Considering pooled data for the five species most frequently included in the survey, the exotics *G. robusta*, *C. calothyrsus*, *D. caffra*, *S. siamea* and *C. lusitanica*, the proportion of cases varied from a maximum of 40 of 54 at Arusha to a minimum of two of 15 at Kabale and three of 26 at Mabira. Important seed-propagated nursery species at Arusha therefore appear to be strongly biased toward a small number of exotics. Common species have variable importance across the region, with *G. robusta* mentioned in only three areas, *C. calothyrsus* and *D. caffra* in only two areas and *S. siamea* in one area only (data not shown in Table 1).

Considering cases in the survey where nursery lots were established from seed collected from single trees, Kabale and Meru showed the greatest proportion of cases (seven of 15 and seven of 17, respectively), with Arusha the lowest (five of 54).

Mean N_m ranged by area from 3.7 at Kabale to 8.2 at Arusha, while mean N_s varied from < 800 at Nairobi to > 2,000 at Mabira. Mean N_c varied widely between areas, with values from 12 at Kabale to 81 at Meru (client figures based on a subset of cases; see Table 1). The range of values for N_m, N_s and N_c varied very widely within areas, including for individual species between nurseries, resulting in heavily skewed distributions and large standard deviation values. Undertaking $\log_{10}$ transformations resulted in more normal distributions and pair-wise analysis between areas suggested statistically significant differences for $\log_{10} N_c$ values in two cases (Table 1). 95% confidence intervals did not overlap for $\log_{10} N_c$ values for Meru compared to both Kabale and Nairobi.

Discussion

Previous on-farm inventories of tree cover within the current survey region indicated that a large proportion of both indigenous (Kindt et al. 2003; Chapter 4) and exotic (Chapter 4) species have very low overall densities and aggregated distributions, with access to germplasm (see also Chapter 2) a likely limiting factor in current planting. Low densities and aggregated distributions may be factors determining the relatively limited number of species (43) detected in the current analysis of nurseries, despite the large number of species with defined functional uses on farms (Kindt et al. 2003; Chapter 4). In addition, these factors may explain the high proportion of species in the current analysis (51%) that occurred once only during survey.

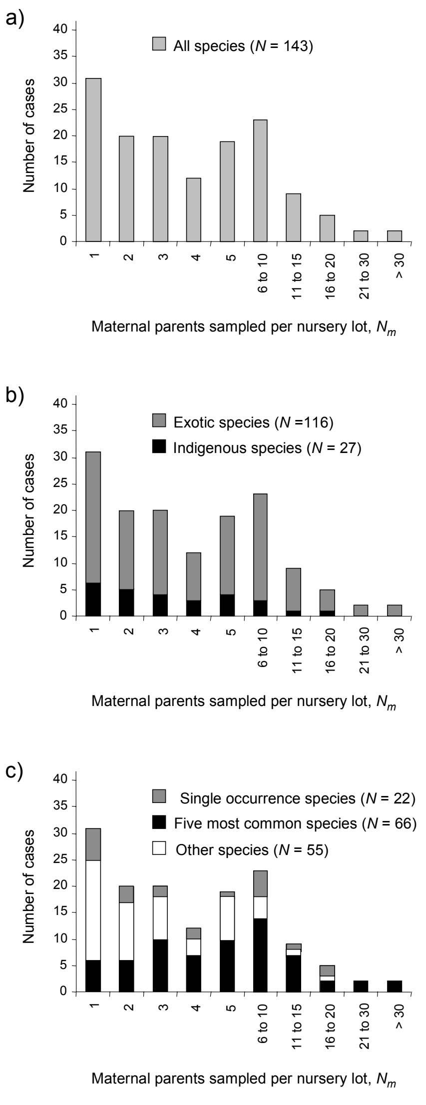

Figure 1. Data showing the number of maternal parents collected for nursery lot establishment (N_m) in a survey of seed-propagated tree species in tree nurseries from five areas in East Africa. (a) data for all analysed species, totalling 143 cases, (b) data split by indigenous and exotic categories. Indigenous species were categorised according to the flora of the entire survey region rather than by specific sites, (c) data split by frequency of species occurrence. Twenty-two species were analysed only once in the survey. The five most common species, *Grevillea robusta*, *Calliandra calothyrsus*, *Dovyalis caffra*, *Senna siamea* and *Cupressus lusitanica*, occurred in a total of 66 cases. For further information, see Results.

Table 1. Data collected in a survey of seed-propagated tree species in tree nurseries from five areas in East Africa

	Survey area (country)					All areas
	Kabale (Uganda)	Mabira (Uganda)	Nairobi (Kenya)	Meru (Kenya)	Arusha (Tanzania)	
Nurseries analysed [client data available*]	7 [6]	9 [7]	21 [16]	12 [8]	22 [22]	71 [59]
Cases analysed [client data available]	15 [8]	26 [16]	31 [25]	17 [10]	54 [54]	143 [113]
All species analysed	11	14	16	7	16	43
Indigenous species analysed	3	6	6	1	3	15
Cases indigenous species	4	10	6	2	5	27
Cases five most common species	2	3	11	10	40	66
Cases of unique species occurrence	3	6	6	2	5	22
Single tree collections all species	7	4	8	7	5	31
Single tree collections indigenous species	2	1	2	0	1	6
Maternal parents per nursery lot, N_m: mean (SD)	3.7 ± 1.8 (3.6)	5.1 ± 2.3 (6.0)	5.8 ± 3.1 (8.9)	5.7 ± 3.1 (6.5)	8.2 ± 3.8 (14.1)	6.4 ± 1.7 (10.3)
Log_{10} maternal parents per nursery lot, $\log_{10} N_m$: mean (SD)	0.38 ± 0.21 (0.41)	0.51 ± 0.15 (0.39)	0.54 ± 0.15 (0.42)	0.49 ± 0.24 (0.50)	0.69 ± 0.11 (0.40)	0.57 ± 0.07 (0.43)
Seedlings per nursery lot, N_s: mean (SD)	871 ± 712 (1408)	2060 ± 1408 (3661)	787 ± 432 (1228)	1339 ± 1011 (2127)	1543 ± 676 (2535)	1378 ± 401 (2446)
Log_{10} seedlings per nursery lot, $\log_{10} N_s$: mean (SD)	2.27 ± 0.46 (0.91)	2.84 ± 0.25 (0.66)	2.38 ± 0.25 (0.72)	2.53 ± 0.36 (0.77)	2.83 ± 0.16 (0.61)	2.64 ± 0.12 (0.72)
Clients per nursery lot, N_c: mean (SD)	12 ± 14 (20)	41 ± 27 (55)	17 ± 9 (22)	81 ± 92 (149)	22 ± 5 (20)	28 ± 10 (53)
Log_{10} clients per nursery lot, $\log_{10} N_c$: mean (SD)	0.71 ± 0.42 (0.61)	1.12 ± 0.38 (0.77)	1.01 ± 0.18 (0.46)	1.55 ± 0.32 (0.52)	1.15 ± 0.12 (0.45)	1.12 ± 0.10 (0.54)

The number of nurseries and cases analysed from each area are shown, as well as the total number of species represented in each area in analysis. Values for indigenous species are based on those species native to the entire survey region rather than to specific sites. Pooled data for the five species most frequently analysed based on overall case occurrence, *Grevillea robusta*, *Calliandra calothyrsus*, *Dovyalis caffra*, *Senna siamea* and *Cupressus lusitanica*, all of which are exotic, are shown. In addition, data for species only occurring once in analysis are indicated, as well as cases where seed for nursery lot establishment were taken from single trees. 95% confidence intervals and standard deviation (SD) values for the three main variables assessed in the survey (N_m, N_s and N_c), and their $\log_{10}$ transformations, are given. For further information, see Results and Discussion. * Client information was only available for a subset of analysed nurseries and cases (values shown in square parentheses, [ ]). Mean values relating to clients are therefore calculated from this subset of data

In a provisional survey of on-farm tree nurseries in the Meru area, Chapter 5 indicated that on average only a small number of maternal parents (5.9) were sampled to establish nursery lots of important, largely exotic, seed-propagated species, leading to genetic diversity concerns for future on-farm tree populations established from nurseries. Furthermore, nursery managers frequently sourced seed for nursery lot establishment from their own or neighbouring farms, suggesting limited opportunities for new germplasm introductions and likely amplifying negative genetic effects associated with the limited number of maternal parents sampled. In the current wider-scale nursery study in five areas of East Africa, in which 143 cases of seed-propagated tree species were analysed, similarly low numbers of maternal parents were sampled for nursery lot establishment, for both exotic and indigenous categories of trees (mean N_m of 6.8 and 4.5, respectively, overall mean of 6.4). In 22% of cases, an extreme situation of nursery lot establishment from single trees was observed. In only two cases were seed collected from the minimum number of 30 trees recommended by Dawson and Were (1997) for adequately capturing genetic variation in outcrossing tree populations. Considering areas independently, Arusha showed the highest mean N_m (8.2), but this value remained low, indicating low mean N_m values at all areas. Our data therefore indicate clearly the potential for current seed collection procedures during nursery lot establishment to contribute significant genetic risks to the productivity and sustainability of on-farm tree cover across the region. From a conservation perspective, low N_m values for indigenous species are of particular concern. Data presented here primarily concerned important seed-propagated species, but differences between the five most common species detected and those that occurred only once in the survey (mean N_m values of 8.9 and 5.9, respectively) suggest that for less important species sampling issues are likely to be even more acute.

Values for the quantity of seedlings in a nursery lot (N_s) and the projected number of clients for a nursery lot (N_c) revealed in the current study indicate that each client should normally receive progeny from most maternal parents collected to establish a nursery lot. However, this assumes mixing of progeny derived from seed of different maternal parents at the nursery stage, since on average each maternal parent sampled provides sufficient progeny to provide all the seedlings received by an individual client. Non-randomisation of progeny arrays within the nursery, for example resulting from a number of separate collections for seed, could therefore have a significant impact on the genetic diversity of material received through nurseries.

The wide range in N_m, N_s and N_c values observed in the current study illustrates further risks to genetic diversity. Values varied widely among cases within areas, including among cases of the same species, suggesting that year to year variation in collection, production and distribution figures is also likely. Thus, effective population sizes may be further reduced through bottlenecks and founder effects, particularly since managers, at least of on-farm nurseries, appear to frequently return to their own or neighbouring farms for seed (Chapter 5). Countering this, however, a key factor in preventing founder effects in tree species is their delayed reproduction, as this allows a large increase in the number of initial founders of a given population before reproduction (and subsequent colonisation) begins (Austerlitz et al. 2000).

The on-farm inventories of Kindt et al. (2003), which have two areas in common with the current study, Mabira and Meru, indicated a greater proportion of established trees to be of planted exotic origin at the latter location. Consistent with this observation, the current nursery study indicated that exotic species formed a greater proportion of analysed cases in the latter area. At Meru, established on-farm exotic trees were apparently more frequently sourced through nurseries than indigenous on-farm tree cover (Chapter 4; AGL, unpublished observations). An assumption that the pattern of current (and future) on-farm establishment bears some relationship to past patterns observed from tree inventory studies must be made cautiously in the context of continual changes in on- and off-farm tree cover. However, it appears reasonable to assume that nursery genetic issues are particularly important when on-farm tree cover is contributed primarily by exotics. A low mean N_m value at Meru would therefore be of more significance than at Mabira, although values were approximately the same in both areas (5.7 and 5.1, respectively).

A number of other factors determine the extent to which nursery genetic management practices for seed-propagated species impact on farm and landscape tree genetic diversity in East Africa. First, on farm inventories of current tree cover (Chapter 4) and the preliminary nursery survey (Chapter 5) indicated the importance of other types of germplasm for on-farm tree establishment. For example, ‘direct’ cuttings had been an important source of germplasm for established stands of both exotic and indigenous tree species at Meru (Chapter 4). In addition, Chapter 5 indicated that around Meru vegetative propagation as well as seed was an important method for producing current nursery stock (although information was not collected on parental sampling for vegetative material). The importance of vegetative propagation revealed by both studies indicates a requirement for additional research that considers sampling issues for clonal material. Nevertheless, research on seed-propagated germplasm can be considered indicative of the issues likely also to be important for vegetative propagules.

Second, the impact of nursery genetic management practices will depend on the origin and history of a given species. Indigenous species may be less sensitive to genetic erosion because of remnant trees that potentially input seed and pollen into subsequent generations of on-farm material. However, the availability of viable remnant trees at locations varies widely (AGL, unpublished observations) and will likely decrease in the future as the date of forest clearance recedes. If tree density decreases, outcrossing levels may fall (Murawski & Hamrick 1992; Murawski et al. 1994), causing a greater proportion of overall genetic variation to partition among maternal parents (Hartl 1987), thereby exacerbating diversity losses through seed collection strategies based on a few trees. Exotic species depend substantially on the initial genetic base of introduced material, which may have already introduced considerable founder effects, particularly if introductions took place before the possible genetic impacts of narrow introductions were widely appreciated. It appears likely that the most common species detected in the current survey, *Grevillea robusta*, an exotic from Australia, was introduced to East Africa with a rather narrow genetic base (Harwood 1992). Because this species is now widely planted in the landscape, new introductions of more diverse material may have a rather limited effect. The extent to which origin and history impact on diversity will depend on the specific biology of individual species.

Third, the impact of nursery genetic management practices will depend on issues of spatial scale. It was outside the scope of the current survey to assess the detailed geographic location of tree nurseries and their clients, but clearly this will impact on landscape genetic diversity. For example, an overlapping geographic distribution of clients from different nurseries is likely to result in a more diverse landscape than restricted local distribution, if nursery managers have different sources of seed for nursery establishment (as suggested in Chapter 5). Furthermore, our sampling of nurseries for inclusion in this survey was not exhaustive and many excluded nurseries (particularly small ones; see Chapter 5) will occupy geographically intermediate positions. Peri-urban nurseries surveyed here from the Nairobi area likely have the widest client distribution, since Nairobi has a regional function in tree seedling provision (Basweti et al. 2001). In addition, farm size also impacts on landscape diversity because of biological constraints to gene flow mechanisms that act to homogenise genetic structure.

Generally, farm sizes are expected to be small within current survey areas, providing opportunities for genetic exchange between farms by pollen flow.

In conclusion, current seed collection procedures practiced by nursery managers provide a clear limiting bottleneck in delivering genetic diversity to farmers. Further research, however, is required on a number of issues, including quantification of other sources of germplasm, assessing the history of exotic introductions and studying the detailed spatial distribution of nurseries and their clients. Due to the wide range of variables that may impact on tree genetic diversity levels on-farm, studies that mathematically simulate (Kindt 2002) or directly measure variation are useful. Direct measurements are however currently limited and have generally involved informal comparisons of native populations with exotic stands (for example, Chamberlain 1998; Muluvi et al. 1999). Rarely have studies directly compared the diversity of natural and on-farm populations within the native range of a tree species (Muchugi 2001). Currently, farm and forest stands of the important and heavily exploited timber tree *V. fischeri* from central Kenya are being tested as a model for genetic erosion concerns on-farm by two of the authors (AGL and IKD), employing molecular genetic markers.

Based on the current study, a number of possible interventions to increase the provision of genetic diversity to farmers through nurseries can be postulated. Chapter 5 indicated that during seed collection by nursery managers the number of trees sampled depended at least partially on the quantity of seed required rather than the availability of seed-bearing trees. There therefore appears scope to encourage the collection of a larger number of maternal parents during seed collection through training of nursery managers. However, access to seed is apparently a limiting factor in current planting activities for many trees (Chapter 2), with many useful species having very low numbers and aggregated distributions (Kindt et al. 2003; Chapter 4). In this situation, an appropriate intervention to increase both intra- and inter-specific tree variation on-farm is the establishment of local nursery networks through which germplasm and information are exchanged and combined.

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Chapter 7

Monitoring genetic variation during tree domestication by farmers: a case study of *Vitex fischeri* Gürke (syn. *Vitex keniensis* Turrill) in central Kenya

Ard G Lengkeek[1,2], Alice Muchugi M.[1], Caroline AC Agufa[1], Joseph O Ahenda[3] & Ian K Dawson[1]

[1] World Agroforestry Centre (ICRAF), PO Box 30677, Nairobi, Kenya
[2] Wageningen University, Biosystematics Group, 6703 BL - 37, Wageningen, The Netherlands
[3] Kenya Forest Seed Centre, Muguga, PO Box 20412, Nairobi, Kenya

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Abstract

It is anticipated that current germplasm collection practices during tree domestication activities conducted by farmers will reduce the genetic base of tree resources on farms, raising concerns regarding the sustainability and conservation value of agroforestry systems. Here, we assessed possible changes in genetic variation during domestication in the important and heavily exploited timber species, *Vitex fischeri*, by comparing matched forest and farm stands in two areas of central Kenya, employing RAPD analysis. In addition, stands from western Kenya were compared with material from central Kenya in order to provide information on partitioning between populations until recently considered as separate species (*V. fischeri* and *Vitex keniensis*, respectively). In total, 106 RAPD markers revealed by five arbitrary primers were tested on 85 individuals. Despite concerns of genetic erosion, geographically proximate forest and farm stands in central Kenya did not differ significantly in levels of genetic variation. However, Mantel tests of individual stands in central Kenya indicated a greater degree of microgeographic structuring within forest than within farm material, suggesting homogenisation of genetic structure during farmer's planting activities. Genetic differentiation between forest and farm stands within central Kenya was low, with 4% of variation partitioning among stands within areas according to an analysis of molecular variance. A clear genetic split between stands from central and western Kenya was observed, although differentiation was no greater than that observed at an intraspecific level in some other African tree species. Several RAPD markers that distinguished between central and western regions and may be employed for diagnostic purposes to assess possible future germplasm exchange between regions were identified. Implications of data for the genetic management of *V. fischeri* stands during tree domestication activities led by farmers are discussed. At present, there appears little reason to reject on-farm *V. fischeri* for conservation purposes and as a source of germplasm for future on-farm planting, although this situation may change in the future.

Keywords: Agroforestry; conservation; genetic erosion; tree domestication; tropical African tree; RAPD; *Vitex fischeri*; *Vitex keniensis*

Introduction

Farmers plant trees in pursuit of their livelihood goals of income generation, household food security and risk management, endeavouring to make optimum use of available land, labour and capital (Arnold & Dewees 1995). In the tropics, Simons et al. (2000) cite examples where the numbers of trees planted in farmer's fields now approaches or exceeds those established in formal plantations. Simons et al. (2000) predict a situation where human populations in many areas rise to the extent that most natural sources of important tree products are exhausted, followed by a lag phase before farmers compensate by increased cultivation of tree products on-farm. In order to exit this lag phase, suitable existing on-farm sources of germplasm are essential to effect extended planting programmes. In some areas where farmers have an active tree planting culture, farmer cultivation already provides important reservoirs of tree biodiversity (Kindt et al. 2003). Bringing more inter- and intra-specific diversity into efficient usage on-farm is a survival mechanism used by farmers (Richards & Ruivenkamp 1997; Tapia & De la Torre 1998; SGRP 2000) and a useful approach for conducting tree domestication activities (Kindt & Lengkeek 1999; Weber et al. 2001).

At an intraspecific level, the proportion and structure of variation brought and maintained on-farm during farmer-led tree domestication is largely uncharacterised. Such knowledge is however of key importance for developing appropriate utilisation and conservation strategies. 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 or planting niche. Moreover, since many tree species are out-breeding, a wide genetic base provides the ability to withstand potential inbreeding depression through future generations of farmer propagation (Simons et al. 1994; Simons 1996; Brodie et al. 1997; Boshier 2000). A number of authors has indicated that farmers and nursery managers often collect germplasm from a relatively narrow range of mother trees (Kindt 1997; Weber 1997; Holding & Omondi 1998; Chapter 5 & 6). This suggests that genetic variation in on-farm stands may often be initially limited and further reduced in subsequent generations. Finally, the conservation value and long-term viability of on-farm stands depends on the genetic integrity of populations. In the absence of information on the implications of population interactions on agronomic performance, intraspecific hybridisation is generally assumed to reduce long-term fitness. Germplasm distribution policy guidelines therefore generally seek to maintain stand integrity, in the face of possible long distance germplasm exchange by farmers through informal pathways of introduction (Basweti et al. 2001; Kindt 2002).

Vitex fischeri Gürke (Verbenaceae), a tree indigenous to east, central and southern Africa, is generally a relatively small tree of 3 to 15 m occurring in wooded grassland. Until recently, stands in the central highlands of Kenya, which grow to 35 m with a trunk diameter of up to 2 m and primarily occupy moist evergreen mountain forest, were recognised as a separate species, *Vitex keniensis* Turrill (Beentje 1994). However, Dale and Greenaway (1961) recognised that the distinction between the two species was unclear and recent research on east African stands (Ahenda 1999) concluded that morphological, cytological and isozyme similarity merited placing *V. keniensis* in synonymy with *V. fischeri* (the name with priority), in spite of differences in site ecology and geography. In central Kenya *V. fischeri*, known locally as Meru oak or Muuru, is a popular timber species, producing an attractive high quality termite- and fungus-resistant wood that is widely used for furniture and joinery (Benghou 1971). Recent surveys found *V. fischeri* to be either the first or second most important indigenous timber species around Mount Kenya and Meru (Betser et al. 2000; MOA 2000; Appendix 6). Nurseries and farmers surrounding Meru and in proximate areas indicated that the species has been one of the most popular indigenous trees for planting over a number of years (Roothaert & Tuwei 1994; Chapter 5). The demand for *V. fischeri* timber in some parts of central Kenya exceeds the capacity of both natural stands and commercial plantations, with the natural distribution of the species shrinking due to specific exploitation as well as more general habitat destruction (Kigomo 1985; WCMC 1996; Ahenda 1999; KWS 1999). As a result, some saw-millers in parts of central Kenya have shifted sourcing of timber to on-farm stands (Holding & Carsan 2001). In such areas, farmers have become increasingly interested in on-farm management of the species for purposes of commercial sale rather than domestic use. Apart from timber, the species is also important as a boundary marker, for fruit and for firewood production (Ahenda 1999).

Vitex fischeri is believed to have a mixed mating system, though it is considered to be predominantly outcrossing in natural stands (Ahenda 1999). Hermaphrodite flowers are considered to be pollinated primarily by bees and seed dispersed by hornbills and monkeys (and occasionally humans), which eat the sweet fruit pulp and discard the nut, which contains up to four seeds of orthodox storage behaviour (Ahenda 1999). In plantations, trees fruit within eight years, indicating a relatively short juvenile phase compared to a potential longevity of several hundred years (JOA unpublished observations). The species is considered to be an autotetraploid, with 2n = 96 (Ahenda 1999).

In this study, we use *V. fischeri* as a model species to test concerns regarding genetic erosion during farmer-led domestication by employing random amplified polymorphic DNA (RAPD) analysis (Williams et al. 1990) to assess the genetic composition of populations. Our primary objective was to assess possible losses in genetic variation in farm stands in central Kenya by comparing with proximate forest stands. In addition, we compared stands from central Kenya with populations from western Kenya in order to provide information on partitioning between stands until recently considered as separate species (*V. keniensis* and *V. fischeri*, respectively). Finally, we wished to develop tools that may be used to monitor possible anthropogenic interactions between stands. Our overall aim was to provide information to help guide genetic management strategies that benefit farmers during farmer-led tree domestication activities on *V. fischeri* and provide indicators for the management of other species.

RAPD analysis has been employed widely to assess genetic variation in a range of tropical trees (Gillies et al. 1997; Cardoso et al. 1998; Dawson & Powell 1999; Lowe et al. 2000; Agufa 2002; Jamnadass et al. 2003). The technique is able to provide a large number of predominantly nuclear-encoded (Rieseberg, 1996) markers, allowing resolution of complex patterns of genetic variation (Huff et al. 1993; Peakall et al. 1995), and may be applied to previously unstudied taxa since DNA sequence information is not required (Williams et al. 1990). Although applied widely, RAPD analysis suffers from a number of limitations when employed to address ecological questions (Lynch & Milligan 1994), primarily associated with dominance and the potential non-homology of apparently similar character states, where shared product absences are especially problematic (Black 1993). The impact of these limitations can however be reduced by scoring an appropriate number of RAPD fragments (usually > 30) and using appropriate techniques for analysis (Lynch & Milligan 1994; Jenczewski et al. 1999).

Materials and methods

Sampling of material, DNA isolation and RAPD analysis

Our primary concern during sampling was to allow valid comparison between forest and farm stands of *V. fischeri*. To minimise the effect of spatial variation on comparisons, two areas were identified in central Kenya, the eastern foothills of Mount Kenya and the south-western slopes of the Nyambene Hills, where forest and farm categories were distinct but in close geographic proximity to each other (Table 1). Within an area careful attention was taken to ensure that forest and farm sampling covered a similar scale by recording the geographic position of each sampled tree during collection using a GPS receiver. Due to a number of practical limitations on collection, the overall dimensions for sampling were somewhat greater in the Mount Kenya area than for Nyambene. For both forest and farm categories a range of tree diameters was sampled, with mean tree diameter somewhat greater for forest than farm material. For both stand categories in both areas the majority of trees sampled were expected to be sexually mature (based on extrapolations from diameter measurements). For natural forest stands, sampled trees were separated by a minimum distance of 100 m. The strategy for sampling farm stands involved the collection of single trees from a series of separate farms and did not have a minimum distance requirement. For forest and farm stands, leaf samples were collected from individual trees during survey work in 2000 or 2001 and silica gel employed to dry and preserve material.

The detailed approach for the collection of farm material was somewhat different in Mount Kenya and Nyambene areas. At Mount Kenya, sampling was undertaken on a random subset of small-scale farms involved in earlier participatory research trials (Chapter 1 & 2) that had been subject to on-farm tree inventories by van Oijen (2002). In this area, van Oijen (2002) identified a total of 597 *V. fischeri* trees on 35 farms surveyed (average farm area approximately 1.7 ha). Farmers indicated the most significant source of trees to be seedlings raised from local seed sources either in local community (25%) or their own on-farm (24%) small tree nurseries. Significant material was also introduced to farms in the form of wild seedlings either transplanted from local sites (22%) or naturally regenerating in farmland (21%) (both categories assumed to represent germplasm of local origin). For only 4% of on-farm *V. fischeri* was germplasm known to have been sourced from outside the local community. At Nyambene, no prior survey information on the occurrence of *V. fischeri* on-farm was available. Here, sampling from small-scale farms involved the visual location of trees along roadsides by one of the authors (AGL), followed by collection with farmers of single trees from particular farms. During collection, individual farmers were questioned on the original germplasm source of collected trees. Responses suggested that most *V. fischeri* trees located on Nyambene farms were introduced in the form of wild seedlings either transplanted from local forest or naturally regenerating in farmland (both categories assumed to represent germplasm of local origin) (AGL unpublished observations).

To provide information on the relationship between populations until recently considered as separate species, natural stands from the Lake Victoria region and Mount Elgon in western Kenya were included in the analysis (Table 1). These stands represent the only areas outside central Kenya where *V. fischeri* is found naturally in Kenya (Ahenda 1999). Leaf samples were collected from nursery seedlings established from individual-tree seed collections made during 1996 and 1997 for a previous isozyme survey by Ahenda (1999). *Vitex fischeri* is generally not cultivated in western Kenya and therefore no opportunity existed to sample matched farm stands. Finally, seedlings produced by Ahenda (1999) from a putative artificial cross between emasculated Lake Victoria individuals treated with pollen from the Mount Kenya forest stand were included in analysis. These individuals provide an opportunity to understand the genetic characteristics of possible hybrid individuals arising from potential anthropogenic germplasm transfer between western and central Kenya.

In total, leaf material was sampled from 85 individuals. Total genomic DNA preparations were undertaken using a modification of the CTAB method of Doyle and Doyle (1987) and RAPD analysis carried out according to Dawson et al. (1995). Polymorphisms were scored as presence (1) or absence (0) after resolution on 2% agarose gels and sized against DNA cut with *Eco*RI and *Hin*dIII. Initially, 18 arbitrary primers were screened on a test panel of eight individuals (Table 1). Five primers that revealed clear polymorphisms were chosen for analysis of all 85 individuals (primer sequences are available upon request from the authors).

Data analysis

The genetic diversity of each stand (*H*), according to Nei's (1978) unbiased measure, was generated from stand allele frequency data estimated assuming Hardy-Weinberg equilibrium within stands and further assuming that *V. fischeri* acts as a true autotetraploid (Ahenda, 1999). A principal co-ordinate analysis (PCoA; Legendre & Legendre 1998) of individual phenotypes based on Sorensen's (1948) similarity coefficient was undertaken with the PAST 0.82 software package (Hammer et al. 2002). An analysis of molecular variance (AMOVA; Excoffier et al. 1992) based on Euclidean distances between individual phenotypes was undertaken with the ARLEQUIN 1.1 software package (Schneider et al. 1997). During AMOVA, genetic variation was partitioned within and among stands and significance values assigned to variance components based on 5,000 random permutations of individual phenotypes assuming no genetic structure. To assess possible microgeographic genetic structuring in central Kenya, the standardised Mantel Statistic (r_M; Mantel 1967; Legendre & Legendre 1998) was calculated for each sampled stand. This was undertaken by comparing a Euclidean distance matrix of RAPD phenotypes with a geographic distance matrix of individuals based on latitude/longitude co-ordinates, employing the PC-ORD software package (McCune & Mefford 1999). A positive r_M value indicates that geographically proximate individuals within a stand are on average more similar genetically than distant individuals, while a negative value indicates the opposite. PC-ORD was used to assign significance to r_M values based on a randomisation (Monte Carlo) test (5,000 permutations).

Results

The five arbitrary primers employed in this study revealed a total of 106 clear polymorphisms that could be scored for all 85 individuals surveyed. Excluding putative hybrid individuals, mean product presence frequency across all markers was 0.279. Estimates of Nei's unbiased genetic diversity (Table 1) indicated little difference between stands sampled from central Kenya, regardless of their forest or farm origin, with values ranging from a minimum of 0.248 (Nyambene forest) to a maximum of 0.275 (Mount Kenya forest). The mean *H* value across stands from central Kenya was 0.262 (mean $N = 16.3$). Two accessions from western Kenya, Lake Victoria ($H = 0.212$, $N = 8$) and Mount Elgon ($H = 0.175$, $N = 8$), appeared somewhat less diverse than stands from central Kenya. The first two axes of a PCoA of individual phenotypes accounted for 21% of total variation and revealed little differentiation among stands within central Kenya (Fig. 1). However, differentiation among *V. fischeri* stands from central and western Kenya was observed. As putative hybrid individuals grouped with western Kenya accessions, doubt was raised regarding the efficacy of artificial crosses undertaken between Lake Victoria (maternal parent) and Mount Kenya (prescribed pollen donor) stands. Unstructured AMOVA excluding putative hybrid individuals (Table 2) indicated 19% of variation among six stands ($P < 0.0002$), which may be attributed primarily to differentiation between central and western Kenya. Nested AMOVA based on four geographic areas (Lake Victoria, Mount Elgon, Mount Kenya and Nyambene), which provides information on partitioning between forest and farm categories in central Kenya through the 'within areas' component, allowed 18% of variation ($P < 0.0125$) to be accounted for among areas and a relatively low 4% ($P < 0.0002$) among stands within areas (Table 2). Since differentiation among central Kenya forest and farm stands appeared low and Mount Kenya and Nyambene are relatively proximate geographically, we undertook a further analysis of genetic diversity in which Mount Kenya and Nyambene stands were merged by category. Values of H, 0.273 (N = 32) and 0.264 (N = 33) for forest and farm stands respectively, were little different by category.

Mantel tests indicated varying degrees of genetic structure among individuals within central Kenya stands (Table 1). Significant positive associations between geographic and genetic distance (i.e., more geographically proximate individuals tend to be more similar genetically) were observed for Mount Kenya forest and farm stands, with the former of greater significance (r_M values of 0.228 and 0.179, respectively; P values of 0.009 and 0.030, respectively). Nyambene stands had lower r_M values that were not significant, although forest material appeared to demonstrate a degree of positive association between geographic and genetic distances.

Analysis of product presence frequency data revealed no individual RAPD markers that could be considered absolutely diagnostic of central or western Kenya natural stands. However, a number of highly differentiated markers, which in combination may be employed for diagnostic purposes, were identified. In total, 19 product presences showed frequency differences of > 0.5 between central (N = 33) and western (N = 16) Kenya natural stands. Thirteen presences revealed by four primers were diagnostic of western Kenya and six product presences revealed by three primers were characteristic of central Kenya. Assuming these markers to be of nuclear origin, nuclear index values were generated by calculating the number of western-diagnostic markers present as a proportion of all diagnostic polymorphisms scored. Western Kenya individuals are therefore expected to have a value approaching 1 and central Kenya individuals a value approaching zero. Mean values for natural and on-farm stands are shown in Table 1. For both central Kenya farm stands, index values were higher than corresponding forest stands. Putative hybrid individuals did not show the expected intermediate index value but, in correspondence with PCoA, appeared similar to the Lake Victoria stand. Data therefore indicated that the putative cross between Lake Victoria and Mount Kenya accessions failed. Most likely, this failure is due to methodological reasons connected with the efficacy of flower emasculation and isolation, although biological factors are not ruled out.

Table 1 *Vitex fischeri* leaf samples from seven accessions for RAPD analysis of genetic variation. *N* denotes the number of individuals tested (values in parentheses indicate the number of individuals employed in initial primer screening). *H* denotes genetic diversity based on Nei's (1978) unbiased measure for 106 RAPD markers assuming Hardy-Weinberg equilibrium in stands and autotetraploidy. Mean nuclear index values based on diagnostic product presences from central and western Kenya are shown (for information on calculation see Results). Western Kenya stands are expected to have a nuclear index value approaching 1 and central Kenya accessions a value approaching zero. Values of the standardised Mantel statistic (r_M; Legendre and Legendre, 1998), which compare genetic and geographic distance matrices, are shown for stands where detailed information on the position of individual trees was available. Significance (*P*) values, based on a Monte Carlo randomisation test (5,000 permutations), are also shown. For detailed information on sampling see Materials and Methods

		Coordinates °				
Stand designation	*N*	Latitude	Longitude	H	*Mean nuclear index*	r_M (P)
Mount Kenya farm	16 (1)	0°10' N - 0°11'	37°36' E - 37°41' E	0.263	0.214	0.179
Mount Kenya	17 (2)	0°04' N - 0°20'	37°33' E - 37°37' E	0.275	0.177	0.228
Nyambene farm	17	0°07' N - 0°09'	37°48' E - 37°54' E	0.260	0.178	-0.060
Nyambene forest	15 (2)	0°10' N - 0°13'	37°50' E - 37°53' E	0.248	0.137	0.102
Lake Victoria	8 (1)	1° S	35° E	0.212	0.817	-
Mount Elgon	8 (1)	1° N	35° E	0.175	0.941	-
Putative hybrid	4 (1)	-	-	0.177	0.745	-

° Range of values shown where available. Coordinates approximate only for Lake Victoria and Mount Elgon.

Table 2 Analysis of Molecular Variance (AMOVA; Excoffier *et al.*, 1992) for 81 individuals of *Vitex fischeri* from six stands sampled from Kenya, employing 106 RAPD markers. Nested analysis was undertaken by area (Lake Victoria, Mount Elgon, Mount Kenya and Nyambene). The 'among stands within areas' component therefore refers to variation among forest and farm categories for Mount Kenya and Nyambene (for detailed information see Results). Degrees of freedom (d.f.), mean squared deviations (MSDs) and the significance (*P*) of the variance components are shown. Significance values were based on the random permutation (5,000 times) of individuals assuming no genetic structure

Sources of variation	d.f.	MSD	Variance component	% of total variation	*P*-value
Unstructured analysis					
Among stands	5	52.24	3.00	19.4	<0.0002
Among individuals within stands	75	12.47	12.47	80.6	
Nested analysis					
Among areas	3	72.03	2.95	18.4	0.0125
Among stands within areas	2	22.56	0.62	3.9	<0.0002
Among individuals within stands	75	12.47	12.47	77.7	<0.0002

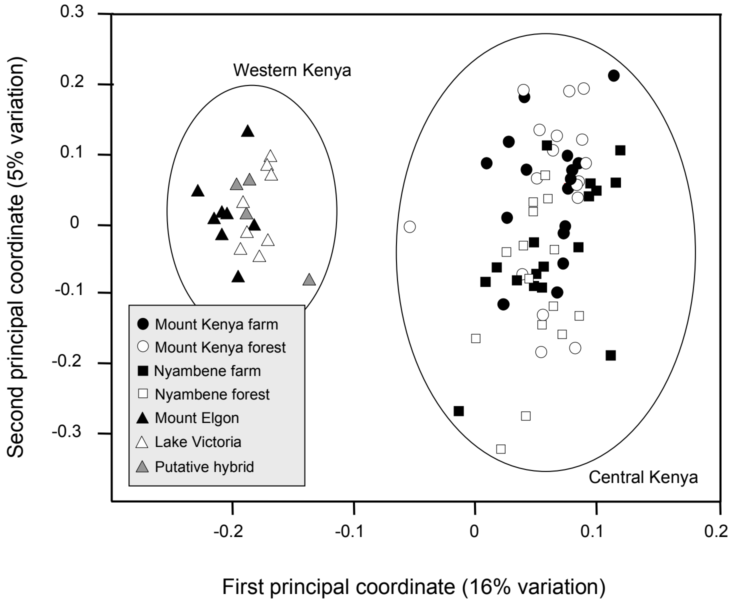

Fig. 1: Principal coordinate analysis based on Sorensen's (1948) similarity coefficient for 85 individuals of *V. fischeri* employing 106 RAPD markers revealed by five arbitrary primers. Individuals associate by central or western Kenya origin (indicated) but little differentiation is observed between stands within central Kenya. Individuals considered to be putative hybrids between central and western Kenya accessions group with western Kenya, suggesting a non-hybrid origin (see Results for further information).

Discussion

Diversity of forest and farm stands

A number of authors have indicated that farmers and nursery managers in the tropics often collect germplasm from a relatively narrow range of mother trees during propagation in agroforestry systems (Kindt 1997; Weber 1997; Holding & Omondi 1998; Chapter 5 & 6), raising concerns regarding the sustainability and conservation value of cultivated tree stands. In a survey undertaken on a wide range of tree species found in tree nurseries in the Meru region of central Kenya, results from Chapter 5 indicated that on average germplasm collected from six trees of a given species was used to raise nursery lots. Furthermore, after initial farm introductions most germplasm for subsequent planting rounds was harvested from trees on the same farm or, less frequently, from neighbouring farms. In the study presented here, we used the important and heavily exploited timber tree *V. fischeri* as a model species to test concerns of genetic erosion in central Kenya by employing random amplified polymorphic DNA (RAPD) analysis to assess the genetic composition of forest and farm populations.

Information on the impact of cultivation on the diversity of tree populations generally originates from informal comparisons of native populations with exotic stands (for example, Chamberlain 1998; Muluvi et al. 1999). Rarely have studies directly compared the diversity of natural and cultivated populations within the native range of a tree species. Muchugi (2001), in a RAPD analysis of the African highland tree *Prunus africana*, compared natural, nursery and planted stands from the native range of the species in Cameroon and Kenya and found little difference in diversity between categories. However, sampling did not specifically consider geographic matching between stand categories and therefore was not primarily concerned with local domestication events. Here, RAPD analysis of geographically matched forest and farm stands of *V. fischeri* provided a formal comparison for the possible effects of local farmer-led tree domestication activities on nuclear genetic diversity. Despite concerns of genetic erosion (Chapter 4 to 6), genetic variation of forest and farm categories of *V. fischeri* in central Kenya did not differ markedly, suggesting that to date local farmer-led domestication activities have had little effect on nuclear diversity levels in the species. The mode of sampling employed in the present study was similar to a survey of the leguminous woody perennial *Inga edulis*, in which geographically matched wild and cultivated stands from the Peruvian Amazon Basin were tested with nuclear and organelle markers (James Richardson personal communication; IKD unpublished observations). *Inga edulis*, cultivated as a fruit tree in Peru over millennia, was found to contain lower levels of allelic diversity at nuclear microsatellite loci in cultivated stands compared to neighbouring wild populations. Chloroplast variation in the *trnL-F* region was also lower in the former, possibly reflecting limited seed introductions into cultivation.

The maintenance of nuclear genetic diversity in on-farm stands of *V. fischeri* in central Kenya may reflect a number of specific factors. First, effective population sizes of farm stands are expected to be high compared to other tree species because of the unusually high tree density of *V. fischeri* on-farm in central Kenya (at least for the Mount Kenya stand; van Oijen 2002; Appendix 6). This may delay a decline in diversity levels by promoting outcrossing (Chapter 4). Furthermore, effective population sizes are expected theoretically to be relatively high for an autotetraploid such as *V. fischeri* (compared to a diploid species). Second, although the juvenile phase of *V. fischeri* is relatively short (approximately eight years) compared to it's potential longevity (several hundred years), this length of juvenile phase provides multiple opportunities for germplasm introductions on-farm to take place before original immigrants can set seed. A key factor in avoiding founder effects in tree species is delayed reproduction, as this allows a large increase in the number of initial founders of a given population before reproduction and subsequent colonisation begins (Austerlitz et al. 2000). Third, although none of our sampled farm trees were considered more than 25 years old (based on diameter observations; AGL unpublished observations), a number of considerably older remnant trees are observed in proximity to farm sample sites, particularly in the rather heterogeneous environment of forest patches in the Nyambene area. Although only a small number of individual remnants may contribute seed or wildings to a particular nursery or farm, the overall effect of a number of remnants dispersed in the landscape may prevent genetic diversity on-farm from decaying quickly. This is particularly the case when such remnants may also contribute pollen to the significant proportion of on-farm trees that are expected to be sexually mature.

Whilst this study gave no indication of changes in diversity levels in on-farm material compared to forest stands, it does provide some evidence for structural changes in variation. Values of the standardised Mantel statistics indicated a greater positive association between geographic and genetic distance in forest stands than was observed in farm material. The 'homogenisation' of genetic structure in on-farm material suggests that anthropogenic exchange of germplasm within individual cultivation stands exceeds natural exchange in forest material. Interestingly, greater structuring was observed in both forest and farm categories at Mount Kenya than at Nyambene, likely reflecting the greater overall sampling dimensions of the first area. In addition, the use of wild seedlings to establish trees in the Nyambene area may limit structuring in on-farm material compared to Mount Kenya, where farmers are more dependent on nurseries for germplasm.

Genetic differentiation and germplasm pathways

Compared to other classes of flora, woody perennial species are typically expected to partition relatively little variation among populations (Hamrick & Godt 1989; Hamrick et al. 1992; Nybom & Bartish 2000). Tree studies conducted at a similar spatial scale to the current analysis therefore generally indicate little nuclear differentiation among stands (for example, Chung & Kang 1994; Maguire & Sedgley 1997; Russell et al. 1999). The level of variation we detected here in an unstructured AMOVA analysis (19% among six stands, $P < 0.0002$) appears relatively high, especially for an autotetraploid, where a comparatively greater proportion of overall variation is expected theoretically to partition within rather than among populations when compared to a diploid species. However, markedly greater differentiation than observed in *V. fischeri* is sometimes detected among quite proximate tree stands in Africa (Jamnadass et al. 2003) and our data should not therefore be considered as exceptional. In a study of *Prunus africana*, a species restricted to highland forest 'islands', Muchugi (2001) found that 59% of RAPD variation partitioned among nine accessions in Kenya. Similar to *V. fischeri*, most of the differentiation observed was attributable to a split between central and western Kenya stands of the species. In the case of *P. africana*, western Kenya stands were more similar to material from Cameroon than to populations from central Kenya, consistent with theories of the evolution of flora in the region, in which forest in western Kenya is considered the most easterly remnant of the Guinea-Congolian forest block (Muchugi 2001; White 1983). For both *P. africana* and *V. fischeri*, the Rift Valley, which runs between central and western Kenya stands, has likely acted as a barrier to gene exchange, extending back through periods of prehistoric vegetation change associated with climatic fluctuation.

In an isozyme study of variation in *V. fischeri* conducted by one of the authors (Ahenda 1999), 12 loci revealed by eight isozyme systems found little differentiation between four natural stands from Lake Victoria, Mount Elgon, Mount Kenya and Nyambene (Nei's G_{ST} value = 0.035). Combined with morphological and cytological data, this lack of differentiation was used to justify placing central Kenya stands, previously identified as *Vitex keniensis*, in synonymy with *V. fischeri* (Ahenda 1999). The contrast between RAPD and isozyme data may reflect a number of methodological differences, including the increased resolution of the RAPD technique, and such differences between RAPD and isozyme studies are not unusual (Dawson et al. 1995). Despite the higher level of differentiation detected by RAPDs between central and western Kenya stands, differentiation remains consistent with variation at an intraspecific level and indeed is considerably less than intraspecific variation detected within *P. africana* over the same geographic area. Ahenda's (1999) conclusion that *Vitex keniensis* should be considered a synonym of *V. fischeri* is therefore not disputed.

The conservation value and long-term viability of on-farm stands depends on the genetic integrity of populations. In the absence of information on the implications of population interactions on agronomic performance, intraspecific hybridisation is generally assumed to reduce long-term fitness if the genetic differences between populations are large. The level of RAPD differentiation detected between western and central Kenya stands of *V. fischeri*, combined with the known different ecologies of these regions (which suggest possible adaptive differences), does therefore indicate the need for caution with germplasm transfer between western and central Kenya. This is particularly the case when farmers in Kenya are known to exchange tree germplasm through informal pathways over relatively long distances (Basweti et al. 2001; Kindt 2002).

Here, RAPD analysis indicated a suite of diagnostic markers that may be used for future tracking of possible germplasm transfer from western into central Kenya. Interestingly, both central Kenya on-farm stands had slightly higher nuclear index values than corresponding forest stands, possibly indicating small levels of germplasm infusion from western Kenya. For Mount Kenya, tree inventories on 35 farms indicated that 4% of on-farm *V. fischeri* was sourced from outside the local community (van Oijen 2002). Although the origin of this material is unknown, it appears most likely to have come from the central Kenya region rather than western Kenya. Furthermore, PCoA indicated that none of the central Kenya on-farm individuals tested had overall RAPD profiles typical of western Kenya. Therefore, any infusion that has taken place must have been followed by introgression. Germplasm transfer from western to central Kenya has been detected in the case of *P. africana*, where western Kenya material was detected in a nursery relatively close to our Mount Kenya on-farm stand (Muchugi 2001). In this case, evidence suggested transfer of seedlings in a formal planting project, rather than informal exchange by farmers. Such formal transfer of *V. fischeri* from western Kenya to central Kenya appears unlikely because the Kenya Forest Seed Centre does not distribute seed of western *V. fischeri* stands.

Conclusion

Despite concerns of genetic erosion our observations on *V. fischeri* suggest the utility of on-farm stands for conservation purposes and as sources of germplasm for farmer planting exercises. In the future, more emphasis may therefore be placed on strategies for germplasm supply based on farmer collection activities. Our diversity estimates must, however, be interpreted with caution. Sample sizes were relatively low for diversity estimation using dominant RAPD markers. Furthermore, our analysis of RAPD data assumed Hardy-Weinberg equilibrium within both forest and farm stands. Isozyme data (Ahenda 1999) indicate that natural stands of *V. fischeri* deviate somewhat from a Hardy-Weinberg equilibrium and a different level of deviation may be anticipated in cultivated material. In addition, our data should be treated cautiously when extrapolating to other tree species, since specific factors may have contributed to maintaining genetic variation in *V. fischeri* on-farm stands.

Our data may be considered as baseline information for future studies on *V. fischeri*. In the future, natural stands of *V. fischeri* in central Kenya are likely to continue to contract and changes may be expected in germplasm sourcing for on-farm planting as this happens. Future genetic erosion is considered more likely around our Mount Kenya sample site, where the agricultural landscape contains fewer forest fragments than Nyambene, where considerable scattered forest currently remains in farmland. Possibly indicative of this difference, already around Mount Kenya a large proportion of on-farm material comes through nurseries rather than as wildings. As forest cover contracts, seed- and pollen-vector behaviour is also influenced (Nason & Hamrick 1997). Lower tree densities may be expected to reduce outcrossing rates, causing a lower proportion of overall genetic variation within stands to partition within rather than among tree families (Hartl 1987; Chapter 4), thereby exacerbating diversity losses through germplasm collection strategies based on a few mother trees.

Although RAPD data indicated differentiation between western and central Kenya stands of *V. fischeri*, Ahenda's (1999) contention that both regions represent the same species remains valid. The differentiation observed does however raise concerns regarding germplasm transfer. To date, no clear evidence exists for informal germplasm transfer from western to central Kenya. Markers were however identified here that may be used for future tracking of germplasm distribution pathways, thereby assisting our understanding of the mechanisms that determine access to germplasm by small-scale farmers. Within central Kenya, low differentiation among sampled areas indicated that these may currently be considered as a unit for utilisation and conservation purposes.

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General discussion, conclusions and recommendations

Introduction

This research project was conceived to address the problem of Meru farmers in central Kenya relying heavily on a single species, *Grevillea robusta* A. Cunn. (Proteaceae), an Australian species used mainly for construction, firewood and as a boundary marker. With the disappearance of natural forest around Meru (KWS 1999), this over-reliance increasingly poses economic and environmental risks. Building on earlier research (Betser et al. 2000; NARP 2000), this project was begun in 1998. To ensure farmers would benefit maximally, a research approach that was participatory and constructivist was chosen, however, without neglecting a more analytical approach further on in the research. Initial research questions therefore had to be both broad and flexible. How can tree species improve farmers' livelihood goals of income generation, risk management, household food security and optimum use of available land, labour and capital? As a secondary question, how can the use and conservation (in the face of continued natural deforestation) of tree species in the region be improved? Given an over reliance on *Grevillea robusta*, my starting point was to undertake on farm tree species trials in Meru to identify a number of suitable species for diversification purposes (Diversity being a function of the number and the evenness in distribution (Magurran 1988; Purvis & Hector 2000)). Additionally a general nursery survey in Meru was conducted to improve the understanding of nursery practices and the delivery pathways of tree species to the farms.

Chapter 1 showed that the project had a flexibility to learn of the continuous input from the farmers, extension workers and scientists thereby shaping a research activity. Starting as a species preference trial, the research project developed into an analysis of the opportunities and constraints of domestication of the total tree component in the landscape of Meru, Kenya.

In Chapter 2 the various research activities that evolved in the process (Chapter 1) of carrying out the project were discussed. Results were triangulated, giving a detailed analysis of the Meru farmers' perception of tree species diversity and tree diversity management in general. Concerns for losses of local knowledge and biodiversity (including genetic erosion) were observed.

Chapter 3 showed that many findings of the Meru case study (Chapter 2) are supported by other case studies from Cameroon, Western Kenya and Uganda. This larger data set allowed for more thorough statistical analyses. Again, concerns for genetic erosion were observed.

Chapter 4 addressed some of the constraints identified in Chapters 2 and 3; with low densities and a limited amount of germplasm from outside the farming community, some species may be vulnerable for inbreeding and genetic erosion in the landscape.

Chapter 5 surveyed the current knowledge and practices of on-farm nursery managers in Meru. Nurseries are an important part of future on-farm tree cover. This study supported the results about knowledge losses and biodiversity losses, in particular the vulnerability for genetic erosion.

Chapter 6 expanded on the results of Chapter 5 regarding seed collection practices. The research was extended by additional surveys from Arusha Tanzania, Nairobi Kenya, Kabale Uganda and Mukono Uganda. It showed that current seed collection procedures practiced by nursery managers provide a clear limiting bottleneck in delivering genetic diversity to farmers.

Chapter 7 provides an in-depth case study of a single species (*Vitex fischeri*), in order to quantify the anthropogenic effect on the domestication process as identified in Chapters 2 to 6.

Most research activities described in this book were conducted in Meru. The inclusion of data from other locations allowed for a greater quantitative basis for addressing the specific research questions highlighted (Chapters 3, 6 & 7). Another reason to include data from other locations was the geographic mismatch between the inventory and nursery survey. Specifically, the nurseries studied at Meru (Chapter 5) did not directly relate to the area covered by the on-farm tree inventories (direct overlap of one farm only) (see Chapters 2, 4 & Appendix 6)[1]; i.e., farms were sampled in social and geographic clusters (Chapter 2) and nurseries were sampled more randomly (Chapter 5). As a result of this sampling decision, Meru nurseries were sampled over a wider eco-geographic range than the tree inventories on the farms. This situation was however unavoidable; in a farming community, there will always be fewer nurseries compared to farms. This research tried to counter this mismatch through the inclusion of more locations for both inventories (Chapter 3) and nurseries (Chapter 6). By looking for similarities between the different locations, indicative conclusions could be drawn that minimise the geographic mismatch.

In this concluding chapter, general conclusions will be drawn, from the whole study. To obtain the specific conclusions, the individual chapter publications remain the best source of information. The results from other locations supported the Meru results; however, only small parts of the outside research were included. Therefore caution is required in drawing more general conclusions for wider application than Meru.

Research approach

In this participatory research project, innovation emerged from interaction with and not from the imposition of technology. The research activities were based on the various knowledge systems of farmers, extension workers and scientists. The specific objectives remained flexible and were repeatedly reformulated during implementation as a result of partner interactions, in a shared process of learning and debate. The approach can be described as one of ‘constructivism’ (see Chapter 1).

We conducted this participatory research project on agroforestry tree domestication in the Meru area of Kenya. Continual interaction and flexibility are particularly important components in agroforestry research because of multiple and sometimes incompatible goals.

The process of trial evolution, although unsettling at times, allowed us to understand the decision-making processes of farmers more fully. Despite the evolution of the activities - from a tree species suitability test, to a species saturation study, and finally to a perception of tree species diversity survey - the initial assumption of over-reliance on a single tree species, *Grevillea robusta*, was validated, however, the means to address this problem changed. Had we chosen to rely on a more detailed positivist research approach, we would have obtained the result of a tree species suitability test only, but this would have had limited value for meeting the preferences and needs of farmers (Chapters 1 & 2).

[1] Similarly, the Mabira nurseries (Chapter 6) did not directly relate to the Mabira farms surveyed in Chapter 3.

Knowledge and local interactions

Farmers differ in many aspects. Individuals have different needs and capabilities and may be engaged in different practices and technologies. A vast knowledge base is already dispersed throughout the Meru farming community. Similarly in the nursery survey, there was an enormous range of knowledge and practices. All farmers and nursery managers interviewed had something unique to contribute to the overall knowledge base (Chapters 2, 3 & 5). Also, other more specialised groups, such as Traditional Medicinal Practitioners (TMPs) from the Ameru Traditional Doctors of African Medicine (ATDAM), showed a wide range of knowledge and preferences of (medicinal) plants and their uses (AGL unpublished data). Differences in practices or knowledge went beyond the frequently cited characteristics such as gender or wealth (Chapters 1, 2 & 5).

The most effective means to increase knowledge seems to be to increase farmer interaction. An option is to facilitate (existing) farmer groups to share information within and among groups (Chapter 2). Similarly, fostering information exchange between nursery operators can be an important step (Chapter 5). The latter has already resulted in the development of nursery associations for information exchange both on technical as well as marketing issues (Muriuki & Jaenicke 2001).

Additionally, it seems useful to stimulate interactions between the various associations. Farmers and nursery managers can share information and access germplasm at the same time. Associations of TMPs, such as ATDAM, can be used to provide additional information not readily available to the communities. It was especially evident, through interaction with the ATDAM, that knowledge gaps are certainly not restricted to unknown or exotic species only. All these forums can provide an effective means to share information with research and extension as well (Chapter 2 & 5).

The meetings with farmers, the training given to the farmers by an ATDAM TMP and the several meetings and training activities with ATDAM showed that not all information can be shared (Chapter 2; AGL & Sammy Carsan personal observations; Carsan 2001; Lengkeek 2001). Farmers already recognise 97 species with medicinal value (Chapter 2). Nevertheless while farmers were very clear in naming fruit and fodder species to add in the trial, they were less able to be this specific for medicinal species (AGL unpublished data). Farmers are willing to use and conserve an increasing number of medicinal trees and species on their farms; however, if species are unknown or recipes are not shared, farmers have little possibilities or incentive to grow these species. TMPs, however, cannot disclose their recipes as: (i) this will result in them losing their job, or (ii) the knowledge cannot be shared for cultural reasons (ATDAM personal communications). Nevertheless, it would be beneficial for both groups to find some sort of agreement to generate mutual benefits: farmers are looking for more options to address their over-reliance on *Grevillea robusta* and low coffee prices, whereas with the decreasing forest base, TMPs need farmers to grow medicinal trees to ensure the production of raw material for their health care practices.

Farmer management of diversity

The research and extension activities conducted in this study helped to gain a better understanding about farmers' perspectives on tree species, tree diversity and agroforestry in general. Farmers plant trees in pursuit of their livelihood goals of income generation, risk management, household food security and optimum use of available land, labour and capital

(Arnold & Dewees 1997). Trees also play a crucial role in the cultural life of people. The many products, services and roles needed by people to be fulfilled by trees cannot be provided by only a few species (Appendix 7 to 9). As a result, farmers have a wide variety of tree species on their farms (Chapters 2, 3, 4 & Appendix 6). Farmers clearly expressed the wish to further diversify their agroforestry systems; in terms of species, use groups and evenness of distribution (Chapters 1, 2 & 3). The most limiting factor for a farmer to diversify was access to germplasm. Farmers have no choice but to plant what is available, which restrained them in optimising their farming system, and using and conserving the species they need (Chapters 2 & 5).

Species preferences by farmers were largely determined by knowledge of a species (Chapter 2). In many species preference exercises, the common, well-known species were ranked higher (Roshetko & Evans 1999; Maghembe et al. 1998; van Duijl 1998; Weber et al. 1997; Dery et al. 2000; Betser et al. 2000). It is therefore not entirely clear how to rate the value of the rankings – how much of the higher ranking is due to species characteristics and how much is it influenced by how familiar they are with it.

When farmers cannot access a species, their knowledge may get lost in time. Several examples or indications of such losses were found in the diversity studies and in the Meru on-farm nursery survey (Chapters 2, 3 & 5). It was clear that knowledge losses can be a very local phenomenon.

Germplasm and information should be provided simultaneously to improve farmers' decision-making and practices. Limited access to species and loss of knowledge will lead to more of the common species and fewer rare species (Chapters 2 & 5). Indeed, biodiversity and its use and management rest on cultural diversity; conversely, conserving biodiversity often helps strengthen cultural integrity and values (WRI/IUCN/UNEP 1992; Chapter 2).

The findings of this research may contribute to the design of more productive and sustainable agroforestry systems in the Meru region. They may be used to further improve domestication strategies; they could focus on tree diversity or 'landscape domestication[2]' instead of only on a few priority species. Offering more species with better information attached is important in the design of seed and seedling systems in support of farmers' planting. This will likely make agroforestry practices more sustainable (SGRP 2000) and productive (Tilman et al. 2001; Chapter 3) and it will help conserve the biodiversity on which farmers depend (CBD 2003).

Diversification of sections of landscapes that have a lower diversity at the present time is expected to have a larger effect on ecosystem function (Chapter 3). The results from that chapter indicate the presence of spatial patterns in the distribution of diversity of many use groups or niches. In many cases, a more random distribution of species – and of their uses – would result in higher average species wealth of villages. Such results indicate the potential for diversification of the landscape without introducing new species. For example, species that are dominant in one village and not in another could be prime species to introduce in neighboring villages where they have low abundance, since such species would already have demonstrated their fitness in the landscape. Landscape sections with low evenness could also be targeted by future interventions that seek to diversify agroforest ecosystems.

[2] In contrast to domestication of agroforestry species aimed at using the diversity present in individual species - for instance selection, domestication of the landscape proposes using the diversity of the tree component in agroecosystems (see also introduction chapter).

Species accumulation curves provided information to enhance diversity by modifying the distribution of species. Most effective would be a wider distribution of species with lower frequencies in landscapes where within farm (alpha) diversity is low and diversity between farms (beta) is high (Chapter 3).

Genetic resource management

Genetic processes largely determine the vitality of individual components of an ecosystem, and consequently the vitality of the ecosystem itself (SGRP 2000). Without a broad genetic base, tree species lack the capacity to adapt to changing conditions in their ecosystem. Therefore, the management of genetic resources should be an important consideration in any natural resource management scheme, including agro ecosystems. The scope of the focus can range from individuals (for instance a particular sacred tree), populations and species, and from interactions between individuals to events across landscapes or entire ecosystems (SGRP 2000) and to the Earth itself (Sauchanka 1997; Lovelock 1995). Although it may be convenient to view these components or processes separately, this division is artificial; genetic resources are an integral component of ecosystems and thus of natural resources (SGRP 2000). The additive and interactive effects of inter- and intraspecific genetic diversity determine both the resilience of agro ecosystems and the evolutionary potential of species (SGRP 2000; Sauchanka 1997). This is becoming more important as we live in an increasingly changing environment with agricultural developments, global warming, pollution and desertification (IUFRO 1996; CBD 2003).

Similarly, the vitality of an agroforest ecosystem builds on a well-adapted broad genetic base, and an adaptive capacity in response to environmental fluctuations and changing farmer practices and markets. However, because tree species are primarily outcrossing (Hamrick & Godt 1996), trees are adversely affected by inbreeding, resulting in poor growth, productivity, survival and seed set (Charlesworth & Charlesworth 1987; Mouna 1989).

Farmers need productivity and sustainability of their agroforestry ecosystem and are therefore dependent on a broad genetic base. They use this (agroforestry) biodiversity as a survival mechanism (IPGRI 1999; Richards & Ruivenkamp 1997; Tapia & De la Torre 1998; Kindt 2002; Chapter 2). Tree domestication efforts by farmers and researchers could therefore be focused on genetic resource management of the landscape as a whole and not only on a few species (Kindt 2002; CGIAR 2002; Chapters 1 to 6). In this research, some general constraints have been targeted for interventions that support the resilience of agroforest ecosystems and their evolutionary potential:

- Tree densities
- Germplasm transfer
- Nursery practises
- Farmer dynamics

The genetic base of a species is maintained by adequate gene migration within the species populations. Recorded tree densities of many species were critically low on farms, likely resulting in an insufficient level of gene migration (Chapters 3 & 4). In Meru, more than half of the species had less than one individual tree per four hectares. Similar results were obtained in Mabira, Uganda, the cacao zone in Cameroon and western Kenya. Therefore, particularly in a constantly changing environment, a considerable percentage of species in agroforestry ecosystems may be vulnerable for inbreeding and genetic erosion. Additionally chapter 5 indicated that larger genepool in place, reduce the effects of genetic bottlenecks of these species when propagated in nurseries (Chapter 6).

Influxes from exterior germplasm lower chances of losing levels of diversity; however in Meru, on-farm trees predominantly originate from local sources (Chapter 4). About 9% of trees of all species and 3% of the indigenous species originated from a distant source. Similarly, 29% of all species and 14% of indigenous species were represented by one or more individual trees from a distant source. The trees coming from an exterior source predominantly originated from nurseries, respectively 83% and 98% for all and indigenous species (the overall number of trees originating from nurseries was 19% and 11%).

The Meru nursery survey (Chapter 5) indicated a danger of escalation into genetic erosion as shown by the following results: (i) a very low number of mother trees (six on average) was used for seed collection, representing only a small sample of the genetic variation present in a species population; (ii) most germplasm (57 %) was collected from farmers' own or neighbouring farms, emphasising a danger of inbreeding in future generations; (iii) the large variation in practices observed increases the chance of genetic bottlenecks occurring - for instance, seed collection from a single and solitary mother tree was no exception; (iv) the few cases of selection were applied without considering the necessary genetic implications; and (v) farmers returned to the earlier used seed sources, limiting the effect of multiple introductions. The East African nursery survey confirmed that germplasm was collected from a low number of mother trees. It also indicated that this variable is the most important bottleneck (chapter 6).

Farmer dynamics go beyond the natural cycles of expansion and contraction in populations or natural adaptive capacity. These dynamics are important as they may increase the chance for genetic bottlenecks (Chapters 4, 5 & 6).

Conservation through use

Especially in areas where forests are under threat of fragmentation and extinction, on-farm conservation and use may offer the most realistic conservation approach for forest genetic resources (Simons et al. 2000; Chapters 2, 3 & 5). Additionally, this may be the most realistic conservation approach for species with high value (Dawson et al. 2000; Chapter 7). Not all (indigenous) genetic resources would be conserved, but farmers' practices appeared to be promising for at least a substantial part (Chapters 2 & 3). However, as mentioned, this highly depended on knowledge of species and access to germplasm, and furthermore, genetic erosion was a concern.

Although this seems the most realistic approach, there is an increased chance of common species becoming more common and rare species, rarer; such a change in tree cover is one of the indicators of ecosystem degradation (Legendre & Legendre 1998). This is caused by:

- Species preferences by farmers are largely determined by knowledge of a species (Chapter 2). The knowledge of rare species is dispersed, whereas the knowledge of the common species is widespread. Many farmers plant common species and few farmers plant rare species.
- Although farmers wish to diversify their agroforestry systems, they have no choice but to plant what is available (Chapter 2), which is usually the more common species (Chapter 5).

- Rare species increasingly risk genetic erosion compared to common species. The rare species were recorded in such low densities that their survival is doubtful (Chapters 3 & 4). Sometimes only a single tree of a species is observed: in Igoji, this was the case for 44 species, in Nkubu, 39 species and in Ruiri, 28 species (Appendix 6). Contrary to the common species, rare species have a small genepool in the landscape compared to the number of seedlings of the nursery stock, increasing the risks of genetic erosion (Chapters 5 & 6). Genetic erosion, however, is a process and in the worst-case scenario it is possible that basic levels have already been reached.

The level of genetic diversity is quantified using an example species to test the hypotheses of losses occurring in the domestication process (Chapters 2 to 6). In Chapter 7, RAPD analysis of geographically matched forest and farm stands of *Vitex fischeri* provided a formal comparison of the possible effects of local farmer-led tree domestication activities on nuclear genetic diversity. Genetic variation of forest and farm categories of *Vitex fischeri* in Meru and the closely situated Nyambene did not differ markedly, suggesting that to date, local farmer-led domestication activities have had little effect on nuclear diversity levels in the species. Muchugi (2001) obtained comparable results in a RAPD analysis of the African highland tree *Prunus africana*, for populations in Cameroon and Kenya, including Meru. However, sampling did not specifically consider geographic matching between stand categories. Geographically matched wild and cultivated stands of *Inga edulis* in the Peruvian Amazon Basin were tested with nuclear and organelle markers (James Richardson, personal communication; Ian Dawson, unpublished observations; Chapter 7); these results indicated limited seed introductions into cultivation, as was hypothesised in Chapters 5 and 6.

Using a common species, *Vitex fischeri,* as an example, we found no indication that genetic erosion had as of yet occurred in the domestication process. The species, classified under its 'old' name *Vitex keniensis* as locally vulnerable on the CITES list, is conserved through its use. The maintenance of nuclear genetic diversity in on-farm stands of *Vitex fischeri* in central Kenya may reflect a number of specific factors. The most logical hypothesis, however, is that *Vitex fischeri* is a common species, and for a number of reasons, common species suffer less from genetic erosion; *Vitex fischeri* is well known, its seeds and seedlings are easy to access, it has an unusually high on-farm tree density in Meru and it is the most popular indigenous species in Meru nurseries (van Oijen 2002; Chapters 2 to 7 & Appendix 6). Other, more species-related factors might include longevity of the species, a relatively long juvenile period and being an autotetraploid (Ahenda 1999; Chapter 7).

Indigenous or exotic

One controversy remains the further introduction of exotic species. Many exotic species in agroforestry are considered successful and are widely dispersed. Species for a wide variety of functional uses are available, such as wood (*Grevillea robusta,* Harwood 1992), fruit (*Mangifera indica*, Litz 1997), fodder (*Leucaena leucocephala,* Hughes 1997) and medicine (*Azadirachta indica,* National Academy Press 1992). With the use of exotics, there are serious disadvantages from a biological conservation perspective. There is the risk that an exotic species will displace an indigenous species, either through its product and services or through its weediness (Chapters 2 & 4). Weediness may affect the farmer as it requires more labour for weeding and it may affect the more preferred (tree)crops production and survival. Many conservationists are strongly opposed to further introductions, and movement of forestry and agroforestry germplasm has been the target of specific criticism (Richardson 1998; Janzen 1987; Stirton 1978; Hughes 1994). Despite the damage caused by these exotics, most farmers cannot currently survive without exotic germplasm, and some of the weeds can even be called successful. In certain areas in southern India, for example, fuelwood is easier to get than a generation ago, which is entirely due to the presence of the weedy *Prosopis juliflora* (Hughes & Styles 1987). The discussion on the use of exotics is still very lively, but the arguments are getting more and more emotional (see Hudson[3] 2000).

Farmers are, and should be, in charge of their species choices; farmers need access to quality germplasm of all species, including exotics (Chapters 2, 3 & 5). Domesticating both indigenous and exotic species will assist farmers in their livelihood goals. Additionally, a further understanding of diversity perceptions of all stakeholders may help to remove constraints that, for instance, hamper the integration of more indigenous species on the farm (Chapter 2 to 6). Nevertheless, indigenous species are perhaps the most threatened group and merit more immediate attention for conservation, this is valid from a biological perspective as well as from a farmers'[4] perspective (Chapters 4 & 6).

Emphasis on 'the poor'

Biodiversity would increase on the farms for all wealth groups if knowledge and access to germplasm would increase. More emphasis on the poor would, however, be the most logical approach. First, the poor are more dependent on biological diversity than other wealth classes and are therefore the first ones to suffer in cases of biodiversity loss (CBD 2003). Second, this research found indications that the poor seem to contribute most to the use and conservation of biodiversity (Chapters 2 & 5). Poorer farmers had more species diversity per hectare on their farm. Poorer nursery managers had more diverse nursery populations in their nurseries, including rare species.

One of the unpublished findings of this research deals with the definition of 'what is a nursery'. Continuous interaction with farmers revealed many more 'hidden nurseries'. When a farmer was asked if he had a nursery most said 'no'. However if farmers were asked if by any chance they sometimes tried to raise one or two species for own use we were often led to a banana plant providing shade for ten to a hundred seedlings, often these are given away, either for free or in exchange for other goods. Many of these nurseries are temporary in business and may disappear when the most urgent tree need is covered or if the efforts outweigh the benefits. The nursery managers did not call it a nursery, and if we called it a nursery the farmers modestly replied that it was too small to be a nursery. Besides the fact that it again confirms that phrasing a question correctly makes a significant difference in the answer received, it also shows that farmer initiatives may reduce the risk on genetic erosion. Genetic erosion will be less because all these nurseries collect their own subset of the genepool. All these few mother trees produce very few seedlings, with a few seedlings per client, leading to a small number of progeny per farm. More small (often equals 'poor') nurseries may decrease chances for genetic erosion.

[3] J.L Hudson (2000), in the seedsman ethnobotanical catalogue California: 'Also ominous is the fact that during Adolf Hitler's Third Reich the national socialists had an identical program to rid the landscape of foreign plants. See: Groening, G. & Wolschke-Bulmahn J. (1992) Some notes on the mania for native plants in Germany. Landscape journal, Vol. 11, No 2 1992. The extension of the nazi pseudoscience of racial purity to the natural world is chillingly identical to the modern anti exotica agenda, down to the details of genetic contamination. With the current rise of racism, immigrant scapegoating and other noxious un-American ideologies, we must be prepared to hold all those who are promoting the anti-exotics frenzy personally responsible for their part in legitimizing a pseudoscience which lead directly to the horrors we saw in the 1940s. Clearly 'eco-fascists' is not too strong a term to describe these people.'

[4] Indigenous species are rarer: less knowledge, less access and increased genetic erosion. Exotics harbour more trees from exterior sources; also, it is easier to obtain quality seeds from exterior sources.

Although more emphasis on the poor would certainly contribute to the use and conservation of tree diversity, this is not necessarily valid for the poorest of the poor. Agroforestry, and to a lesser extent running a nursery, requires access to land, something the poorest do not have.

Recommendations

This study observed a limited access to species, a risk of losing knowledge and a vulnerability for genetic erosion. These factors likely cause short-term productivity and long-term stability losses in agroforest ecosystems and hamper farmers from making optimal decisions and to act accordingly to optimise their livelihood goals. It also erodes the biodiversity on which farmers depend. The best option to prevent this degradation of agroforest ecosystems is to assist farmers in diversifying the farm in terms of species as well as species evenness through increasing the number of trees of rarer species, or through a substitution of the more common species. Farmers, extension workers and scientists active in tree domestication could focus on improving access to germplasm of a wider range of species. Addressing access to germplasm and knowledge simultaneously will allow farmers to decide for themselves, instead of research and extension only concentrating on a few 'high priority' species.

Tree species preferences are largely determined by knowledge and this may lead to a bias for common species. Therefore, species preference lists must be interpreted with great caution.

Using two common species, *Vitex fischeri* (Chapter 7) and *Prunus africana* (Muchugi 2001), as examples, no indications were found that genetic erosion has as of yet occurred in the domestication process. The on-farm stands are still suitable as seed source and farmers can continue accessing their own germplasm. The species, although both classified as locally vulnerable on the CITES list, are conserved through their use.

Because of the large number of species concerned, interventions in the genetic resource management of the species diversity on farm should be facilitating and training farmers in accessing their own germplasm, preferably from other farms not within the near vicinity. For indigenous species sourcing within the same agro-ecological zone is preferred to ensure productivity and conserve the genetic integrity of the local populations.

Farmers' use and conservation efforts to increase the densities of the rarer species should be guided, because (i) populations have been reduced to a few individuals, so a reduction in diversity among trees is possible within populations; and (ii) the germplasm of the current populations is mainly from local sources, and therefore the increased chance for a limited genetic diversity is more likely. For specific actions, see Chapters 2 to 6.

An efficient means to support the use and conservation of tree biodiversity is through local interactions and including the poor.

Future research

We experienced three years of major changes in the experimentation (Chapter 1). Although ICRAF's direct involvement in the project has now ended, farmers and staff of the Ministry of Agriculture continue to optimise the farming system. Innovation is still going on through farmer-led seed production mechanisms and nurseries. It is likely that changes will continue and in time the wish to diversify may very well evolve into something else. The question of how sustainable the diversification of agroforestry ecosystems is should, however, not necessarily be of as much concern as the sustainability of the process of innovation itself. It would therefore be interesting to follow up in a few years on the innovation process.

The farmers planted trial species for reasons of experimentation and not necessarily with the intention to keep them (Chapter 2). It could be useful to follow up this research in a few years with another survey on the species maintenance and preferences, not in the least for future projects that deal with diversification or species preferences.

To conserve indigenous species, more planting is required (Chapter 4), yet the nursery inventories indicate that indigenous species are not widely available (Chapters 4 to 6). Access to quality germplasm is one of the recommendations, for instance through making more material available to nurseries. Regularly surveying the local nurseries on species availability, number of mother trees and germplasm sources, could be a good option for monitoring the genetic sustainability of agroforestry systems.

All chapters recognise the need for information exchange and training (Chapters 1 to 7). Besides facilitating or conducting the realisation of these needs, future research may also focus on what interventions are likely to be most successful.

As a result of the sampling choice, nurseries were sampled over a wider eco-geographic range than the tree inventories on the Meru farms. This was unavoidable as farming communities always have fewer nurseries compared to farms. An option for future research could be to sample all nurseries in a geographic area and then to draw up a random subset of farms allowing a geographic match. This will allow for a better study on the past, present and future impacts of nurseries on the tree cover in agroforestry systems.

No indications were found that genetic erosion had occurred in the domestication process. Only a few species were tested. It could be useful to examine a species that may be at risk, using the knowledge we gathered in this research.

Appendixes

Wealth

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Trees, Species and Families

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***Vitex fischeri* data**

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Appendix 1: Meru farmers grouped according to wealth criteria.

	gender	age	education level	house type	farm in Ha	- cow - pure	mix	local	sheep	goat	subs. level	labour	income	other work	child farm	marital status	land owner	extra capital
	Wealthy																	
	male	68	n/a	n/a	20	-	1	-	2	2	yes	t5-p2	yes	no	many	m-o	own	buildings
	male	60+	primary 5-8	semi	7	-	3	-	-	-	yes	-	yes	no	3	m-o	own	
	Intermediate																	
	male	40	primary 5-8	semi	2.5	-	2	-	-	-	yes	t4	yes	yes	4	m-o	own	
I	female	35	primary 5-8	wood	5	-	1	-	1	1	yes	-	yes	no	5	m-o	husband	
G	female	50	primary 5	wood	2	-	3	-	-	4	yes	-	no	no	6	m-f	husband	
O	male	57	secondary		3	-	1	-	-	1	no	-	no	no	5	m-o	own	
J	male	52	primary 5-8	wood	3	-	3	-	-	4	yes	n/a	no	yes	8	m-f	own	
I	**Resource-limited**																	
	male	48	primary 1-4	wood	0.5	-	1	-	1	2	no	-	no	no	7	m-o	f.i.l.	
	male	40	secondary	wood	0.5	-	2	-	-	-	no	-	no	no	4	m-o	father	nursery
	female	60	primary 1-4	wood	7	-	1	-	-	3	yes	-	yes	no	3	gone	own	
	male	22	primary 5-8	semi	14	-	1	-	-	-	yes	-	no	no	2	m-f	f.i.l.	
	female	30	secondary	wood	0.49	-	1	-	-	-	no	-	no	no	2	m-o	husband	
	Wealthy																	
	male	58	university	permanent	3.75	-	6	-	-	-	yes	t6-p4	yes	yes	3	m-o	own	house
	male	58	≥ college	semi	5	-	3	-	2	6	yes	t3-p4	yes	yes	5	m-f	own	
	male	52	primary 5-8	semi	5	4	1	-	-	2	yes	t4-p2	yes	no	0	m-o	own	
	female	60	secondary	semi	2	1	1	-	-	1	yes	t5-p1	yes	no	5	m-o	husband	
N	**Intermediate**																	
K	male	38	secondary	permanent	2	1	-	-	-	3	yes	t2-p1	yes	no	2	m-o	own	
U	female	45	primary 1-4	semi	4.5	-	2	-	-	-	yes	t2-p1	yes	no	4	gone	own	
B	male	59	primary 5-8	semi	4.85	-	1	-	-	-	yes	t2	yes	no	2	m-o	own	
U	male	40	primary 5-8	semi	1.75	-	2	-	-	3	yes	t2	yes	no	3	m-o	own	
	Resource-limited																	
	male	35	primary 5-8	wood	2.5	-	3	-	-	2	no	-	yes	no	8	not	father	shop
	male	50	primary 5-8	wood	2.25	-	2	-	-	-	no	t1	yes	no	4	m-o	own	
	male	45	none	wood	2.4	-	-	-	-	-	yes	t1	yes	no	8	m-o	own	
	female	39	primary 5-8	semi	1.25	-	2	-	-	-	yes	-	yes	no	5	gone	own	

	gender	age	education level	house type	farm in Ha	- cow - pure	mix	local	sheep	goat	subs. level	labour	income	other work	child farm	marital status	land owner	extra capital
	Wealthy																	
	male	65	≥ college	permanent	15	-	2	-	-	-	no	p1		yes	8	m-o	own	
	male	62	primary 5-8	permanent	10	-	4	-	-	-	yes	t2-p1	yes	no	0	m-o		land
	female	60	adult edu.	permanent	15.7	-	4	-	3	2	yes	p1	yes	no	10	gone	own	
	male	50		semi	12	1	3	-	3	1	yes	-	no	yes	5	m-f	own	
	Intermediate																	
	male	47	secondary	semi	5	-	1	-	-	2	no	t2	no	yes	4	m-o	own	construct
R	male	63	primary 5-8	semi	4	-	-	1	-	11	no	p1	yes	no	5	m-o	own	2 acres
U	male	52	primary 5-8		4	-	4	-	1	2	yes	p1	no	no		m-o	f.i.l.	Land
I	male	32	secondary	semi	3	-	3	-	-	2	yes	p2	no	no	5	m-f	own	
R	**Resource-limited**																	
I	male	54	secondary	semi	2.5	-	3	-	4	-	n/a	t2	no	yes	4	m-o	own	construct
	male	45	primary 5-8	semi	2.5	-	-	2	-	-	yes	-	no	yes	6	m-o	own	dryland 4
	female	45	secondary	wood	1	-	1	1	-		no	-	no	yes	4	m-o	husband	1.5 acre
	female	40	secondary	semi	2	-	-	-	2	2	no	-	no	no	7	m-f	husband	
	female	65	none	wood	10.4	-	-	5	-	2	no	-	no	no	2	gone	own	
	male	57	adult edu.	wood	2	-	2	-	2	-	no	-	no	no	3	m-o	own	
	male	52	n/a	wood	1	-	-	1	-	-	no	-	no	no	4	m-o	own	
	male	60	primary 5-8	wood	n/a	-	1	-	-	-	no	-	no	no	5	m-o	own	

n/a = no data available; semi = permanent basis with wooden walls; Cows = pure breed, mixed breed and local; Subs.level, farm produces enough for subsistence level; Labour hired; number of temporarily (t) and permanent (p); Income; if income is generated through farm activities; Other work outside farming; ‘m’ = married, ‘o’ partner lives on farm, ‘f’ partner lives off farm; ‘f.i.l.’ = father in law; Construct = farmer constructs permanent house. Child = the number of children resident on farm.
N.B. Names of farmer are not included for reasons of privacy.

Appendix 2: Meru nursery managers grouped according to wealth criteria.

	age	gender	education	off-farm employment	house	farm size (ha)	use of labour	cow pure	cow mix	cow local	sheep	goat
Resource-limited												
	51-60	m	none or no	no	n/a	n/a	seasonal	-	1	-	-	-
	31-40	m	primary 5-8	no	n/a	1	no	-	-	-	-	-
	41-50	m	primary 5-8	no	thatch roof	1	no	-	-	-	-	-
	41-50	m	primary 1-4	no	thatch roof	2	no	-	-	-	-	-
	31-40	f	none	no	iron roof	2	no	-	-	1	-	-
	20-30	m	primary 5-8	no	iron roof	3	no	-	-	1	-	1
	n/a	m	n/a	no	iron roof	1.5	no	-	2	-	-	-
	20-30	m	secondary	no	iron roof	0.5	seasonal	-	1	-	-	2
Intermediate												
	51-60	m	secondary	no	iron roof	3	no	-	3	-	-	-
	20-30	m	primary 5-8	no	iron roof	2	seasonal	-	3	-	1	-
	n/a	m	n/a	no	iron roof	1.8	no	-	2	-	-	-
	31-40	m	secondary	no	iron roof	4.5	yes	-	1	-	5	-
	61+	m	none	no	iron roof	21	yes	-	3	-	-	-
	31-40	f	secondary	no	permanent	4	seasonal	1	-	-	-	-
	51-61	m	primary 5-8	no	iron roof	7	seasonal	-	3	-	-	-
	61+	m	primary 1-4	no	iron roof	23	no	-	-	5	-	-
Wealthy												
	n/a	m	n/a	no	permanent	3	seasonal	-	3	-	-	-
	41-50	m	secondary	yes	permanent	1.8	seasonal	-	5	-	-	-
	61+	m	primary 5-8	no	n/a	8	seasonal	-	10	-	-	-
	31-40	m	primary 5-8	no	iron roof	15	yes	-	6	-	-	-
	51-60	m	secondary	yes	permanent	1	yes	-	1	-	-	1
	n/a	m	n/a	no	iron roof	1	yes (3)			n/a		
	31-40	m	secondary	no	permanent	3	yes (3)	-	2	2	-	2
	61+	m	secondary	no	permanent	5	yes (3)	4	-	-	-	-
	n/a	n/a	n/a	yes	n/a	500	yes (2)			n/a		

n/a = no data available, - = zero value
N.B. Names of nursery managers are not included for reasons of privacy.

Appendix 3: Species planted in the tree species planting trial.

Species	Planting date	Meru name	English name	Botanic Family	Origin	Provenance
1. *Acacia angustissima*	April 2000	-	-	Fabaceae - Mimosoideae	Exotic	Tutule - Honduras
2. *Azadirachta indica*	March 1999	Mwarubaine	Neem	Meliaceae	Naturalised	Marigat & Bomet-Kericho (both ex India)
3. *Carissa spinarum (=edulis)*	November 2000	Mukawa	Simple spined carissa	Apocynaceae	Indigenous	Kajulu (Kisumu)
4. *Casimiroa edulis*	March 1999	Mutunda	White sapote	Rutaceae	Exotic	Cultivar 'Sue Belle' & 'Kubwa' Rootstock Machakos & Meru
5. *Casuarina equisetifolia*	November 2000	-	Swamp oak	Casuarinaceae	Naturalised	Gede (92) (Malindi - ex Australia)
6. *Cordia africana*	March 1999	Muringa	East African Cordia	Boraginaceae	Indigenous	Nyeri
7. *Cyphomandra betacea*	April 2000	Matunda ya ndamu	Tree tomato	Betaceae	Exotic	Cultivar 'Giant select red'
8. *Grevillea robusta*	October 1999	Mukima	Silver oak	Proteaceae	Exotic	Boyd River – Australia
9. *Juniperus procera*	April 2001	Murana	Pencil cedar	Cupressaceae	Indigenous	Seed from KFSC
10. *Leucaena pallida*	April 2000	Lukina safi	-	Fabaceae - Mimosoideae	Exotic	Machakos (ex San Pedro Chapulco - Mexico) Seed ID OFI 52/87
11. *Leucaena trichandra*	March 1999	Lukina safi	-	Fabaceae - Mimosoideae	Exotic	Muguga (ex Los Guates – Guatemala) Seed ID OFI 53/88
12. *Lovoa swynnertonii*	April 2001	Mukongoro	Nkobo	Meliaceae	Indigenous	Igoji - Meru
13. *Maesopsis eminii*	October 1999	-	-	Rhamnaceae	Indigenous	Kakamega
14. *Markhamia lutea*	March 1999	Mugwani	-	Bignoniaceae	Indigenous	Nyeri-muringato
15. *Melia volkensii*	November 2000	Mukau	Bead tree	Meliaceae	Indigenous	Kavisuni (Kitui)
16. *Milicia excelsa*	November 2000	Mururi	Iroko	Moraceae	Indigenous	Seed from KFSC
17. *Moringa oleifera*	November 2000	Muguunda	Horse radish	Moringaceae	Naturalised	Kibwezi (ex Mbololo, ex India)
18. *Ocotea usambarensis*	November 2000	Muthaiti	Camphor	Lauraceae	Indigenous	Chuka
19. *Olea capensis* ssp. *macrocarpa*	April 2001	Mutharage	Olive	Oleaceae	Indigenous	Malava forest (Kisumu)
20. *Prunus africana*	March 1999	Mweria	Pygeum	Rosaceae	Indigenous	Kobujoi
21. *Rosmarinus officinalis*	November 2000	Rosemary	Rosemary	Labiatae	Naturalised	Nairobi
22. *Sapium ellipticum*	November 2000	Muthatha	-	Euphorbiaceae	Indigenous	Igoji - Meru
23. *Sclerocarya birrea*	April 2001	Mura	Marula	Anacardiaceae	Indigenous	Kibwezi
24. *Tamarindus indica*	April 2000	Muthithi	Tamarind	Fabaceae - Caesalpinioideae	Naturalised	Tharaka (ex India) / Pachmahal – India
25. *Telfairia pedata*	April 2000	Nkweme / Muthanduru	Oyster nut	Cucurbitaceae	Exotic	Arusha & Mt Meru – Tanzania
26. *Tephrosia vogelii*	October 1999	Mucugucugu	Fish poison bean	Fabaceae - Papilionoideae	Indigenous	Maseno
27. *Trichilia emetica*	October 1999	Mutuati	Cape mahogany	Meliaceae	Indigenous	Siaya
28. *Rauvolfia caffra*	November 2000	Mutu	Quinine tree	Apocynaceae	Indigenous	Tengeru – Tanzania
29. *Vangueria madagascariensis*	November 2000	Mubiru	-	Rubiaceae	Indigenous	Mwala (Kisumu)
30. *Vitex fischeri* (= *keniensis*)	October 1999	Muuru	Meru Oak	Verbenaceae	Indigenous	Nyambene, Mt Kenya, Mt Elgon, Lake V., hybrid
31. *Warburgia ugandensis*	March 1999	Musunui	Green heart	Canellaceae	Indigenous	Muguga

Appendix 3: Species planted in the tree species planting trial (suite).

Period	No species	Species.
Mar-99	7	*Azadirachta indica, Casimiroa edulis, Cordia africana, Leucaena trichandra, Markhamia lutea, Prunus africana, Warburgia ugandensis*
Oct-99	5	*Grevillea robusta, Maesopsis eminii, Tephrosia vogelii, Trichilia emetica, Vitex fischeri (= keniensis)*
Apr-00	5	*Acacia angustissima, Cyphomandra betacea, Leucaena pallida, Tamarindus indica, Telfairia pedata*
Nov-00	10	*Carissa spinarum (=edulis), Casuarina equisetifolia, Melia volkensii, Milicia excelsa, Moringa oleifera, Ocotea usambarensis, Rosmarinus officinalis, Sapium ellipticum, Rauvolfia caffra, Vangueria madagascariensis*
Apr-01	4	*Juniperus procera, Lovoa swynnertonii, Olea capensis* ssp. *macrocarpa, Sclerocarya birrea*

Origin	No species	Species
Exotic	5	*Acacia angustissima, Casimiroa edulis, Cyphomandra betacea, Leucaena pallida, Leucaena trichandra*
Naturalised	7	*Azadirachta indica, Casuarina equisetifolia, Grevillea robusta, Moringa oleifera, Rosmarinus officinalis, Tamarindus indica, Telfairia pedata*
Indigenous	19	*Carissa spinarum, Cordia africana, Juniperus procera, Lovoa swynnertonii, Maesopsis eminii, Markhamia lutea, Melia volkensii, Milicia excelsa, Ocotea usambarensis, Olea capensis* ssp. *macrocarpa, Prunus africana, Sapium ellipticum, Sclerocarya birrea, Tephrosia vogelii, Trichilia emetica, Rauvolfia caffra, Vangueria madagascariensis, Vitex fischeri, Warburgia ugandensis*

Family	Species	Family	Species
1. Anacardiaceae	*Sclerocarya birrea*	12. Lamiaceae	*Rosmarinus officinalis*
2. Apocynaceae	*Carissa spinarum, Rauvolfia caffra*	13. Lauraceae	*Ocotea usambarensis*
3. Betaceae	*Cyphomandra betacea*	14. Meliaceae	*Azadirachta indica, Lovoa swynnertonii, Melia volkensii, Trichilia emetica*
4. Bignoniaceae	*Markhamia lutea*	15. Moraceae	*Milicia excelsa*
5. Boraginaceae	*Cordia africana*	16. Moringaceae	*Moringa oleifera*
6. Canellaceae	*Warburgia ugandensis*	17. Oleaceae	*Olea capensis* ssp. *macrocarpa*
7. Casuarinaceae	*Casuarina equisetifolia*	18. Proteaceae	*Grevillea robusta*
8. Cucurbitaceae	*Telfairia pedata*	19. Rhamnaceae	*Maesopsis eminii*
9. Cupressaceae	*Juniperus procera*	20. Rosaceae	*Prunus africana*
10. Euphorbiaceae	*Sapium ellipticum*	21. Rubiaceae	*Vangueria madagascariensis*
11. Fabaceae (Caesalpinioideae, Mimosoideae (3), Papilionoideae)	*Tamarindus indica, Leucaena pallida, Leucaena trichandra, Acacia angustissima, Tephrosia vogelii*	22. Rutaceae	*Casimiroa edulis*
		23. Verbenaceae	*Vitex fischeri*

Appendix 4: Species recorded in the Meru tree° inventory.

Species	Family	Local names°°	Origin
Abrus fruticulosus Wall. ex Wight & Arn.	Fabac. - Papilionoideae	Menu	indigenous
Abutilon sp.	Malvaceae		indigenous
Acacia albida Del.	Fabac. - Mimosoideae	Kabubu, Mugaa	indigenous
Acacia brevispica Harms	Fabac. - Mimosoideae	Wait-a-bit thorn (t)	indigenous
Acacia hockii De Wild.	Fabac. - Mimosoideae	Mucurai, Muruai	indigenous
Acacia mearnsii De Wild.	Fabac. - Mimosoideae	Muthanduku	indigenous
Acacia seyal Del.	Fabac. - Mimosoideae	Murui	indigenous
Acacia xanthophloea Benth.	Fabac. - Mimosoideae	Murera	indigenous
Acalypha racemosa Baill.	Euphorbiaceae		indigenous
Acalypha sp.	Euphorbiaceae	Ornamental (t)	exotic
Achyranthes aspera Duss	Amaranthaceae	Devils horsewhip (t), Mucegene	indigenous
Acokanthera schimperi (A.DC.) Schweinf.	Apocynaceae	Mururu	indigenous
Acrocarpus fraxinifolius Wight & Arn.	Fabac. - Caesalpinioideae		exotic
Albizia amara (Roxb.) Boiv.	Fabac. - Mimosoideae	Mukuruu, Mukuru(w)e	indigenous
Albizia gummifera (JF Gmel.) C.A. Sm.	Fabac. - Mimosoideae	Mukuruu, Mukuru(w)e	indigenous
Anacardium occidentale L.	Anacardiaceae	Cashew nut (t)	exotic
Annona cherimola Millar	Annonaceae	Mucimoko	exotic
Annona muricata L.	Annonaceae	Israeli Custard Apple (t)	exotic
Anthocleista grandiflora Gilg	Loganiaceae	Murigurigu	indigenous
Artocarpus heterophyllus Lam.	Moraceae	Jackfruit (t)	exotic
Arundinaria alpina K.Schum.	Poaceae	Murangi	indigenous
Aspilia mossambicencis (Oliv.) Wild	Asteraceae	Muti	exotic
Azadirachta indica A. Juss.	Meliaceae	Muarubaine	exotic
Azanza garckeana (F. Hoffm.) Excell & Hillcoat	Malvaceae	Mutoo	indigenous
Basella alba L.	Basellaceae		indigenous
Bauhinia tomentosa L.	Fabac. - Caesalpinioideae	Mugandagandu	indigenous
Bersama abyssinica Fres. ssp. abyssinica Verdc.	Melianthaceae	Muthandathande	indigenous
Bothriocline fusca (S.Moore) M.G. Gilbert	Asteraceae		indigenous
Bougainvillea glabra Choisy	Nyctagynaceae	Buganville (t)	exotic
Bridelia micrantha (Hochst.) Baill.	Euphorbiaceae	Mukuengwe, Mukwego	indigenous
Brunfelsia australis Benth.	Solanaceae	Yesterdaytodaytomorrow (t)	exotic
Caesalpinia decapetala (Roth) Alston	Fabac. - Caesalpinioideae	Mujana, Kejana	indigenous
Caesalpinia volkensii Harms	Fabac. - Caesalpinioideae	Mujuthi	indigenous
Calliandra calothyrsus Meissner	Fabac. - Mimosoideae	Calliandra (t)	exotic
Callistemon citrinus Skeels var. splendens	Myrtaceae	Bottlebrush (t)	exotic
Calpurnia aurea (Ait.) Benth.	Fabac. - Papilionoideae	Mugu	indigenous
Capsicum sp.	Solanaceae	Pilipili (t)	exotic
Carica papaya L.	Caricaceae	Pawpaw (t), Mubaibai	exotic
Carissa spinarum L.	Apocynaceae	Mukawa	indigenous

Species	Family	Local names°°	Origin
Carphalea glaucescens (Hiern) Verdc.	Rubiaceae		indigenous
Carphalea glaucescens (Hiern) Verdc. ?	Rubiaceae	Kanyiri, Mutoronboro	indigenous
Casearia battiscombei R.E. Fries	Flacourtiaceae	Munogo	indigenous
Casimiroa edulis La Llave	Rutaceae	Mutunda	exotic
Casuarina equisetifolia Blanco	Casuarinaceae	Casuarina (t)	indigenous
Catha edulis (Vahl.) Endl.	Celastraceae	Miraa	indigenous
Chamaecrista kirkii (Oliv.) Standley	Fabac. - Caesalpinioideae		indigenous
Chrysanthenum sp.	Asteraceae	Ornamental (t)	exotic
Cissampelos mucronata A.Rich.	Menispermaceae	Kariginana	indigenous
Cissus rotundifolia (Forssk.) Vahl.	Vitaceae		indigenous
Citrus limon Burm.f.	Rutaceae	Murimuu, Metonguu	exotic
Citrus sinensis Osbeck	Rutaceae	Mucunkwa	exotic
Citrus x paradisi Macfad.	Rutaceae	Grapefruit (t)	exotic
Clematis brachiata (Thunb.)	Ranunculaceae	Mwimba muthumbi	indigenous
Clerodendrum johnstonii Oliv.	Verbenaceae	Muarankware, Kiarankware	indigenous
Coccinia adoensis (A.Rich) Cogn. Plate	Cucurbitaceae	Kariamungu	indigenous
Coffea spp.	Rubiaceae	Coffee (t), Kaua	exotic
Combretum molle G. Don	Combretaceae	Murama, Miurama	indigenous
Combretum sp.	Combretaceae	Mukola	indigenous
Commiphora eminii Engl.	Burseraceae	Mutungugu	indigenous
Commiphora sp.	Burseraceae	Muthithio, Muthigio?(k)	indigenous
Commiphora sp. ?	Burseraceae	Gazurai	unknown
Cordia ? monoica Roxb.	Boraginaceae	Muthatha	indigenous
Cordia africana Lam.	Boraginaceae	Muringa	indigenous
Cordia monoica Roxb.	Boraginaceae	Mukuo, Muthii, Muthigi (k)	indigenous
Crotalaria axillaris Ait.	Fabac. - Papilionoideae		indigenous
Crotalaria brevidens Benth. var. parviflora (Bak.f.) Pohl.	Fabac. - Papilionoideae	Mucugucugu	indigenous
Crotalaria goodiiformis Vatke	Fabac. - Papilionoideae	Muambura	indigenous
Crotalaria incana L. var. purpurascens (Lam.) Milne-Redh.	Fabac. - Papilionoideae	Mucugucugu	indigenous
Crotalaria lachnocarpoides Engl.	Fabac. - Papilionoideae	Mucugucugu	indigenous
Crotalaria sp. (agatiflora Schweinf. ?)	Fabac. - Papilionoideae	Mwethia	indigenous
Croton macrostachyus Del.	Euphorbiaceae	Mutuntu, Mutonto	indigenous
Croton megalocarpus Hutch.	Euphorbiaceae	Marabai, Mukinduri (k)	indigenous
Croton sylvaticus Hochst.	Euphorbiaceae	Mutundu	indigenous
Cucumis dipsaceus Spach	Cucurbitaceae	Kamugu	indigenous
Cucumis sp. or Zehneria scabra (L.f.) Sond.	Cucurbitaceae	Kaungunjwe, Murangare	indigenous
Cupressus lusitanica Carr.	Cupressaceae	Mutarakwa, Muthithinda	exotic
Cupressus sempervirens L. var. piramidalis	Cupressaceae	Ornamental (t)	exotic
Cussonia holstii Engl.	Araliaceae	Mwenjera, Murogorogo	indigenous

Species	Family	Local names°°	Origin
Cyatula uncinulata (Schrad.) Schinz	Amaranthaceae	Mugwata ng'ondu, Kagwata ng'ondu	indigenous
Cyphomandra betacea Miers	Solanaceae	Matunda ya ndamu	exotic
Cyphostemma bambusati (Gilg & Brandt.) Desc.	Vitaceae	nGaigai, Mugaigai, Mutuhutu	indigenous
Cyphostemma sp.	Vitaceae		indigenous
Dalbergia lactea Vatke	Fabac. - Papilionoideae	Mugu	indigenous
Datura candida (Pers.) Saff.	Solanaceae	Moonflower (t)	exotic
Desmodium repandum (Vahl) DC. or adscendens (Sw.) DC.	Fabac. - Papilionoideae	Mutuuma	indigenous
Diospyros mespiliformis A.DC.	Ebenaceae	Mucone, Mukoro, Munyoronyoro	indigenous
Dodonaea angustifolia L.f.	Sapindaceae		indigenous
Dombeya torrida (J.F.Gmel.) Bamps	Sterculiaceae	Mukeu, Mukao	indigenous
Dovyalis abyssinica (A. Rich.) Warb.	Flacourtiaceae	Muroo, Kiroo	indigenous
Dovyalis caffra Hook.f. & Harvey	Flacourtiaceae	Kayebe, Kei-apple (t)	exotic
Dracaena sp.	Dracaenaceae	Makonge	indigenous
Dracaena sp.	Dracaenaceae	Mweng(j)eng(j)e	indigenous
Dracaena steudneri Engl.	Dracaenaceae	Muthari	indigenous
Dregea schimperi (Decne.) Bullock	Asclepidiaceae	Mugu	indigenous
Duosperma kilimandscharica (Lindau) Dayton	Acanthaceae	Matutei	indigenous
Duranta erecta L.	Verbenaceae	Mukurungu	indigenous
Ehretia cymosa Thonn.	Boraginaceae	Murembu	indigenous
Erianthemum dregei (Eckl. & Zeyh.) Tiegh.	Loranthaceae	Thiina	indigenous
Eriobotrya japonica Lindley	Rosaceae	Murungati (k)	exotic
Erythrina abyssinica DC.	Fabac. - Papilionoideae	Muuti, Muhuti	indigenous
Erythrococca fischeri Pax	Euphorbiaceae	Chesiseiyey (k)	indigenous
Eucalyptus saligna Hort Berol. ex Maiden	Myrtaceae	Mubau muta, Maguta	exotic
Eucalyptus sp.	Myrtaceae	Mubau	exotic
Euclea divinorum Hiern	Ebenaceae	Mukirinyai	indigenous
Euphorbia friesiorum (Hassler) S.Carter	Euphorbiaceae	Muthuuri	indigenous
Euphorbia pulcherrima Willd. ex Klotzsch	Euphorbiaceae	Ornamental (t)	exotic
Euphorbia tirucalli Forssk.	Euphorbiaceae	Mureman(gigi)(gugu), Muthuuri, Ndaru	exotic
Fagaropsis hildebrandtii (Engl.) Milne-Redh.	Rutaceae	Mukibia, Mukithia	indigenous
Ficus benjamina L.	Moraceae		exotic
Ficus natalensis Hochst.	Moraceae	Mugumo	indigenous
Ficus stuhlmannii Warb.	Moraceae	Mujua	indigenous
Ficus sur Forssk.	Moraceae	Mukuu	indigenous
Ficus sycomorus L.	Moraceae	Mukua	indigenous
Ficus thonningii Blume	Moraceae	Mutanta	indigenous
Flacourtia indica (Burm. f.) Merrill	Flacourtiaceae	Muraga, Muratha njuki, Muthamu	indigenous
Flacourtia sp.	Flacourtiaceae	Mukambura	indigenous
Garcinia livingstonei T. Anders	Clusiaceae	Mubiribiri, Muthunthuri	indigenous

Species	Family	Local names°°	Origin
Glycine wightii Verdc.	Fabac. - Papilionoideae	Mutuuma	indigenous
Grevillea robusta A. Cunn.	Proteaceae	Mukima	exotic
Grewia similis K.Schum.	Tiliaceae	Murenda	indigenous
Grewia similis K.Schum. or trichocarpa A.Rich.	Tiliaceae	Murenda	indigenous
Grewia sp.	Tiliaceae	Mugumwa, Mugumue, Mucamaru	indigenous
Harungana madagascariensis Poir.	Clusiaceae	Munyamwe	indigenous
Helinus mystacinus (Ait.) Steud.	Rhamnaceae		indigenous
Heteromorpha trifoliata (Wendl.) Eckl. & Zeyh.	Apiaceae		indigenous
Hibiscus flavifolius Ulbr.	Malvaceae	Hibiscus (t)	indigenous
Hibiscus fuscus Garcke	Malvaceae	Mukuma	indigenous
Hibiscus sp.	Malvaceae	Hibiscus (t)	exotic
Hippocratea africana (Willd.) Loes.	Celastraceae	Mugu	indigenous
Indigofera arrecta A.Rich.	Fabac. - Papilionoideae	Muthaara	indigenous
Indigofera arrecta A.Rich. or swaziensis Bolus	Fabac. - Papilionoideae	Riungoo	indigenous
Indigofera binderi Kotschy	Fabac. - Papilionoideae	Muthaara	indigenous
Indigofera lupatana Baker f.	Fabac. - Papilionoideae	Muthaara	indigenous
Indigofera swaziensis Bolus	Fabac. - Papilionoideae	Muthaara	indigenous
Indigofera sp.?	Fabac. - Papilionoideae	Mugundugundu	unknown
Ipomoea donaldsonii Rendle	Convolvulaceae		indigenous
Ipomoea hildebrandti Vatke	Convolvulaceae		indigenous
Ipomoea indica (Burm.) Merr.	Convolvulaceae	Ornamental (t)	indigenous
Jacaranda mimosaefolia D. Don.	Bignoniaceae	Mucakaranda (k)	exotic
Jasminum fluminense Vell.	Oleaceae		indigenous
Jasminum sp.	Oleaceae		exotic
Jatropha curcas L.	Euphorbiaceae	Mubariki	indigenous
Juniperus procera Endl.	Cupressaceae	Murana	indigenous
Kigelia africana (Lam.) Benth.	Bignoniaceae	Murantina	indigenous
Lagenaria abyssinica (Hook.f.) C.Jeffrey	Cucurbitaceae	Kamunguru	indigenous
Lannea schimperi (A.Rich.) Engl.	Anacardiaceae		indigenous
Lantana camara L.	Verbenaceae	Haraka, Muchomoro	exotic
Lantana trifolia L.	Verbenaceae	Muthiriti, Muthrithia	indigenous
Leucaena leucocephala (Lam.) De Wit	Fabac. - Mimosoideae	Lukina	exotic
Leucas grandis Vatke	Lamiaceae		indigenous
Macadamia integrifolia Maiden & Betche	Proteaceae	Macadamia (t)	exotic
Macadamia tetraphylla L. Johnson	Proteaceae	Macadamia (t)	exotic
Maerua decumbens (Brongn.) De Wolf	Capparaceae	Munati	indigenous
Malus sp.	Rosaceae	Apple tree (t)	exotic
Mangifera indica Blume	Anacardiaceae	Mango, Mwembe	exotic
Manihot glaziovii Muell. Arg.	Euphorbiaceae	Mukueci we mbio, Cassava tree (t), Sierra rubber (t), Kimukwaacii	exotic
Markhamia lutea (Benth.) K.Schum.	Bignoniaceae	Mungwani, Muu (k), Mogu	indigenous

Species	Family	Local names°°	Origin
Melhania velutina Forssk.	Sterculiaceae	Gicabi	indigenous
Melia azedarach Blanco	Meliaceae	M(w)/(u)arubaine	exotic
Melia volkensii Gürke	Meliaceae	Local neem (t)	indigenous
Milicia excelsa (Welw.) C.C.Berg	Moraceae	Murierie, Murure, Murule (s)	indigenous
Millettia dura Dunn	Fabac. - Papilionoideae	Mwangua	indigenous
Millettia tanaensis Gillett	Fabac. - Papilionoideae	Mwangua	indigenous
Mitragyna rubrostipulata (K.Schum.) Havil.	Rubiaceae	Mukundukundu	indigenous
Momordica foetida Schumach.	Cucurbitaceae	Kinunka	indigenous
Monanthotaxis schweinfurthii (Engl. & Diels)	Annonaceae	Mugaa-njuki	indigenous
Mondia whytei (Hook.f.) Skeels	Asclepidiaceae	Mugu, Mukuura	indigenous
Morus alba Y.B. Wu	Moraceae	Mutaratare	exotic
Mussaenda microdonta Wernh.	Rubiaceae	Murema muthua (k)	indigenous
Myrianthus holstii Engl.	Moraceae	Mutuya	indigenous
Nerium oleander L.	Apocynaceae	Oleander (t)	exotic
Newtonia buchananii (Baker) Gilb. & Bout.	Fabac. - Mimosoideae	Mugui, Mukui	indigenous
Ocimum kilimandscharicum Gürke	Lamiaceae	Makuri	indigenous
Ocimum suave Willd.	Lamiaceae	Mukandu, Mukandakandu, Mugio (k)	indigenous
Olea capensis L. var. hochstetteri (Baker) Friis & P.S. Green	Oleaceae	Mutero, Mutoro?	indigenous
Olea europaea L.	Oleaceae	Muthatha	indigenous
Ozoroa insignis Del.	Anacardiaceae	Mukununu	indigenous
Pachystela brevipes (Baker) Engl.	Sapotaceae	Muthenthea, Munoa (k), Muthankume	indigenous
Passiflora edulis Sims	Passifloraceae	Ntunda cia mingu	exotic
Passiflora quadrangularis L.	Passifloraceae	Giant passionfruit (t), Kimeru	exotic
Passiflora sp.	Passifloraceae	Passion fruit (t)	exotic
Pavonia patens (Andr.) Chiov.	Malvaceae		indigenous
Pavonia urens Cav.	Malvaceae	Muondoe, Mureranjau	indigenous
Pentas lanceolata (Forssk.) Deflers	Rubiaceae	Muumia	indigenous
Peponium vogelii (Hook.f.) Engl.	Cucurbitaceae	Murigi	indigenous
Pergularia daemia Chiov.	Asclepidiaceae	Kagombagombwe	indigenous
Persea americana Mill.	Lauraceae	Mwabokando	exotic
Phyllanthus odontadenius Muell. Arg.	Euphorbiaceae		indigenous
Picea sp.	Pinaceae	Ornamental (t)	exotic
Pinus patula Schiede & Deppe	Pinaceae		exotic
Pistacia aethiopica Kokwaro	Anacardiaceae	Muthingiri	indigenous
Plectranthus barbatus Andr.	Lamiaceae	Majara, Kijara	indigenous
Plumeria alba Aubl.	Apocynaceae	Mubono, Frangipane (t)	exotic
Prunus africana (Hook.f.) Kalkm.	Rosaceae	Mueria	indigenous
Prunus salicina Lindl.	Rosaceae	Plum (t)	exotic
Psidium guajava L.	Myrtaceae	Guava (t), Mbela, Mubera	exotic
Psychotria kirkii Hiern.	Rubiaceae	Mubiru, Mugimbi, Munyua cubu, Mukira muthwa, Mutheriga	indigenous
Psychotria kirkii Hiern. ?	Rubiaceae		unknown

Species	Family	Local names°°	Origin
Psychotria kirkii Hiern. var. nairobiensis (Brem.) Verdc.	Rubiaceae	Mutheriga, Mukira muthua	indigenous
Psychotria kirkii Hiern. var. tarambassica (Brem.) Verdc.	Rubiaceae	Munyna cubu, Mugimbi	indigenous
Psydrax parviflora (Afz.) Bridson ssp. parviflora	Rubiaceae	Muratha iiga	indigenous
Punica granatum L.	Punicaceae	Kukumanga, Mukumu mwnga, Pomme granate (t)	exotic
Pycnostachius umbrosa (Vatke) Perkins	Lamiaceae	Maboru, Kiboru, Muari, Muoru, Mioru, Maoru	indigenous
Pyrostegia venusta (Ker-Gawl.) Miers	Bignoniaceae	Golden shower (t)	exotic
Pyrus communis Dur.	Rosaceae	Pear (t)	exotic
Rauvolfia caffra Sond.	Apocynaceae	Mutuu	indigenous
Rhoicissus tridentata (L.f.) Wild & Drumm.	Vitaceae		indigenous
Rhus ruspolii Engl. ?	Anacardiaceae	Munonanthenge	indigenous
Ricinus communis L.	Euphorbiaceae	Castor oil (t), muariki	indigenous
Rosa sp.	Rosaceae	Rose (t)	exotic
Rosmarinus officinalis L.	Lamiaceae	Rosemary (t)	exotic
Rothmannia urcelliformis (Hiern) Robyns	Rubiaceae	Mukomere	indigenous
Rubus scheffleri Engl.	Rosaceae	Mataratare	indigenous
Rumex abyssinicus Jacq.	Polygonaceae	Muraiguna	indigenous
Saba comorensis (Bojer) Pichon	Apocynaceae	Meungo	indigenous
Sambucus sp.	Caprifoliaceae	Ornamental (t)	exotic
Sapium ellipticum (Krauss) Pax	Euphorbiaceae	Muthath(i)(a)	indigenous
Schinus molle L.	Anacardiaceae		exotic
Senna bicapsularus (L.) Roxb.	Fabac. - Caesalpinioideae		indigenous
Senna didymobotrya (Fresen.) Irwin & Barneby	Fabac. - Caesalpinioideae	Kirao	indigenous
Senna septemtrionalis (Viviani) Irwin & Barneby	Fabac. - Caesalpinioideae	Kirao	indigenous
Senna siamea (Lam.) H.S. Irwin & Barneby	Fabac. - Caesalpinioideae	Kirao	exotic
Senna spectabilis (DC.) H.S. Irwin & Barneby	Fabac. - Caesalpinioideae	Mukenya	exotic
Sesbania sesban (L.) Merrill	Fabac. - Caesalpinioideae	Mucugu, Musungiri (k)	indigenous
Sida tenuicarpa Vollesen	Malvaceae	Gatiki	indigenous
Solanecio angulatus (Vahl) C. Jeffrey	Asteraceae	Munorianthenge, Muturutua	indigenous
Solanecio mannii (Hook.f.) C. Jeffrey	Asteraceae	Mutomboro	indigenous
Solanecio sp.	Asteraceae	Ornamental (t)	exotic
Solanum incanum L.	Solanaceae	Mutongu	indigenous
Solanum nigrum L.	Solanaceae	Marajgu	indigenous
Spathodea campanulata P. Beauv.	Bignoniaceae	Mucebe, Flame tree (t), Mucababunduki	indigenous
Stephania abyssinica (Dillon & A.Rich.) Walp.	Menispermaceae	Gatamba nanthi	indigenous
Stereospermum kunthianum Cham.	Bignoniaceae	Mutendera	indigenous
Strychnos henningsii Gilg	Loganiaceae	Mucambe	indigenous
Syzygium guineense (Willd.) DC.	Myrtaceae		indigenous

Species	Family	Local names°°	Origin
Syzygium guineense (Willd.) DC. ssp. guineense	Myrtaceae	Muriru, Mururi, Muthankume	indigenous
Tabernaemontana ventricosa A.DC.	Apocynaceae	Muerere	indigenous
Tamarindus indica L.	Fabac. - Caesalpinioideae	Muthithiu	indigenous
Tapinanthus constrictiflorus (Engl.) Danser	Loranthaceae		indigenous
Teclea simplicifolia (Engl.) Verd. ?	Rutaceae	Muteretu	indigenous
Telfairia pedata (Sims) Hook.	Cucurbitaceae	Oister nut (t), Muthanduru	exotic
Tephrosia vogelii Hook.f.	Fabac. - Papilionoideae	Mucugucugu	indigenous
Terminalia brownii Fresen.	Combretaceae	Muthiti, Muthumuki	indigenous
Terminalia catappa L.	Combretaceae		exotic
Terminalia mantaly H. Perrier	Combretaceae	Umbrella tree (t)	exotic
Terminalia sp.	Combretaceae	Munuruku	indigenous
Terminalia sp. ?	Combretaceae		unknown
Tetradenia riparia (Hochst.) Codd.	Lamiaceae	Muaraka, Kiaraka	indigenous
Theobroma cacao L.	Sterculiaceae		exotic
Thevetia peruviana (Pers.) K.Schum.	Apocynaceae	Thevetia (t)	exotic
Tipuana tipu Kuntze	Fabac. - Papilionoideae		exotic
Tithonia diversifolia (Hemsl.) A.Gray	Asteraceae	Maatha, Mung'ana	exotic
Trema orientalis (L.) Bl.	Ulmaceae	Muethu	indigenous
Trichilia emetica Vahl.	Meliaceae	Mutuati	indigenous
Triumfetta rhomboidea Jacq.	Tiliaceae		indigenous
Triumfetta tomentosa Boj.	Tiliaceae	Mujijo, Kijijo	indigenous
Vangueria madagascariensis Gmel.	Rubiaceae	Mubiru, Muiru	indigenous
Vangueria sp.?	Rubiaceae	Muirontue	unknown
Vernonia auriculifera Hiern	Asteraceae	Muthakwa	indigenous
Vernonia brachycalyx O.Hoffm.	Asteraceae		indigenous
Vernonia lasiopus O.Hoffm.	Asteraceae	Muatha	indigenous
Viscum fischeri Engl.	Viscaceae		indigenous
Viscum sp.	Viscaceae	Mistletoe (t), Kiea	indigenous
Vitex fischeri Gürke	Verbenaceae	Muuru	indigenous
Vitis sp.	Vitaceae	Mataratare	exotic
Waltheria indica L.	Sterculiaceae	Murinda ngengurwi	indigenous
Zanthoxylum gilletii (De Wild.) Waterm.	Rutaceae	Mugocwa	indigenous

Species	Family	Local names°°	Origin
Zanthoxylum usambarense (Engl.) Kokwaro	Rutaceae	Muruirii	indigenous
Zehneria scabra (L.f.) Sond. or Cucumis sp.	Cucurbitaceae	Kaungunjwe, Murangare	indigenous
Ziziphus abyssinica A.Rich.	Rhamnaceae	Mutandanderi	indigenous
	Bignoniaceae	Ornamental (t)	exotic
	Convolvulaceae		unknown
	Cucurbitaceae		unknown
	Euphorbiaceae	Ornamental (t)	exotic
	Euphorbiaceae		exotic
	Geraniaceae		unknown
	Lamiaceae	Mutaria	unknown
	Malvaceae		unknown
	Malvaceae	Ornamental (t)	exotic
	Rosaceae		unknown
	Rubiaceae	Mukirithia	unknown
	Rubiaceae		exotic
	Thymelaceae	Ornamental (t)	exotic
	Thymelaceae	Ornamental (t)	exotic
	Vitaceae	Muturutua	unknown
		Gaturutua	unknown
		Karugoya, Ruogoya	unknown
		Kebota	exotic
		Muambanare, Muambanj?re	unknown
		Muboru	unknown
		Mugundire	unknown
		Muithia	unknown
		Munampithia	unknown
		Musala	unknown
		Muthati itema	unknown
		Mutirankongu	unknown
		Muturiawiga	unknown
		Nthnth	exotic
		Ornamental (t)	exotic
		Ornamental (t)	exotic
			unknown
			unknown
			unknown
			unknown
			unknown
			unknown

° Woody perennials > 1.5 m, species primarily identified using Beentje (1994) and Agnew & Agnew (1994)

°° In Ki-Meru most tree species names start with 'Mu' or 'Mi'. For some tree species the names are in plural, these species are the lianas and some minor (small) species and their names start with 'Ku' or 'Ki'. All names have been recorded, where applicable both singular & plural forms of tree names are mentioned in the list.

(t) Trade name, usually English or Kiswahili; (k) Kikuyu name; 'or' the species could not be distinguished on farm; '?' Species identity is unsure.

Appendix 5: Plant (sub)families recorded in the Meru tree inventory (n=64).

Botanical family
Acanthaceae
Amaranthaceae
Anacardiaceae
Annonaceae
Apiaceae
Apocynaceae
Araliaceae
Asclepidiaceae
Asteraceae
Basellaceae
Bignoniaceae
Boraginaceae
Burseraceae
Capparaceae
Caprifoliaceae
Caricaceae

Botanical family
Casuarinaceae
Celastraceae
Clusiaceae
Combretaceae
Convolvulaceae
Cucurbitaceae
Cupressaceae
Dracaenaceae
Ebenaceae
Euphorbiaceae
Fabaceae - Caesalpinioideae
Fabaceae - Mimosoideae
Fabaceae - Papilionoideae
Flacourtiaceae
Geraniaceae
Lamiaceae

Botanical family
Lauraceae
Loganiaceae
Loranthaceae
Malvaceae
Meliaceae
Melianthaceae
Menispermaceae
Moraceae
Myrtaceae
Nyctagynaceae
Oleaceae
Passifloraceae
Pinaceae
Poaceae
Polygonaceae
Proteaceae

Botanical family
Punicaceae
Ranunculaceae
Rhamnaceae
Rosaceae
Rubiaceae
Rutaceae
Sapindaceae
Sapotaceae
Solanaceae
Sterculiaceae
Thymelaceae
Tiliaceae
Ulmaceae
Verbenaceae
Viscaceae
Vitaceae

Appendix 6a: Number of plants per species in the Meru on farm tree° inventory (Igoji, 16734 plants and 178 species).

Species	No trees
Abrus fruticulosus	2
Abutilon sp.	1
Acacia hockii	363
Acalypha racemosa	1
Acalypha sp.	7
Achyranthes aspera	1
Albizia amara	36
Albizia gummifera	3
Annona cherimola	1
Annona muricata	1
Azadirachta indica	1
Azanza garckeana	13
Basella alba	44
Bauhinia tomentosa	2
Bersama abyssinica ssp. abyssinica	1
Bothriocline fusca	3
Bougainvillea glabra	11
Bridelia micrantha	277
Brunfelsia australis	2
Caesalpinia decapetala	7
Caesalpinia volkensii	1
Callistemon citrinus var. splendens	3
Calpurnia aurea	1
Capsicum sp.	3
Carica papaya	137
Casimiroa edulis	1
Catha edulis	122
Chrysanthenum sp.	12
Cissampelos mucronata	1
Citrus limon	10
Citrus sinensis	3
Clerodendrum johnstonii	17
Coffea spp.	6300
Combretum molle	17
Combretum sp.	1
Commiphora eminii	419
Commiphora sp.	7
Cordia africana	192
Cordia monoica	13
Crotalaria lachnocarpoides	14
Crotalaria sp. (agatiflora ?)	12
Croton macrostachyus	39
Croton megalocarpus	89
Croton sylvaticus	3
Cupressus lusitanica	380
Cyphomandra betacea	2
Cyphostemma bambusati	12
Dalbergia lactea	30
Datura candida	5

Species	No trees
Desmodium repandum or adscendens	18
Diospyros mespiliformis	47
Dombeya torrida	20
Dovyalis caffra	5
Dracaena sp.	2
Dracaena sp.	2
Dregea schimperi & Hippocratea africana	5
Duosperma kilimandscharica	6
Ehretia cymosa	36
Eriobotrya japonica	57
Erythrina abyssinica	26
Erythrococca fischeri	1
Eucalyptus sp.	1
Euphorbia friesiorum	4
Euphorbia tirucalli	3
Ficus natalensis	53
Ficus sur	2
Ficus thonningii	5
Flacourtia indica	1
Flacourtia sp.	2
Garcinia livingstonei	2
Grevillea robusta	918
Grewia similis or trichocarpa	40
Grewia sp.	1
Harungana madagascariensis	4
Hibiscus fuscus	1
Hibiscus sp.	11
Indigofera arrecta & binderi & lupatana & swaziensis	14
Indigofera arrecta or swaziensis	59
Indigofera sp.?	2
Ipomoea donaldsonii	3
Jacaranda mimosaefolia	17
Jasminum sp.	893
Jatropha curcas	64
Kigelia africana	1
Lantana camara	967
Lantana trifolia	1
Leucaena leucocephala	512
Macadamia integrifolia	23
Macadamia tetraphylla	18
Malus sp.	1
Mangifera indica	63
Manihot glaziovii	20
Markhamia lutea	26
Milicia excelsa	4
Millettia dura	226
Millettia tanaensis	1

Species	No trees
Monanthotaxis schweinfurthii	21
Mondia whytei	1
Morus alba	14
Mussaenda microdonta	2
Myrianthus holstii	1
Nerium oleander	1
Newtonia buchananii	3
Ocimum kilimandscharicum	2
Ocimum suave	35
Olea capensis var. hochstetteri	1
Olea europaea	76
Pachystela brevipes	3
Passiflora edulis	52
Pavonia urens	30
Pentas lanceolata	10
Persea americana	170
Phyllanthus odontadenius	5
Plectranthus barbatus	354
Plumeria alba	3
Prunus africana	12
Psidium guajava	131
Psychotria kirkii	1
Psychotria kirkii ?	10
Psychotria kirkii var. nairobiensis	26
Punica granatum	5
Pycnostachius umbrosa	80
Pyrostegia venusta	1
Rauvolfia caffra	7
Ricinus communis	11
Rosa sp.	1
Rothmannia urcelliformis	4
Rubus scheffleri	17
Saba comorensis	1
Sapium ellipticum	62
Senna bicapsularus	5
Senna septemtrionalis & didymobotrya	2
Senna siamea	3
Senna spectabilis	18
Solanecio mannii	1
Solanum incanum	106
Solanum nigrum	3
Spathodea campanulata	16
Stereospermum kunthianum	5
Syzygium guineense	2
Tabernaemontana ventricosa	46
Tamarindus indica	3
Tephrosia vogelii	6
Terminalia brownii	1
Terminalia catappa	1

Species	No trees
Terminalia mantaly	3
Terminalia sp.	1
Tetradenia riparia	144
Theobroma cacao	1
Thevetia peruviana	5
Tithonia diversifolia	1233
Trema orientalis	9
Trichilia emetica	49
Triumfetta tomentosa	48
Vangueria madagascariensis	99
Vangueria sp.?	18
Vernonia auriculifera	8
Vernonia lasiopus	3
Viscum sp.	4
Vitex fischeri	36
Waltheria indica	195
Karugoya, Ruogoya	1
Kebota	1
Muambanare = Muambanj?re	3
Muboru	605
Mugundire	1
Muithia	2
Mukirithia	17
Musala	1
Muthati itema	1
Muturiawiga	1
Nthnth	1
ornamental	38
ornamental	1
ornamental	1
	1
	1
	2
	18

'or' the species could not be distinguished in the field.

'&' All species were identified, but practical constraints prohibited to distinguish individuals.

'?' Species identity unsure

° Woody perennials > 1.5 m

Appendix 6b: Number of plants per species in the Meru on farm tree° inventory (Nkubu, 17112 plants and 171 species).

Species	No trees
Acacia brevispica	9
Acacia mearnsii	91
Acacia seyal	1
Acalypha racemosa	1
Acalypha sp.	4
Achyranthes aspera	9
Albizia gummifera	17
Anacardium occidentale	1
Annona cherimola	4
Anthocleista grandiflora	2
Arundinaria alpina	1
Azanza garckeana	2
Bersama abyssinica ssp. abyssinica	29
Bougainvillea glabra	26
Bridelia micrantha	162
Caesalpinia decapetala	1140
Caesalpinia volkensii	2
Calliandra calothyrsus	77
Callistemon citrinus var. splendens	4
Capsicum sp.	1
Carica papaya	219
Carphalea glaucescens	9
Carphalea glaucescens?	3
Casearia battiscombei	1
Casuarina equisetifolia	4
Catha edulis	9
Chamaecrista kirkii	1
Chrysanthenum sp.	177
Citrus limon	5
Clematis brachiata	26
Clerodendrum johnstonii	28
Coffea spp.	4360
Combretum molle	12
Commiphora eminii	823
Cordia ? monoica	1
Cordia africana	220
Cordia monoica	10
Crotalaria axillaris	1
Croton macrostachyus	64
Croton megalocarpus	3
Cupressus lusitanica	321
Cupressus sempervirens var. piramidalis	1
Cussonia holstii	36
Cyphomandra betacea	123
Cyphostemma bambusati	5
Cyphostemma sp.	5

Species	No trees
Dalbergia lactea	6
Desmodium repandum or adscendens	23
Diospyros mespiliformis	2
Dovyalis abyssinica	23
Dovyalis caffra	106
Dracaena sp.	1
Dracaena steudneri	6
Duranta erecta	132
Ehretia cymosa	201
Eriobotrya japonica	364
Erythrina abyssinica	68
Erythrococca fischeri	1
Eucalyptus saligna	18
Eucalyptus sp.	14
Euphorbia friesiorum	43
Euphorbia pulcherrima	4
Euphorbia tirucalli	235
Fagaropsis hildebrandtii	1
Ficus benjamina	2
Ficus natalensis	5
Ficus stuhlmannii	5
Ficus sur	2
Ficus sycomorus	3
Flacourtia indica	1
Garcinia livingstonei	1
Glycine wightii	24
Grevillea robusta	582
Grewia similis	1
Grewia similis or trichocarpa	3
Harungana madagascariensis	10
Heteromorpha trifoliata	3
Hibiscus fuscus	1
Hibiscus sp.	5
Indigofera arrecta & binderi & lupatana & swaziensis	42
Ipomoea hildebrandti	1
Jacaranda mimosaefolia	21
Jasminum sp.	338
Juniperus procera	1
Kigelia africana	2
Lantana camara	730
Leucaena leucocephala	134
Leucas grandis	40
Macadamia integrifolia	67
Macadamia tetraphylla	65
Malus sp.	1
Mangifera indica	57
Manihot glaziovii	540

Species	No trees
Markhamia lutea	6
Melia volkensii	5
Milicia excelsa	1
Millettia dura	239
Millettia tanaensis	8
Mitragyna rubrostipulata	4
Momordica foetida	38
Monanthotaxis schweinfurthii	1
Mondia whytei	8
Morus alba	30
Myrianthus holstii	11
Nerium oleander	5
Ocimum kilimandscharicum	20
Ocimum suave	15
Olea europaea	1
Passiflora edulis	75
Passiflora quadrangularis	2
Passiflora sp.	1
Pavonia patens	20
Pentas lanceolata	230
Peponium vogelii	1
Pergularia daemia	9
Persea americana	126
Picea sp.	1
Pinus patula	2
Plectranthus barbatus	452
Plumeria alba	2
Prunus africana	392
Prunus salicina	1
Psidium guajava	169
Psychotria kirkii	25
Punica granatum	4
Pycnostachius umbrosa	355
Rauvolfia caffra	31
Rhus ruspolii ?	1
Ricinus communis	16
Rosa sp.	86
Rosmarinus officinalis	22
Rubus scheffleri	319
Rumex abyssinicus	4
Sambucus sp.	12
Senna septemtrionalis & didymobotrya	19
Sesbania sesban	30
Solanecio angulatus	2
Solanum incanum	47
Spathodea campanulata	13
Stephania abyssinica	30
Syzygium guineense	12

Species	No trees
Syzygium guineense ssp. guineense	11
Tabernaemontana ventricosa	1
Telfairia pedata	2
Tephrosia vogelii	4
Terminalia catappa	2
Terminalia mantaly	1
Tetradenia riparia	929
Tipuana tipu	1
Tithonia diversifolia	429
Trema orientalis	4
Trichilia emetica	48
Triumfetta rhomboidea	10
Triumfetta tomentosa	17
Vangueria madagascariensis	105
Vernonia auriculifera	32
Vernonia lasiopus	15
Viscum sp.	1
Vitex fischeri	546
Waltheria indica	13
Zanthoxylum gilletii	3
Zehneria scabra or Cucumis sp.	25
Mukirithia	1
Munampithia	1
Muturutua	4
ornamental	1
ornamental	2
	1
	1
	1
	1
	2
	10

'or' the species could not be distinguished in the field.
'&' All species were identified, but practical constraints prohibited to distinguish individuals.
'?' Species identity unsure
° Woody perennials > 1.5 m

Appendix 6c: Number of plants per species in the Meru on farm tree° inventory (Ruiri, 29100 plants and 173 species).

Species	No trees
Acacia albida	1
Acacia brevispica	10
Acacia hockii	6
Acacia seyal	24
Acacia xanthophloea	17
Achyranthes aspera	222
Acokanthera schimperi	233
Acrocarpus fraxinifolius	7
Annona cherimola	97
Annona muricata	10
Artocarpus heterophyllus	1
Aspilia mossambicencis	48
Azadirachta indica	5
Azanza garckeana	114
Bauhinia tomentosa	65
Bersama abyssinica ssp. abyssinica	1
Bougainvillea glabra	84
Bridelia micrantha	3
Caesalpinia decapetala	16
Calliandra calothyrsus	3
Callistemon citrinus var. splendens	9
Carica papaya	31
Carissa spinarum	321
Carphalea glaucescens?	13
Casearia battiscombei	1
Casimiroa edulis	12
Casuarina equisetifolia	22
Catha edulis	1050
Chrysanthenum sp.	47
Cissus rotundifolia	2
Citrus limon	139
Citrus sinensis	18
Citrus x paradisi	1
Clematis brachiata	88
Coccinia adoensis	1
Coffea spp.	10151
Combretum molle	111
Commiphora eminii	276
Commiphora sp.	2
Commiphora sp. ?	1
Cordia africana	232
Cordia monoica	8
Crotalaria goodiiformis	2
Crotalaria incana var. purpurascens & brevidens var. parviflora	2
Croton macrostachyus	59
Croton megalocarpus	123
Cucumis dipsaceus	7

Species	No trees
Cupressus lusitanica	604
Cussonia holstii	5
Cyatula uncinulata	61
Cyphostemma bambusati	284
Desmodium repandum or adscendens	94
Dodonaea angustifolia	4
Dombeya torrida	145
Dovyalis abyssinica	1
Dovyalis caffra	121
Dracaena sp.1	11
Ehretia cymosa	6
Erianthemum dregei	2
Eriobotrya japonica	40
Erythrina abyssinica	180
Eucalyptus saligna	96
Eucalyptus sp.	1
Euclea divinorum	500
Euphorbia friesiorum	212
Euphorbia pulcherrima	2
Euphorbia tirucalli	3068
Fagaropsis hildebrandtii	1
Ficus natalensis	7
Ficus stuhlmannii	1
Flacourtia indica	161
Grevillea robusta	1482
Grewia similis	7
Grewia similis or trichocarpa	40
Grewia sp.	21
Helinus mystacinus	20
Heteromorpha trifoliata	1
Hibiscus flavifolius	1
Indigofera arrecta & binderi & lupatana & swaziensis	89
Ipomoea indica	11
Jacaranda mimosaefolia	14
Jasminum fluminense	108
Jasminum sp.	113
Jatropha curcas	53
Juniperus procera	47
Kigelia africana	2
Lagenaria abyssinica	1
Lannea schimperi	1
Lantana camara	2579
Lantana trifolia	446
Leucaena leucocephala	209
Macadamia integrifolia	60
Macadamia tetraphylla	61

Species	No trees
Maerua decumbens	16
Malus sp.	4
Mangifera indica	73
Markhamia lutea	52
Melhania velutina	22
Melia azedarach	8
Melia volkensii	24
Milicia excelsa	118
Millettia dura	10
Mondia whytei	3
Morus alba	17
Nerium oleander	11
Ocimum kilimandscharicum	1
Ocimum suave	430
Olea capensis var. hochstetteri	70
Olea europaea	1
Ozoroa insignis	2
Passiflora edulis	40
Passiflora quadrangularis	3
Pavonia urens	15
Pentas lanceolata	1
Pergularia daemia	63
Persea americana	200
Pinus patula	20
Pistacia aethiopica	6
Plectranthus barbatus	485
Psidium guajava	49
Psychotria kirkii	19
Psychotria kirkii var. nairobiensis	4
Psychotria kirkii var. tarambassica	149
Psydrax parviflora ssp. parviflora	9
Punica granatum	17
Pycnostachius umbrosa	387
Pyrus communis	5
Rhoicissus tridentata	3
Rhus ruspolii ?	2
Ricinus communis	78
Rubus scheffleri	1
Schinus molle	8
Senna septemtrionalis & didymobotrya	85
Senna spectabilis	8
Sesbania sesban	1
Sida tenuicarpa	1
Solanecio angulatus	26
Solanecio sp.	1
Solanum incanum	128
Solanum nigrum	2

Species	No trees
Spathodea campanulata	7
Strychnos henningsii	3
Tamarindus indica	102
Tapinanthus constrictiflorus	1
Teclea simplicifolia?	9
Tephrosia vogelii	8
Terminalia brownii	3
Terminalia mantaly	7
Terminalia sp. ?	2
Tetradenia riparia	55
Thevetia peruviana	2
Tithonia diversifolia	919
Triumfetta tomentosa	2
Vangueria madagascariensis	263
Vernonia brachycalyx	2
Vernonia lasiopus	27
Viscum fischeri	1
Vitex fischeri	15
Vitis sp.	2
Waltheria indica	36
Zanthoxylum usambarense	7
Zehneria scabra or Cucumis sp.	179
Ziziphus abyssinica	3
Gaturutua	10
Mukirithia	14
Mutaria	1
Mutirankongu	7
Muturutua	53
ornamental	2
ornamental	1
ornamental	3
	1
	2
	4

'or' the species could not be distinguished in the field.
'&' All species were identified, but practical constraints prohibited to distinguish individuals.
'?' Species identity unsure
° Woody perennials > 1.5 m

Appendix 7: Species uses according to the Meru farmers (ordered by botanical name).

Species	Human & animal consumption	Fuel	Medicinal values	Rituals	Wood and other uses	Timber	BM
Abrus fruticulosus							
Abutilon sp.							
Acacia albida		firewood					
Acacia brevispica							*
Acacia hockii		firewood	not specified				*
Acacia mearnsii		charcoal, firewood				not specified, poles, rafters, furniture	
Acacia seyal							
Acacia xanthophloea							*
Acalypha racemosa							
Acalypha sp.					ornamental		
Achyranthes aspera	fodder	firewood	toothache				*
Acokanthera schimperi	fruit, fodder	firewood		arrow poison	plant support	not specified, poles	*
Acrocarpus fraxinifolius		firewood				not specified	
Albizia amara	fodder, ripening bananas	charcoal, firewood				not specified	
Albizia gummifera		charcoal, firewood			ornamental, shade	not specified	
Anacardium occidentale	nuts						
Annona cherimola	fruit	firewood	cattle				
Annona muricata	fruit						
Anthocleista grandiflora		firewood	colds		animal traps	not specified	
Artocarpus heterophyllus	fruit						
Arundinaria alpina							
Aspilia mossambicencis	fodder						
Azadirachta indica			not specified				
Azanza garckeana	fodder, fruit	firewood	stomach pain		tool handles, I	not specified	
Basella alba							
Bauhinia tomentosa	fodder	firewood			tool handles	rafters	
Bersama abyssinica ssp. abyssinica		charcoal, firewood			wedges, honey/beehives	poles	*
Bothriocline fusca							
Bougainvillea glabra					ornamental, shade, weddings		*
Bridelia micrantha	fodder	charcoal, firewood	general health		plant support	not specified, poles	*
Brunfelsia australis					ornamental		
Caesalpinia decapetala		firewood	not specified				*
Caesalpinia volkensii			malaria				
Calliandra calothyrsus	fodder				ornamental		
Callistemon citrinus var. splendens					ornamental		*
Calpurnia aurea					weaving		
Capsicum sp.	vegetable, spice						
Carica papaya	fruit, tenderising meat, fodder, soup	firewood	sexual transitional diseases, stomach pain, amoeba, not specified				
Carissa spinarum	fruit, soup		not specified, toothache		ornamental		*
Carphalea glaucescens							
Carphalea glaucescens?			cattle		broom, biocide		*
Casearia battiscombei	fruit	firewood				not specified	
Casimiroa edulis	fruit						
Casuarina equisetifolia		firewood			ornamental	not specified, poles	*
Catha edulis	stimulant		not specified				
Chamaecrista kirkii							
Chrysanthenum sp.					ornamental		
Cissampelos mucronata			stomach pain				

Species	Human & animal consumption	Fuel	Medicinal values	Rituals	Wood and other uses	Timber	BM
Cissus rotundifolia							
Citrus limon	fruit, fermentation, soup		not specified, malaria, joints and bones				
Citrus sinensis	fruit						
Citrus x paradisi	fruit						
Clematis brachiata	fodder		colds, throat, headache				*
Clerodendrum johnstonii	fodder	firewood	stomach pain, cattle		animal traps, hooks, weaving	rafters	*
Coccinia adoensis	vegetable						
Coffea spp.	coffee beans	firewood			plant support	rafters	
Combretum molle	fodder	charcoal, firewood	fracture span, swellings			not specified	*
Combretum sp.			not specified				
Commiphora eminii	fodder	firewood	cattle	bowls for fire with Mujijo sticks	plant support, soil fertility, combs, spoons	poles	*
Commiphora sp.	fodder, fruit	firewood					
Commiphora sp. ?			malaria		honey/beehives		
Cordia ? monoica							
Cordia africana	fodder	firewood	cattle, colds, fracture span		ropes, bark on fire to scare bees, honey/beehives, firesticks, tool handles	not specified, furniture	
Cordia monoica		firewood			washing utensil	not specified, poles	
Crotalaria axillaris							
Crotalaria brevidens var. parviflora					soil fertility		
Crotalaria goodiiformis					ropes		
Crotalaria incana var. purpurascens					soil fertility		
Crotalaria lachnocarpoides	fodder						
Crotalaria sp. (agatiflora ?)					soil fertility		
Croton macrostachyus	ripening bananas, fodder	charcoal, firewood	cattle, fresh cuts, throat	dance for curing disease	plant support	not specified, furniture	*
Croton megalocarpus	fodder	charcoal, firewood	cattle, treat poisoning, fresh cuts		ornamental, shade	not specified, poles	*
Croton sylvaticus			cattle		attract rain		
Cucumis dipsaceus							
Cucumis sp. or Zehneria scabra	fodder, fruit		cattle, toothache				*
Cupressus lusitanica		firewood			ornamental	not specified, rafters	*
Cupressus sempervirens var. piramidalis					ornamental		
Cussonia holstii	fodder	firewood		carving (shields, scabbard)	plant support	not specified	*
Cyatula uncinulata	fodder						
Cyphomandra betacea	tenderising meat, fruit	firewood					
Cyphostemma bambusati	fodder	firewood	worms, cattle			rafters	*
Cyphostemma sp.							
Dalbergia lactea					weaving, ropes		
Datura candida		firewood			ornamental		
Desmodium repandum or adscendens	fodder						
Diospyros mespiliformis	fodder	charcoal, firewood				not specified, poles, rafters	
Dodonaea angustifolia							
Dombeya torrida	fodder	firewood			ropes		*
Dovyalis abyssinica	fruit	firewood	colds		needle		*
Dovyalis caffra	fruit						*
Dracaena sp.1					ropes		
Dracaena sp.2	fodder		colds				
Dracaena steudneri	fodder		not specified, colds	slaughter on a bed			

Species	Human & animal consumption	Fuel	Medicinal values	Rituals	Wood and other uses	Timber	BM
				of leaves			
Dregea schimperi & Hippocratea africana					weaving, Calabashes		
Duosperma kilimandscharica	vegetable						
Duranta erecta		firewood	malaria		plant support	rafters	*
Ehretia cymosa	fodder	charcoal, firewood	cattle		plant support, tool handles	not specified, poles, rafters	
Erianthemum dregei							
Eriobotrya japonica	fruit, fodder	firewood				rafters, poles	*
Erythrina abyssinica	fodder	firewood	not specified, cattle, fresh cuts, amoeba, colds	carving (shields, scabbard)	carvings, plant support, tool handles, firesticks, honey/beehives, washing utensil	not specified	*
Erythrococca fischeri	fruit						
Eucalyptus saligna		firewood	small pocks			not specified, poles	
Eucalyptus sp.		firewood	measles			not specified, poles	*
Euclea divinorum	fruit, fodder	firewood			tooth brush	not specified, rafters	*
Euphorbia friesiorum			cattle				*
Euphorbia pulcherrima					ornamental		
Euphorbia tirucalli		firewood	fresh cuts, cattle, not specified				*
Fagaropsis hildebrandtii	fruit	firewood	stomach pain		tooth brush	rafters	
Ficus benjamina					ornamental		
Ficus natalensis	fodder	firewood		protects against hawks	cleaning water, ornamental, elastoplast, animal traps, attract rain	poles	*
Ficus stuhlmannii				arrow poison	shade	not specified	
Ficus sur	fodder	firewood			washing utensil, attract rain, shade		
Ficus sycomorus	fodder	firewood			attract rain, animal traps	not specified	
Ficus thonningii	fodder	firewood			cleaning water, attract rain		
Flacourtia indica	fodder	charcoal, firewood	toothache		mortar,		*
Flacourtia sp.	fruit						
Garcinia livingstonei	fruit		not specified		washing utensil		
Glycine wightii	fodder						
Grevillea robusta	fodder	firewood			shade, firesticks, tooth brush, gum	not specified, poles, furniture	*
Grewia similis		firewood					
Grewia similis or trichocarpa	fodder	firewood			traditional huts, ropes		
Grewia sp.	fodder	firewood					
Harungana madagascariensis	food colouring	charcoal, firewood				not specified, poles, rafters	
Helinus mystacinus							
Heteromorpha trifoliata							
Hibiscus flavifolius					ornamental		
Hibiscus fuscus	fodder	firewood			tooth brush		
Hibiscus sp.		firewood			ornamental		*
Hippocratea africana & Dregea schimperi					weaving, Calabashes		
Indigofera arrecta or swaziensis	fermentation						
Indigofera arrecta	fodder, soup		amoeba, stomach pain		traditional huts, animal traps, broom	rafters	*
Indigofera binderi	fodder, soup		amoeba, stomach pain		traditional huts, animal traps, broom	rafters	*
Indigofera lupatana	fodder, soup		amoeba, stomach pain		traditional huts, animal traps, broom	rafters	*

Species	Human & animal consumption	Fuel	Medicinal values	Rituals	Wood and other uses	Timber	BM
Indigofera swaziensis	fodder, soup		amoeba, stomach pain		traditional huts, animal traps, broom	rafters	*
Indigofera sp.?	fodder						
Ipomoea donaldsonii							
Ipomoea hildebrandti					ornamental		
Ipomoea indica					ornamental		
Jacaranda mimosaefolia	fodder	charcoal, firewood			plant support, honey/beehives, ornamental	not specified, poles, rafters	
Jasminum fluminense							
Jasminum sp.	fodder				ornamental		*
Jatropha curcas	fat		not specified, stomach pain				*
Juniperus procera		firewood			tooth brush, broom	not specified, poles, rafters	
Kigelia africana	fermentation, fruit		cattle, colds, malaria				
Lagenaria abyssinica	vegetable		fungus				
Lannea schimperi							
Lantana camara	fodder	firewood	cattle, colds		broom, ornamental	not specified, poles, rafters	*
Lantana trifolia		firewood	cattle, colds		bows		
Leucaena leucocephala	fodder	firewood					*
Leucas grandis							
Macadamia integrifolia	nuts, fat	firewood				poles	*
Macadamia tetraphylla	nuts, fat	firewood				poles	*
Maerua decumbens		firewood	fresh cuts				
Malus sp.	fruit						
Mangifera indica	fruit, fodder	charcoal, firewood				not specified, poles	
Manihot glaziovii	fodder, vegetable				ornamental, shade		
Markhamia lutea		firewood			soil fertility, shade, plant support	not specified, poles, rafters	
Melhania velutina			malaria				
Melia azedarach		firewood	cattle			not specified	
Melia volkensii		firewood	not specified, cattle, malaria			not specified	
Milicia excelsa	fodder	charcoal, firewood			soil fertility	not specified	
Millettia dura	fruit, fodder	firewood	cattle, malaria, colds		tool handles, plant support	not specified, poles, rafters	*
Millettia tanaensis		firewood				poles	*
Mitragyna rubrostipulata	fodder	firewood	not specified				*
Momordica foetida			colds		animal traps, biocide		
Monanthotaxis schweinfurthii	fodder	firewood				not specified	
Mondia whytei	soup		colds		animal traps, weaving		
Morus alba	fruit, fodder	firewood	not specified, aids				*
Mussaenda microdonta		firewood			animal traps	not specified	
Myrianthus holstii	fruit	firewood				poles	
Nerium oleander					ornamental, shade		
Newtonia buchananii		charcoal, firewood				not specified	
Ocimum kilimandscharicum	fruit		colds		honey/beehives, nice smell		
Ocimum suave	fodder, tea	firewood	colds, stomach pain		animal traps, broom, attract rain, honey/beehives		*
Olea capensis var. hochstetteri	fermentation, fodder	firewood	amoeba, malaria			not specified, poles	
Olea europaea	fodder	firewood	diarrhoea			not specified, poles	
Ozoroa insignis		charcoal, firewood					
Pachystela brevipes	fruit	firewood			tool handles	rafters	
Passiflora edulis	fruit						
Passiflora quadrangularis	fruit						
Passiflora sp.	fruit						

Species	Human & animal consumption	Fuel	Medicinal values	Rituals	Wood and other uses	Timber	BM
Pavonia patens							
Pavonia urens	fodder		pneumonia				
Pentas lanceolata			not specified, worms, stomach pain		animal traps, traditional huts		
Peponium vogelii					washing utensil		
Pergularia daemia	fodder, vegetable						
Persea americana	fruit, fodder	firewood			shade	not specified, poles	
Phyllanthus odontadenius							
Picea sp.					ornamental		
Pinus patula		firewood			paper	not specified	*
Pistacia aethiopica		charcoal, firewood				poles	
Plectranthus barbatus	fodder	firewood	cattle, fresh cuts, stomach pain, not specified, measles		soil fertility, toilet paper		*
Plumeria alba			fresh cuts, not specified		ornamental, tooth brush		
Prunus africana		firewood	not specified, old mans disease, throat		traditional huts, wedges	not specified, poles	*
Prunus salicina	fruit						
Psidium guajava	fruit, fodder	firewood				poles, rafters	
Psychotria kirkii	fruit	charcoal, firewood			plant support	not specified, rafters	*
Psychotria kirkii ?							
Psychotria kirkii var. nairobiensis		firewood			animal traps	not specified, rafters	
Psychotria kirkii var. tarambassica	soup	firewood	joints and bones				
Psydrax parviflora ssp. parviflora		firewood					
Punica granatum	fruit	firewood	not specified, aids				
Pycnostachius umbrosa			toothache, eye ailments, treat poisoning		animal traps		*
Pyrostegia venusta					ornamental		
Pyrus communis	fruit						
Rauvolfia caffra		charcoal, firewood	not specified, tuberculosis, diabetes, mental	carving (shields, scabbard)	tool handles, honey/beehives	not specified	
Rhoicissus tridentata							
Rhus ruspolii ?	fodder					poles, rafters	
Ricinus communis	fodder, fat, nuts	firewood	not specified, diarrhoea, cattle, fracture span, stomach pain			poles	
Rosa sp.					ornamental		*
Rosmarinus officinalis	soup						
Rothmannia urcelliformis	fruit						
Rubus scheffleri	fruit, fodder	firewood					*
Rumex abyssinicus	fodder, vegetable		cattle		whistle		
Saba comorensis	fruit						
Sambucus sp.					ornamental		
Sapium ellipticum	fodder				tool handles	not specified	
Schinus molle		firewood			ornamental, shade		
Senna bicapsularus							
Senna didymobotrya		firewood	measles, pneumonia, cattle, colds, swellings, not specified				*
Senna septemtrionalis		firewood	measles, pneumonia, cattle, colds, swellings, not specified				*
Senna siamea		firewood					
Senna spectabilis	fodder, fat	firewood			tooth brush, ornamental	rafters, not specified, poles	*
Sesbania sesban	fodder	firewood			biocide		
Sida tenuicarpa	fodder						
Solanecio angulatus	fodder						*
Solanecio mannii							
Solanecio sp.					ornamental		
Solanum incanum	fodder, soup		malaria, swellings, jiggers, not specified,	arrow poison,	biocide, catapult missiles		

Species	Human & animal consumption	Fuel	Medicinal values	Rituals	Wood and other uses	Timber	BM
			worms	offerings to Ngai			
Solanum nigrum	vegetable						
Spathodea campanulata		firewood			ornamental, honey/beehives, tool handles	not specified	
Stephania abyssinica					soil fertility		
Stereospermum kunthianum							
Strychnos henningsii	fodder	firewood	malaria				*
Syzygium guineense		charcoal, firewood			traditional huts	not specified, poles	
Syzygium guineense ssp. guineense		charcoal, firewood			traditional huts	not specified, poles	
Tabernaemontana ventricosa	fodder	firewood	colds, malaria, stomach pain, not specified		gum		
Tamarindus indica	fodder, fruit	firewood	joints and bones, asthma, aids		arrows		
Tapinanthus constrictiflorus							
Teclea simplicifolia?	fodder	firewood	cattle				
Telfairia pedata	fruit		stimulates old men				
Tephrosia vogelii			abortion, colds		biocide, animal traps		
Terminalia brownii	fruit	firewood			honey/beehives		
Terminalia catappa					ornamental		
Terminalia mantaly					ornamental, shade	not specified	
Terminalia sp.							
Terminalia sp. ?							
Tetradenia riparia	fodder		cattle, fresh cuts, stomach pain, worms, pneumonia		plant support, soil fertility		*
Theobroma cacao							
Thevetia peruviana					ornamental		
Tipuana tipu							
Tithonia diversifolia	fodder		fertility, worms		soil fertility, ornamental, biocide, tooth brush		*
Trema orientalis	fodder	firewood	cattle				
Trichilia emetica		firewood	not specified, stomach pain, colds, amoeba, worms, cattle, joints and bones		soil fertility	not specified	
Triumfetta rhomboidea							
Triumfetta tomentosa	fodder	firewood			ropes, toilet paper, firesticks, bark on fire to scare bees		*
Vangueria madagascariensis	fruit	firewood	not specified, stomach pain		animal traps, plant support	poles, rafters	*
Vangueria sp.?					animal traps	not specified	
Vernonia auriculifera	ripening bananas	firewood	stomach pain		soil fertility		
Vernonia brachycalyx							
Vernonia lasiopus	fodder	firewood	stomach pain		soil fertility, tooth brush	rafters	
Viscum fischeri							
Viscum sp.							
Vitex fischeri	fruit	firewood			shade, soil fertility	not specified, furniture	*
Vitis sp.	fruit						
Waltheria indica	fodder						
Zanthoxylum gilletii			malaria				
Zanthoxylum usambarense			malaria				*
Zehneria scabra or Cucumis sp.	fodder, fruit		cattle, toothache				*
Ziziphus abyssinica		firewood		protection against hawks			*

BM= boundary marker; * species is used as boundary marker; ‘or’ the species could not be distinguished in the field; ‘&’ All species were identified, but practical constraints prohibited to distinguish individuals; ‘?’ Species identity unsure

Appendix 8: Species uses as known by Meru farmers (ordered by local name).

Local species name°	Species	Human & animal consumption	Fuel	Medicinal values	Rituals	Timber	Other uses	BM
Apple tree (t)	Malus sp.	fruit						
Bottlebrush (t)	Callistemon citrinus var. splendens						ornamental	*
Buganville (t)	Bougainvillea glabra						ornamental, shade, weddings	*
Calliandra (t)	Calliandra calothyrsus	fodder					ornamental	
Cashew nut (t)	Anacardium occidentale	nuts						
Cassava tree (t)	Manihot glaziovii	fodder, vegetable					ornamental, shade	
Castor oil (t)	Ricinus communis	fodder, fat, nuts	firewood	not specified, diarrhoea, cattle, fracture span, stomach pain		poles		
Casuarina (t)	Casuarina equisetifolia		firewood			not specified, poles	ornamental	*
Chesiseiyey (k)	Erythrococca fischeri	fruit						
Coffee (stand)	Coffea spp.	coffee beans	firewood			rafters	plant support	
Devils horsewhip (t)	Achyranthes aspera	fodder	firewood	toothache				*
Flame tree (t)	Spathodea campanulata		firewood			not specified	ornamental, honey/beehives, tool handles	
Frangipane (t)	Plumeria alba			fresh cuts, not specified			ornamental, tooth brush	
Gatamba nanthi	Stephania abyssinica						soil fertility	
Gatiki	Sida tenuicarpa	fodder						
Gaturutua		fodder		cattle				
Gazurai	Commiphora sp. ?			malaria			honey/beehives	
Giant passionfruit (t)	Passiflora quadrangularis	fruit						
Gicabi	Melhania velutina			malaria				
Golden shower (t)	Pyrostegia venusta						ornamental	
Grapefruit (t)	Citrus x paradisi	fruit						
Guava (t)	Psidium guajava	fruit, fodder	firewood			poles, rafters		
Haraka	Lantana camara	fodder	firewood	cattle, colds		not specified, poles, rafters	broom, ornamental	*
Hibiscus (t)	Hibiscus flavifolius						ornamental	
Hibiscus (t)	Hibiscus sp.		firewood				ornamental	*
Israeli Custard Apple (t)	Annona muricata	fruit						
Jackfruit (t)	Artocarpus heterophyllus	fruit						
Kabubu	Acacia albida		firewood					
Kagombagombwe	Pergularia daemia	fodder, vegetable						
Kagwata ng'ondu	Cyatula uncinulata	fodder						
Kamugu	Cucumis dipsaceus							
Kamunguru	Lagenaria abyssinica	vegetable		fungus				
Kanyiri	Carphalea glaucescens?			cattle			broom, biocide	*
Kariamungu	Coccinia adoensis	vegetable						
Kariginana	Cissampelos mucronata			stomach pain				
Karugoya (=Ruogoya)							animal traps	
Kaua	Coffea spp.	coffee beans	firewood			rafters	plant support	
Kaungunjwe	Zehneria scabra or Cucumis sp.	fodder, fruit		cattle, toothache				*
Kayebe	Dovyalis caffra	fruit						*
Kebota							ornamental	
Kei-apple (t)	Dovyalis caffra	fruit						*
Kejana	Caesalpinia decapetala		firewood	not specified				*
Kiaraka	Tetradenia riparia	fodder		cattle, fresh cuts, stomach pain, worms, pneumonia			plant support, soil fertility	*
Kiarankware	Clerodendrum johnstonii	fodder	firewood	stomach pain, cattle		rafters	animal traps, hooks, weaving	*

Local species name°	Species	Human & animal consumption	Fuel	Medicinal values	Rituals	Timber	Other uses	BM
Kiea	Viscum sp.							
Kijara	Plectranthus barbatus	fodder	firewood	cattle, fresh cuts, stomach pain, not specified, measles			soil fertility, toilet paper	*
Kijijo	Triumfetta tomentosa	fodder	firewood				ropes, toilet paper, firesticks, bark on fire to scare bees	*
Kimeru	Passiflora quadrangularis	fruit						
Kimukwaacii	Manihot glaziovii	fodder, vegetable					ornamental, shade	
Kinunka	Momordica foetida			colds			animal traps, biocide	
Kirao	Senna septemtrionalis & didymobotrya		firewood	measles, pneumonia, cattle, colds, swellings, not specified				*
Kirao	Senna siamea		firewood					
Kiroo	Dovyalis abyssinica	fruit	firewood	colds			needle	*
Kukumanga	Punica granatum	fruit	firewood	not specified, aids				
Local neem (t)	Melia volkensii		firewood	not specified, cattle, malaria		not specified		
Lukina	Leucaena leucocephala	fodder	firewood					*
M(w)/(u)arubaine	Melia azedarach		firewood	cattle		not specified		
Maatha	Tithonia diversifolia	fodder		fertility, worms			soil fertility, ornamental, biocide, tooth brush	*
Maboru	Pycnostachius umbrosa			toothache, eye ailments, treat poisoning			animal traps	*
Macadamia (t)	Macadamia integrifolia	nuts, fat	firewood			poles		*
Macadamia (t)	Macadamia tetraphylla	nuts, fat	firewood			poles		*
Maguta	Eucalyptus saligna		firewood	small pocks		not specified, poles		
Majara	Plectranthus barbatus	fodder	firewood	cattle, fresh cuts, stomach pain, not specified, measles			soil fertility, toilet paper	*
Makonge	Dracaena sp.						ropes	
Makuri	Ocimum kilimandscharicum	fruit		colds			honey/beehives, nice smell	
Mango (t)	Mangifera indica	fruit, fodder	charcoal, firewood			not specified, poles		
Maoru	Pycnostachius umbrosa			toothache, eye ailments, treat poisoning			animal traps	*
Marabai	Croton megalocarpus	fodder	charcoal, firewood	cattle, treat poisoning, fresh cuts		not specified, poles	ornamental, shade	*
Marajgu	Solanum nigrum	vegetable						
Mataratare	Rubus scheffleri	fruit, fodder	firewood					*
Mataratare	Vitis sp.	fruit						
Matunda ya ndamu	Cyphomandra betacea	tenderising meat, fruit	firewood					
Matutei	Duosperma kilimandscharica	vegetable						
Mbela	Psidium guajava	fruit, fodder	firewood			poles, rafters		
Menu	Abrus fruticulosus							
Metonguu	Citrus limon	fruit, fermentation, soup		not specified, malaria, joints and bones				
Meungo	Saba comorensis	fruit						
Mioru	Pycnostachius umbrosa			toothache, eye ailments, treat poisoning			animal traps	*
Miraa	Catha edulis	stimulant		not specified				
Mistletoe (t)	Viscum sp.							
Miurama	Combretum molle	fodder	charcoal, firewood	fracture span, swellings		not specified		*
Mogu	Markhamia lutea		firewood			not specified, poles, rafters	soil fertility, shade, plant support	
Moonflower (t)	Datura candida		firewood				ornamental	
Muambanare (= Muambanj?re)			firewood					*
Muambanj?re			firewood					*

Local species name°	Species	Human & animal consumption	Fuel	Medicinal values	Rituals	Timber	Other uses	BM
(=Muambanare)								
Muambura	Crotalaria goodiiformis						ropes	
Muaraka	Tetradenia riparia	fodder		cattle, fresh cuts, stomach pain, worms, pneumonia			plant support, soil fertility	*
Muarankware	Clerodendrum johnstonii	fodder	firewood	stomach pain, cattle		rafters	animal traps, hooks, weaving	*
Muari	Pycnostachius umbrosa			toothache, eye ailments, treat poisoning			animal traps	*
muariki	Ricinus communis	fodder, fat, nuts	firewood	not specified, diarrhoea, cattle, fracture span, stomach pain		poles		
Muarubaine	Azadirachta indica			not specified				
Muatha	Vernonia lasiopus	fodder	firewood	stomach pain		rafters	soil fertility, tooth brush	
Mubaibai	Carica papaya	fruit, tenderising meat, fodder, soup	firewood	sexual transitional diseases, stomach pain, amoeba, not specified				
Mubariki	Jatropha curcas	fat		not specified, stomach pain				*
Mubau	Eucalyptus sp.		firewood	measles		not specified, poles		*
Mubau muta	Eucalyptus saligna		firewood	small pocks		not specified, poles		
Mubera	Psidium guajava	fruit, fodder	firewood			poles, rafters		
Mubiribiri	Garcinia livingstonei	fruit		not specified			washing utensil	
Mubiru	Psychotria kirkii	fruit	charcoal, firewood			not specified, rafters	plant support	*
Mubiru	Vangueria madagascariensis	fruit	firewood	not specified, stomach pain		poles, rafters	animal traps, plant support	*
Mubono	Plumeria alba			fresh cuts, not specified			ornamental, tooth brush	
Muboru				toothache				
Mucababunduki	Spathodea campanulata		firewood			not specified	ornamental, honey/beehives, tool handles	
Mucakaranda (k)	Jacaranda mimosaefolia	fodder	charcoal, firewood			not specified, poles, rafters	plant support, honey/beehives, ornamental	
Mucamaru	Grewia sp.	fodder	firewood					
Mucambe	Strychnos henningsii	fodder	firewood	malaria				*
Mucebe	Spathodea campanulata		firewood			not specified	ornamental, honey/beehives, tool handles	
Mucegene	Achyranthes aspera	fodder	firewood	toothache				*
Muchomoro	Lantana camara	fodder	firewood	cattle, colds		not specified, poles, rafters	broom, ornamental	*
Mucimoko	Annona cherimola	fruit	firewood	cattle				
Mucone	Diospyros mespiliformis	fodder	charcoal, firewood			not specified, poles, rafters		
Mucugu	Sesbania sesban	fodder	firewood				biocide	
Mucugucugu	Crotalaria incana var. purpurascens & brevidens var. parviflora						soil fertility	
Mucugucugu	Crotalaria lachnocarpoides	fodder						
Mucugucugu	Tephrosia vogelii			abortion, colds			biocide, animal traps	
Mucunkwa	Citrus sinensis	fruit						
Mucurai	Acacia hockii		firewood	not specified				*
Muerere	Tabernaemontana ventricosa	fodder	firewood	colds, malaria, stomach pain, not specified			gum	
Mueria	Prunus africana		firewood	not specified, old mans disease, throat		not specified, poles	traditional huts, wedges	*
Muethu	Trema orientalis	fodder	firewood	cattle				
Mugaa	Acacia albida		firewood					
Mugaa-njuki	Monanthotaxis schweinfurthii	fodder	firewood			not specified		
Mugaigai	Cyphostemma bambusati	fodder	firewood	worms, cattle		rafters		*
Mugandagandu	Bauhinia tomentosa	fodder	firewood			rafters	tool handles	
Mugimbi	Psychotria kirkii	fruit	charcoal, firewood			not specified, rafters	plant support	*

Local species name°	Species	Human & animal consumption	Fuel	Medicinal values	Rituals	Timber	Other uses	BM
Mugimbi	Psychotria kirkii var. tarambassica	soup	firewood	joints and bones				
Mugio (k)	Ocimum suave	fodder, tea	firewood	colds, stomach pain			animal traps, broom, attract rain, honey/beehives	*
Mugocwa	Zanthoxylum gilletii			malaria				
Mugu	Dalbergia lactea						weaving, ropes	
Mugu	Mondia whytei	soup		colds			animal traps, weaving	
Mugu	Calpurnia aurea						weaving	
Mugu	Dregea schimperi & Hippocratea africana						weaving, Calabashes	
Mugui	Newtonia buchananii		charcoal, firewood			not specified		
Mugumo	Ficus natalensis	fodder	firewood		protects against hawks	poles	cleaning water, ornamental, elastoplast, animal traps, attract rain	*
Mugumue	Grewia sp.	fodder	firewood					
Mugumwa	Grewia sp.	fodder	firewood					
Mugundire				not specified				
Mugundugundu	Indigofera sp.?	fodder						
Mugwata ng'ondu	Cyatula uncinulata	fodder						
Muhuti	Erythrina abyssinica	fodder	firewood	not specified, cattle, fresh cuts, amoeba, colds	carving (shields, scabbard)	not specified	carvings, plant support, tool handles, firesticks, honey/beehives, washing utensil	*
Muirontue	Vangueria sp.?					not specified	animal traps	
Muiru	Vangueria madagascariensis	fruit	firewood	not specified, stomach pain		poles, rafters	animal traps, plant support	*
Muithia					arrow poison		bowes, animal traps	
Mujana	Caesalpinia decapetala		firewood	not specified				*
Mujijo	Triumfetta tomentosa	fodder	firewood				ropes, toilet paper, firesticks, bark on fire to scare bees	*
Mujua	Ficus stuhlmannii				arrow poison	not specified	shade	
Mujuthi	Caesalpinia volkensii			malaria				
Mukambura	Flacourtia sp.	fruit						
Mukandakandu	Ocimum suave	fodder, tea	firewood	colds, stomach pain			animal traps, broom, attract rain, honey/beehives	*
Mukandu	Ocimum suave	fodder, tea	firewood	colds, stomach pain			animal traps, broom, attract rain, honey/beehives	*
Mukao	Dombeya torrida	fodder	firewood				ropes	*
Mukawa	Carissa spinarum	fruit, soup		not specified, toothache			ornamental	*
Mukenya	Senna spectabilis	fodder, fat	firewood			rafters, not specified, poles	tooth brush, ornamental	*
Mukeu	Dombeya torrida	fodder	firewood				ropes	*
Mukibia	Fagaropsis hildebrandtii	fruit	firewood	stomach pain		rafters	tooth brush	
Mukima	Grevillea robusta	fodder	firewood			not specified, poles, furniture	shade, firesticks, tooth brush, gum	*
Mukinduri (k)	Croton megalocarpus	fodder	charcoal, firewood	cattle, treat poisoning, fresh cuts		not specified, poles	ornamental, shade	*
Mukira muthua	Psychotria kirkii	fruit	charcoal, firewood			not specified, rafters	plant support	*
Mukira muthua	Psychotria kirkii var. nairobiensis		firewood			not specified, rafters	animal traps	
Mukirinyai	Euclea divinorum	fruit, fodder	firewood			not specified, rafters	tooth brush	*
Mukirithia		fodder		toothache			tooth brush	
Mukithia	Fagaropsis hildebrandtii	fruit	firewood	stomach pain		rafters	tooth brush	
Mukola	Combretum sp.			not specified				
Mukomere	Rothmannia urcelliformis	fruit						
Mukoro	Diospyros mespiliformis	fodder	charcoal, firewood			not specified, poles, rafters		

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Mukua	Ficus sycomorus	fodder	firewood			not specified	attract rain, animal traps	
Mukueci we mbio	Manihot glaziovii	fodder, vegetable					ornamental, shade	
Mukuengwe	Bridelia micrantha	fodder	charcoal, firewood	general health		not specified, poles	plant support	*
Mukui	Newtonia buchananii		charcoal, firewood			not specified		
Mukuma	Hibiscus fuscus	fodder	firewood				tooth brush	
Mukumu mwnga	Punica granatum	fruit	firewood	not specified, aids				
Mukundukundu	Mitragyna rubrostipulata	fodder	firewood	not specified				*
Mukununu	Ozoroa insignis		charcoal, firewood					
Mukuo	Cordia monoica		firewood			not specified, poles	washing utensil	
Mukuru(w)e (k)	Albizia amara	fodder, ripening bananas	charcoal, firewood			not specified		
Mukuru(w)e (k)	Albizia gummifera		charcoal, firewood			not specified	ornamental, shade	
Mukurungu	Duranta erecta		firewood	malaria		rafters	plant support	*
Mukuruu	Albizia amara	fodder, ripening bananas	charcoal, firewood			not specified		
Mukuruu	Albizia gummifera		charcoal, firewood			not specified	ornamental, shade	
Mukuu	Ficus sur	fodder	firewood				washing utensil, attract rain, shade	
Mukuura	Mondia whytei	soup		colds			animal traps, weaving	
Mukwego	Bridelia micrantha	fodder	charcoal, firewood	general health		not specified, poles	plant support	*
Munampithia			firewood					
Munati	Maerua decumbens		firewood	fresh cuts				
Mung'ana	Tithonia diversifolia	fodder		fertility, worms			soil fertility, ornamental, biocide, tooth brush	*
Mungwani	Markhamia lutea		firewood			not specified, poles, rafters	soil fertility, shade, plant support	
Munoa (k)	Pachystela brevipes	fruit	firewood			rafters	tool handles	
Munogo	Casearia battiscombei	fruit	firewood			not specified		
Munonanthenge	Rhus ruspolii ?	fodder				poles, rafters		
Munorianthenge	Solanecio angulatus	fodder						*
Munuruku	Terminalia sp.							
Munyamwe	Harungana madagascariensis	food colouring	charcoal, firewood			not specified, poles, rafters		
Munyna cubu	Psychotria kirkii var. tarambassica	soup	firewood	joints and bones				
Munyoronyoro	Diospyros mespiliformis	fodder	charcoal, firewood			not specified, poles, rafters		
Munyua cubu	Psychotria kirkii	fruit	charcoal, firewood			not specified, rafters	plant support	*
Muondoe	Pavonia urens	fodder		pneumonia				*
Muoru	Pycnostachius umbrosa			toothache, eye ailments, treat poisoning			animal traps	*
Muraga	Flacourtia indica	fodder	charcoal, firewood	toothache			mortar,	*
Muraiguna	Rumex abyssinicus	fodder, vegetable		cattle			whistle	
Murama	Combretum molle	fodder	charcoal, firewood	fracture span, swellings		not specified		*
Murana	Juniperus procera		firewood			not specified, poles, rafters	tooth brush, broom	
Murangare	Zehneria scabra or Cucumis sp.	fodder, fruit		cattle, toothache				*
Murangi	Arundinaria alpina							
Murantina	Kigelia africana	fermentation, fruit		cattle, colds, malaria				
Muratha iiga	Psydrax parviflora ssp. parviflora		firewood					
Muratha njuki	Flacourtia indica	fodder	charcoal, firewood	toothache			mortar,	*
Murema muthua (k)	Mussaenda microdonta		firewood			not specified	animal traps	
Mureman(gigi)(gugu)	Euphorbia tirucalli		firewood	fresh cuts, cattle, not specified				*
Murembu	Ehretia cymosa	fodder	charcoal, firewood	cattle		not specified, poles, rafters	plant support, tool handles	

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Murenda	Grewia similis		firewood					
Murenda	Grewia similis or trichocarpa	fodder	firewood				traditional huts, ropes	
Murera	Acacia xanthophloea							*
Mureranjau	Pavonia urens	fodder		pneumonia				
Murierie	Milicia excelsa	fodder	charcoal, firewood			not specified	soil fertility	
Murigi	Peponium vogelii						washing utensil	
Murigurigu	Anthocleista grandiflora		firewood	colds		not specified	animal traps	
Murimuu	Citrus limon	fruit, fermentation, soup		not specified, malaria, joints and bones				
Murinda ngengurwi	Waltheria indica	fodder						
Muringa	Cordia africana	fodder	firewood	cattle, colds, fracture span		not specified, furniture	ropes, bark on fire to scare bees, honey/beehives, firesticks, tool handles	
Muriru	Syzygium guineense ssp. guineense		charcoal, firewood			not specified, poles	traditional huts	
Murogorogo	Cussonia holstii	fodder	firewood		carving (shields, scabbard)	not specified	plant support	*
Muroo	Dovyalis abyssinica	fruit	firewood	colds			needle	*
Muruai	Acacia hockii		firewood	not specified				*
Murui	Acacia seyal							
Muruirii	Zanthoxylum usambarense			malaria				*
Murungati (k)	Eriobotrya japonica	fruit, fodder	firewood			rafters, poles		*
Murure / Murule (s)	Milicia excelsa	fodder	charcoal, firewood			not specified	soil fertility	
Mururi	Syzygium guineense ssp. guineense		charcoal, firewood			not specified, poles	traditional huts	
Mururu	Acokanthera schimperi	fruit, fodder	firewood		arrow poison	not specified, poles	plant support	*
Musala				not specified				*
Musungiri (k)	Sesbania sesban	fodder	firewood				biocide	
Mutandanderi	Ziziphus abyssinica		firewood		protection against hawks			*
Mutanta	Ficus thonningii	fodder	firewood				cleaning water, attract rain	
Mutarakwa	Cupressus lusitanica		firewood			not specified, rafters	ornamental	*
Mutaratare	Morus alba	fruit, fodder	firewood	not specified, aids				*
Mutaria								
Mutendera	Stereospermum kunthianum							
Muteretu	Teclea simplicifolia?	fodder	firewood	cattle				
Mutero	Olea capensis var. hochstetteri	fermentation, fodder	firewood	amoeba, malaria		not specified, poles		
Muthaara	Indigofera arrecta & binderi & lupatana & swaziensis	fodder, soup		amoeba, stomach pain		rafters	traditional huts, animal traps, broom	*
Muthakwa	Vernonia auriculifera	ripening bananas	firewood	stomach pain			soil fertility	
Muthamu	Flacourtia indica	fodder	charcoal, firewood	toothache			mortar,	*
Muthandathande	Bersama abyssinica ssp. abyssinica		charcoal, firewood			poles	wedges, honey/beehives	*
Muthanduku	Acacia mearnsii		charcoal, firewood			not specified, poles, rafters, furniture, e		
Muthanduru	Telfairia pedata	fruit		stimulates old men				
Muthankume	Pachystela brevipes	fruit	firewood			rafters	tool handles	
Muthankume	Syzygium guineense ssp. guineense		charcoal, firewood			not specified, poles	traditional huts	
Muthari	Dracaena steudneri	fodder		not specified, colds	slaughter on a bed of leaves			

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Muthath(i)(a)	Sapium ellipticum	fodder				not specified	tool handles	
Muthatha	Olea europaea	fodder	firewood	diarrhoea		not specified, poles		
Muthatha	Cordia ? monoica							
Muthati itema			firewood				sieve (basket)	
Muthenthea	Pachystela brevipes	fruit	firewood			rafters	tool handles	
Mutheriga	Psychotria kirkii	fruit	charcoal, firewood			not specified, rafters	plant support	*
Mutheriga	Psychotria kirkii var. nairobiensis		firewood			not specified, rafters	animal traps	
Muthigi (k)	Cordia monoica		firewood			not specified, poles	washing utensil	
Muthigio?(k)	Commiphora sp.	fodder, fruit	firewood					
Muthii	Cordia monoica		firewood			not specified, poles	washing utensil	
Muthingiri	Pistacia aethiopica		charcoal, firewood			poles		
Muthiriti	Lantana trifolia		firewood	cattle, colds			bows	
Muthithinda	Cupressus lusitanica		firewood			not specified, rafters	ornamental	*
Muthithio	Commiphora sp.	fodder, fruit	firewood					
Muthithiu	Tamarindus indica	fodder, fruit	firewood	joints and bones, asthma, aids			arrows	
Muthiti	Terminalia brownii	fruit	firewood				honey/beehives	
Muthrithia	Lantana trifolia		firewood	cattle, colds			bows	
Muthumuki	Terminalia brownii	fruit	firewood				honey/beehives	
Muthunthuri	Garcinia livingstonei	fruit		not specified			washing utensil	
Muthuuri	Euphorbia friesiorum			cattle				*
Muthuuri	Euphorbia tirucalli		firewood	fresh cuts, cattle, not specified				*
Muti	Aspilia mossambicencis	fodder						
Mutirankongu		fodder	firewood				honey/beehives	
Mutomboro	Solanecio mannii							
Mutongu	Solanum incanum	fodder, soup		malaria, swellings, jiggers, not specified, worms	arrow poison, offerings to Ngai		biocide, catapult missiles	
Mutonto	Croton macrostachyus	ripening bananas, fodder	charcoal, firewood	cattle, fresh cuts, throat	dance for curing disease	not specified, furniture	plant support	*
Mutoo	Azanza garckeana	fodder, fruit	firewood	stomach pain		not specified	tool handles, I	
Mutoro?	Olea capensis var. hochstetteri	fermentation, fodder	firewood	amoeba, malaria		not specified, poles		
Mutoronboro	Carphalea glaucescens?			cattle			broom, biocide	*
Mutuati	Trichilia emetica		firewood	not specified, stomach pain, colds, amoeba, worms, cattle, joints and bones		not specified	soil fertility	
Mutuhutu	Cyphostemma bambusati	fodder	firewood	worms, cattle		rafters		*
Mutunda	Casimiroa edulis	fruit						
Mutundu	Croton sylvaticus			cattle			attract rain	
Mutungugu	Commiphora eminii	fodder	firewood	cattle	bowls for fire with Mujijo sticks	poles	plant support, soil fertility, combs, spoons	*
Mutuntu	Croton macrostachyus	ripening bananas, fodder	charcoal, firewood	cattle, fresh cuts, throat	dance for curing disease	not specified, furniture	plant support	*
Muturiawiga								
Muturutua								
Muturutua	Solanecio angulatus	fodder						*
Mutuu	Rauvolfia caffra		charcoal, firewood	not specified, tuberculosis, diabetes, mental	carving (shields, scabbard)	not specified	tool handles, honey/beehives	
Mutuuma	Desmodium repandum or adscendens	fodder						

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Mutuuma	Glycine wightii	fodder						
Mutuya	Myrianthus holstii	fruit	firewood			poles		
Muu (k)	Markhamia lutea		firewood			not specified, poles, rafters	soil fertility, shade, plant support	
Muumia	Pentas lanceolata			not specified, worms, stomach pain			animal traps, traditional huts	
Muuru	Vitex fischeri	fruit	firewood			not specified, furniture	shade, soil fertility	*
Muuti	Erythrina abyssinica	fodder	firewood	not specified, cattle, fresh cuts, amoeba, colds	carving (shields, scabbard)	not specified	carvings, plant support, tool handles, firesticks, honey/beehives, washing utensil	*
Mwabokando	Persea americana	fruit, fodder	firewood			not specified, poles	shade	
Mwangua	Millettia dura	fruit, fodder	firewood	cattle, malaria, colds		not specified, poles, rafters	tool handles, plant support	*
Mwangua	Millettia tanaensis		firewood			poles		*
Mwembe	Mangifera indica	fruit, fodder	charcoal, firewood			not specified, poles		
Mweng(j)eng(j)e	Dracaena sp.2	fodder		colds				
Mwenjera	Cussonia holstii	fodder	firewood		carving (shields, scabbard)	not specified	plant support	*
Mwethia	Crotalaria sp. (agatiflora ?)						soil fertility	
Mwimba muthumbi	Clematis brachiata	fodder		colds, throat, headache				*
Ndaru	Euphorbia tirucalli		firewood	fresh cuts, cattle, not specified				*
nGaigai	Cyphostemma bambusati	fodder	firewood	worms, cattle		rafters		*
Nthnth		fruit		not specified				
Ntunda cia mingu	Passiflora edulis	fruit						
Oleander (t)	Nerium oleander						ornamental, shade	
Oyster nut (t)	Telfairia pedata	fruit		stimulates old men				
Passion fruit (t)	Passiflora sp.	fruit						
Pawpaw (t)	Carica papaya	fruit, tenderising meat, fodder, soup	firewood	sexual transitional diseases, stomach pain, amoeba, not specified				
Pear (t)	Pyrus communis	fruit						
Pilipili (t)	Capsicum sp.	vegetable, spice						
Plum (t)	Prunus salicina	fruit						
Pomegranate (t)	Punica granatum	fruit	firewood	not specified, aids				
Riungoo	Indigofera arrecta or swaziensis	fermentation						
Rose (t)	Rosa sp.						ornamental	*
Rosemary (t)	Rosmarinus officinalis	soup						
Ruogoya (=Karugoya)							animal traps	
Sierra rubber (t)	Manihot glaziovii	fodder, vegetable					ornamental, shade	
Thevetia (t)	Thevetia peruviana						ornamental	
Thiina	Erianthemum dregei							
Umbrella tree (t)	Terminalia mantaly					not specified	ornamental, shade	
Wait-a-bit thorn (t)	Acacia brevispica							*
Yesterdaytodaytomorrow (t)	Brunfelsia australis						ornamental	
ornamental							ornamental	
	Acalypha sp.						ornamental	
	Acrocarpus fraxinifolius		firewood			not specified		
	Chrysanthenum sp.						ornamental	
	Cupressus sempervirens var. piramidalis						ornamental	
	Euphorbia pulcherrima						ornamental	
	Ficus benjamina						ornamental	
	Ipomoea hildebrandti						ornamental	

Local species name°	Species	Human & animal consumption	Fuel	Medicinal values	Rituals	Timber	Other uses	BM
	Ipomoea indica						ornamental	
	Jasminum sp.	fodder					ornamental	*
	Picea sp.						ornamental	
	Pinus patula		firewood			not specified	paper	*
	Psychotria kirkii ?							
	Sambucus sp.						ornamental	
	Schinus molle		firewood				ornamental, shade	
	Solanecio sp.						ornamental	
	Syzygium guineense		charcoal, firewood			not specified, poles	traditional huts	
	Terminalia catappa						ornamental	

(t) Trade name, usually English or Kiswahili; (k) Kikuyu name; BM= boundary marker; * species is used as boundary marker; 'or' the species could not be distinguished in the field; '&' All species were identified, but practical constraints prohibited to distinguish individuals; '?' Species identity unsure

° In Ki-Meru most tree species names start with 'Mu' or 'Mi'. For some tree species the names are in plural, these species are the lianas and some minor (small) species and their names start with 'Ku' or 'Ki'. All names have been recorded, where applicable both singular & plural forms of tree names are mentioned in the list.

Appendix 9: Tree species uses recorded in the Meru tree inventory.

Human & animal consumption
Coffee beans
Fat
Fermentation
Fodder
Food colouring
Fruit
Nuts
Ripening bananas
Soup
Spice
Stimulant
Tea
Tenderising meat
Vegetable

Timber
Furniture
Poles
Rafters
Use not specified

Fuel
Charcoal
Firewood

Services
Attract rain
Boundary marker
Nice smell
Ornamental
Shade
Soil fertility
Wedding rituals

Wooden products and others
Animal traps
Arrows
Bark on fire to scare bees
Biocide
Bows
Broom
Calabashes
Carvings
Catapult missiles
Cleaning water
Combs
Elastoplast
Firesticks
Gum
Honey/beehives
Hooks
Mortar
Needle
Paper
Plant support
Ropes
Sieves
Spoons
Tannin
Toilet paper
Tool handles
Toothbrush
Traditional huts
Washing utensil
Weaving
Wedges
Whistles

Medicinal values
Abortion
Aids
Amoebae
Asthma
Cattle
Colds
Diabetes
Diarrhea
Eye ailments
Fertility
Fracture span
Fresh cuts
Fungus
General health
Headache
Jiggers
Joints and bones
Malaria
Measles
Mental
Old mans disease (urinate)
Pneumonia
Sexual transitional disease
Small pocks
Stimulates old man (Aphrodisiac)
Stomach pain
Swellings
Throat
Toothache
Cure poisoning
Tuberculosis
Use not specified
Worms

Appendix 10: Tree inventory forms.

Tree details form

Farmer……………………………….Village: Igoji/Kigane/Ncoroiboro. Date:…………… Sheet … of ….

Code/name	Niche	Germpl	Prov	Age	form	DbH	Repr cap	Multiple	Remarks

Species details form

Farmer……………………………….Village: Igoji/Kigane/Ncoroiboro. Date:…………… Sheet … of ….

Code	Ki-Meru name	Uses / Consumed at home, sold or both										Remarks

Codes for tree and species forms

code	**niche**
99	other
cb	crop boundary
cl	cropland
cof	coffee garden
eb	external boundary
fal	fallow
hd	hedge
hg	homegarden
hs	homestead
ib	internal boundary
wl	woodlot

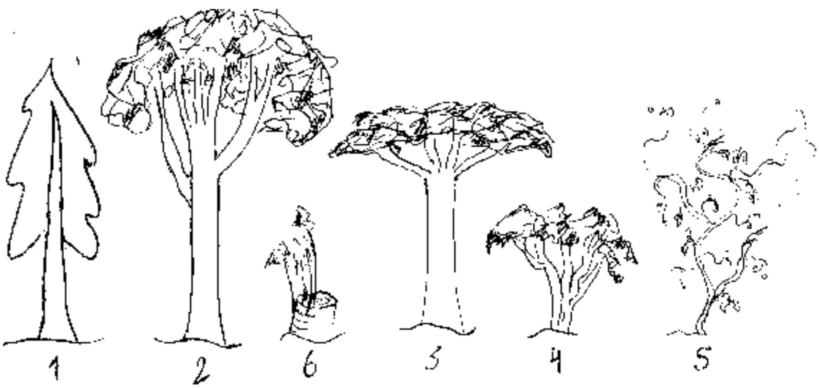
code	**provenance**
?	not known
1	on farm
2	local
3	far
99	other

code	**germplasm**
?	do not know
cu	cutting
ds	direct seeded
fr	forest remnant
O	other (specify)
sf	seedling produced off farm
sn	seedling produced on farm
tw	transplanted wilding
wd	wilding

code	**Reproductive capacity**
?	do not know
ag	unable due to age
al	unable due to altitude
fl	able to flower
O	other (specify)
pr	unable due to management
se	able to seed

Tree shape classes (form)

1 cylindrical, 2 forked, 3 umbrella, 4 shrub, 5 climber, 6 coppicing stump



Appendix 11: Meru diversity study questionnaires.

Questionnaire starts with explaining its purpose and permission. Main language Ki-Meru.

Trial

1st planting round

Individual questionnaires

Name farmer, village, GPS co-ordinates, questionnaire number & date

Bao game exercise for 7 species
Score of species
Did you know this species already?
Do you have this species on farm?
What species would you like for the second round?
Do you have a nursery?
Do you sometimes raise trees yourself?
Which species do you raise?
Do you buy trees at nurseries?
Which species do you buy?

Group discussion and monitoring
Performance of the species
What species (or uses) for the 2nd round?
The way forward?

2nd planting round

Group discussion and monitoring
Performance of the species
The way forward?

3rd planting round

Individual questionnaires

Name farmer, village, GPS co-ordinates, questionnaire number & date

Bao game exercise for 17 species
Score of species
Did you know this species already?
Did you use *Warburgia ugandensis*?
Did you use *Tephrosia vogelii*?
Do you have this species on farm?
Discussion on what to do next

Group discussion and monitoring
Performance of the species
The way forward?

4th planting round

Individual questionnaires
Name farmer, village, questionnaire number and date
Bao game exercise for 25 to 27 species
Score of species
Did you know this species already?
Do you have this species on farm?
If you do not have this species on farm, why did you not plant it before?
Discussion on what species next

Group discussion and monitoring
Performance of the species
Towards finalisation

5th planting round

Individual questionnaires
Name farmer, village, questionnaire number & date

Bao game exercise for 27 to 31 species
Species scores

Group meetings
Final meeting, evaluation and goodbye parties

Diversity questionnaire

Name farmer, village, date, and questionnaire number

Why do you have a range of tree species?

If I would give you three seedlings, what would you like three of the same species or seedlings from three species? (visualise with Bao stones)

If I would give you three seedlings of a [insert use group] species, what would you like three of the same species or seedlings from three species (Ask for 2 - 4 use groups, such as Cash, Firewood, Timber, Fruit, Medicine & Fodder) Continue to zero down on response.

We noticed that someone cut down a *Melia azadarach* tree on the farm because according to the farmer with Neem on his farm he did not need that species anymore. Have you removed a species from the farm because we brought another species or are you planning to do so?

(Ask this question in 'the third person' – less confrontational and more honest answers) If we would give farmers a species that would not do well here, would you think they would plant it? Even if they knew it was bad?

How would you score for uses of trees? Bao ranking exercise with use groups, Fruit, Timber, Medicine, Fodder, Firewood, Soil. Please add any other use you want.

Individual evaluation

Name farmer, village, date, and questionnaire number

If we would have to start the whole trial all over again with other farmers, what would you advise us?

What - in your opinion - should we still do before this part of the trial ends?

Without giving any false promises from our side we would like to ask you: How would you like to see our collaboration continued?

Thanks again for your time and answering our questions, do you have any comments, questions, and remarks?

See you in April for the last planting round.

Appendix 12: Meru nursery questionnaires.

Data are mainly a result of farmer responses, often followed by observations and measurements by interviewer. Questionnaire starts with introduction interviewer and explaining of its purpose. The respondent is kindly requested to participate. Language is mainly Ki-Meru.

Interview number
Date
Division, district & sub-location
GPS co-ordinates
Name of nursery manager
Name of respondent(s)
Gender of respondent
Relation respondent(s) to nursery owner

General information
What species are raised in the nursery?
What is the number plants in the nursery?
What size is the nursery?
What kind of containers do you use?
What soil ingredients do you use?
What sites do you use to obtain soil?
What type of shade do you use?

Are you willing to pay for improved varieties?
What kind of improved varieties?
What do you do if you cannot access plant material?
What is the distance to the main road?
What is the distance to the forest?
Is this a permanent or a temporal nursery?
How many years do you operate this nursery?

Do you have any comments or questions?

Propagation
What method of vegetative propagation do you know?
What method of vegetative propagation do you practise?
Method of vegetative propagation per species?
Do you pre treat seed?
What method of pre treatment do you use?

Cuttings
What is the best time for cuttings?
What length of cutting do you use?
What diameter of cutting do you use?
What part of plant do you use?
What is the age of the mother plant?
How were the edges cut?
Do you use root fasten ingredients
What maintenance do you do?

Grafting
What size of rootstock do you use?
How were both ends cut?
How was the part inserted?
How do you maintain the fusion?

Air layering
What length of air do you use?
What diameter of air do you use?
What do you use as wrapping

Do you have any comments or questions?

Main species questions (for 2 species)
Name and number present of species 1
Output of species 1 per year
What will you do with the tree? (sell / ...)
How many clients do you have?
What price per tree?
Type of material (germplasm) used for propagation
Why did you use this type of material?
Who collected this material?
Where did you collect this material?

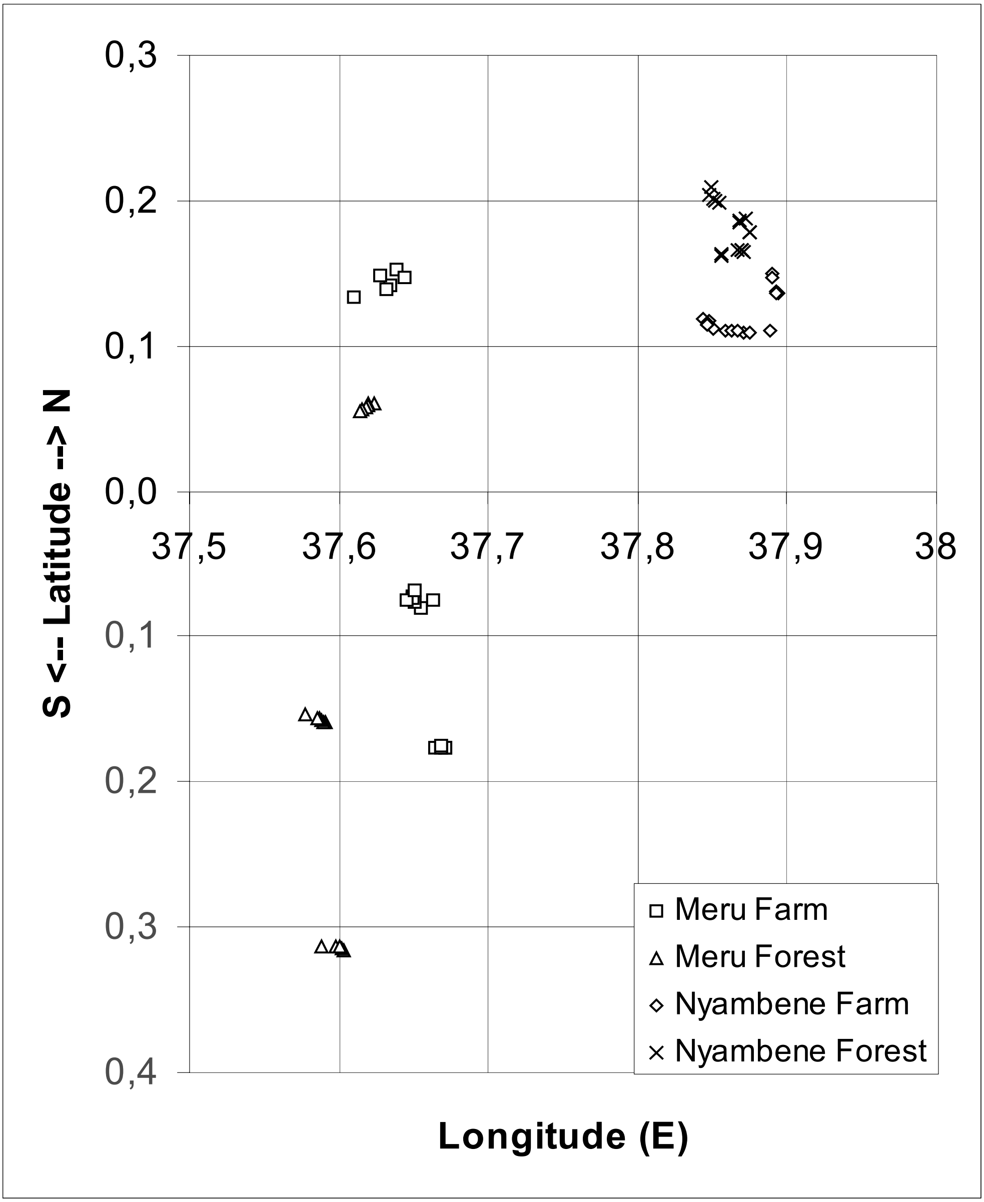
Do you know the number of mother trees?
What number of mother trees did you collect from?
Why did you collect from this number?
What is the number of adult trees around (farm)
Why did you collect from that mother tree(s)?
What selection criteria did you use?

Do you have any comments or questions?

Nursery manager specifics
Gender, Ethnic group, Age & Education
What type of house has the nursery manager?
What is your farm size?
How many cows pure breed, mixed & local.
How many sheep or goats
Do you have off farm employment?
Do you hire labour (temporarily / permanent)?
Additional observations

Do you have any last comments or questions?
The respondent is thanked for the information

Appendix 13: Co-ordinates for *Vitex fischeri* trees for RAPD analysis in matched farm and forest stands in Central Kenya.



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Curriculum Vitae

Arie Gerrit Lengkeek was born on 9 April 1966 in Rijswijk, Zuid Holland, The Netherlands. He grew up in Pijnacker and completed his VWO certificate from CSV 't Loo at Voorburg in 1985. That year he started courses in Plant Breeding at the then Wageningen Agricultural University. As part of this study he spent seven months at the National Tree Seed Centre (CNSF; Centre National de Semences Forestières) in Ouagadougou, Burkina Faso, in 1990. He graduated from Wageningen in June 1992 with a specialisation in Forest Genetics.
After working for two years at the Institute for Forestry and Nature Research in Wageningen on the use and conservation of elm threatened by Dutch elm disease, he left again for Burkina Faso in 1994 to work as a scientist / trainer in statistics at CNSF. Returning to The Netherlands, he had various jobs in forest genetic resources and nursery management until joining DGIS (Ministry of foreign affairs, development cooperation) in 1996. He spent five years in Kenya, first attached to IPGRI (International Plant Genetic Resources Institute) for two years, then attached to ICRAF (International Centre for Research in AgroForestry) for three years. At IPGRI he worked to strengthen and backstop national research institutes in Sub Saharan Africa in projects related to the use and conservation of forest genetic resources. At ICRAF, his activities included research with farmers in the management of tree diversity. In August 2001 he returned to the Netherlands for DGIS study leave and to write this thesis on work conducted at ICRAF. At the moment he is a member of www.Bananahill.net and conducts consultancies in (agro)biodiversity, ethnobotany and medicinal plants, such as for the Royal Tropical Institute (KIT) in Amsterdam and FAO in Rome. Contact Ard.Lengkeek@zonnet.nl.
Ard Lengkeek is married to Saskia Hollants, and they have two daughters, Maud and Isa.

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