Social and Environmental Trade-Offs in Tree Species Selection

A Methodology for Identifying Niche Incompatibilities in Agroforestry[1]

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Abstract

Natural resource degradation in highland regions is of increasing concern to the global community due to its role in aggravating poverty and the loss of environmental services to local and downstream users. The integration of trees into smallholder farming systems has been promoted as a means to enhance rural livelihoods while reversing the degradation of soil, water, biodiversity and related environmental services. Yet in addition to these benefits, negative impacts of trees on certain stakeholders or system components have also accompanied such efforts – suggesting that important trade-offs accompany these efforts. This paper presents a methodology for diagnosing problems stemming from cultivation of certain tree species in specific landscape niches. Data derived from the application of this methodology in two sites in the eastern African highlands are presented. Participatory diagnoses of landscape-level problems suggest that the negative impact of trees on water resource availability and crop yield are of critical concern to smallholder farmers. Ethnoecological data highlight the properties of different tree species that determine their suitability to specific farm and landscape niches. These data point to important opportunities for more socially- and environmentally-optimal integration of indigenous and exotic tree species into agricultural landscapes, and highlight the critical importance of local knowledge in forging solutions appropriate to contemporary realities.

Key words: Agroforestry, Africa, Community-based natural resource management, Stakeholder

Introduction

The importance of trees to smallholder farmers are well-known, and include the provision of diverse products (fodder, fuel, construction materials, food, income) (Ardayfio, 1986; Becker, 1986; FAO, 1986; Gutteridge and Shelton, 1993; Larsson, 1990), as well as a host of environmental services (Arnold, 1992). Agroforestry has therefore been widely promoted within smallholder farming systems as a means to enhance rural livelihoods while reversing the degradation of soil, water, biodiversity and related environmental services. However, tree planting is often uncritically equated with environmental conservation, leading also to negative repercussions. Trees cultivated on farm can have both positive and negative affects on other system components (crops, water, livestock) and users. Yet despite the potential for managing these trade-offs so as to foster more socially- and environmentally-optimal outcomes, many research and development organizations continue to behave as if agroforestry were a purely technical activity devoid of any social or systems repercussions beyond the household level (Lwakuba et al., 2003; Ssekabembe, 2004). Lessons on how to more optimally integrate trees into farming landscapes are therefore sorely needed.

Following a literature review, the paper summarizes results of a participatory diagnosis of landscape-level natural resource management problems in two sites in the eastern African highlands, in which problems related to trees (insufficient access to tree products, negative social and environmental impacts) are highlighted. The paper then presents a methodology for understanding the characteristics that make specific trees compatible with different landscape niches in the minds of local users. Results emerging from the application of this tree

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niche analysis in two sites (Ginchi, Ethiopia and Lushoto, Tanzania) are presented. Results suggest that by breaking a problem down into its component parts – including problem identification, tree niche analysis and stakeholder engagement – solutions to identified problems become much less elusive. The paper concludes with a discussion of implications for agroforestry programs, and for stakeholder engagement and policy interventions in agroforestry.

Background

THE AFRICAN HIGHLANDS INITIATIVE

The African Highlands Initiative (AHI) is an eco-regional program operating in benchmark sites of the highlands of eastern Africa that share similar characteristics: high population density, declining agricultural productivity, and limited economic opportunities. Its mandate is to develop new approaches for addressing the complex interplay of natural resource degradation, declining agricultural productivity and poverty. Since 1995, AHI has worked in partnership with National Agricultural Research and Extension Systems (NARES) of Ethiopia, Kenya, Madagascar, Tanzania and Uganda to develop new working approaches in agriculture in support of local initiatives in natural resource management (NRM) at farm and landscape scale. In 2003, following years of experience with farm and plot-level natural resource management, AHI set out to encompass broader dimensions of NRM, emphasizing the development of an integrated, participatory watershed management approach. In addition to capturing trans-boundary interactions and common property resource issues, this larger scale focuses one's attention on public (as opposed to private or individual) goods and the interactions among diverse actors (trade-offs and synergies among local users, interactions among multiple stakeholders). Benchmark or pilot sites in each country are used as testing grounds for in-field development of new approaches. Comparative research across benchmark sites enables a broader understanding of how widespread certain conditions are, and how context influences what types of approaches work and why.

AGROFORESTRY IN THE CONTEXT OF WATERSHED MANAGEMENT

Natural resource degradation in highland regions is of increasing concern to the global community. This is not due solely to a concern about poverty and the loss of environmental services to local residents; it is also about ensuring the provision of these services to off-site (downstream, urban) users. Watershed management, integrated natural resource management and other multi-stakeholder approaches have gained increasing momentum as promising approaches for reversing these trends. Agroforestry has an important role to play in integrating livelihood and conservation objectives in upper catchments (Denning, 2001; FAO, 1976; Nair, 1993). However, the "deliberate growing of woody perennials on the same unit of land as agricultural crops and/or animals" and "significant interaction (positive and/or negative) between the woody and non-woody components of the system" which define agroforestry (Lundgren, 1982) often result in negative interactions or involve trade-offs between system components and user groups. This is in large part due to the failure to match particular system niches with the species best suited to them, and the interests of the landowners with the interests of other affected parties.

The watershed management approach espoused by AHI emphasizes "participation" in problem definition, planning and implementation. This emphasis makes the watershed as a relevant unit of analysis something hypothetical, whose relevance is only validated once problems and their spatial manifestations are identified. It also means that the conventional goal of watershed management – enhanced hydrological function for multiple uses and users – may or may not factor in prominently to the localized watershed management agenda. Participation also implies that micro-political interests at farm and landscape levels are articulated and negotiated (Meinzen-Dick et al., 2002; Pellow, 1998), posing significant challenges within hierarchical societies and for engaging marginalized groups (Munk Ravnborg and Ashby, 1996; Bachrach and Baratz, 1970; Russell and Harshbarger, 2003). In agroforestry, this means ensuring that diverse stakeholders have a voice in the aims and outcomes of projects aiming to integrate trees into farms and landscapes (Bonnard and Scherr, 1994; Caveness and Kurtz, 1993). This is true not only from the perspective and gender- and wealth-sensitive strategies (Rocheleau and Edmunds, 1997; Schroeder, 1993), but also in the sense of local interest groups having diverse and often opposing interests. For example, farmers with larger plots of land may plant woodlots to save labor and because they are capable of foregoing short-term returns to their investments, while neighboring farmers with smaller plots suffer the consequences through declined crop yield (Nair, 1993). In a similar vein, farms who rely heavily on springs and rivers for drinking and irrigation water may suffer from the hydrological impact of water-demanding trees on private property. Capturing these different 'stakes' and working with them through equitable stakeholder engagement and negotiation are at the core of agroforestry-related watershed interventions.

The AHI approach is also defined by "integration," which can be interpreted in two ways in the context of agroforestry. The first involves understanding and managing the interactions between system components at landscape level – among diverse farm-level components (trees, soil, crops, livestock), waterways, forest, grazing land, and tenure systems (private and common property) (Meinzen-Dick et al., 2002). A second sense involves the integration of diverse dimensions of the problem within solutions, in other words to treat the problem not as something technological alone, but addressing it from its policy, market and/or institutional dimensions (CGIAR, 2002) and acknowledging the role of governance on NRM and livelihoods (Ostrom, 1990, 1998; Wittapayak and Dearden, 1999). Each of these concepts is fundamental to agroforestry due to the impacts of trees on non-forest components of the farming system, broader social impacts of individual management practices, and the need for improved governance to complement technical interventions in agroforestry. Trees have a direct impact upon other system components through positive and negative biophysical interactions with soil (Nair, 1984; Young, 1989), crops (Akbar et al., 1990; Kang et al., 1990; Fernandes, 1990), water (Nair, 1993) and livestock (Ivory, 1990). They have an indirect effect as substitutes for purchased inputs or through individual and collective decisions on the allocation of land, labor, capital or other resources among different system components at farm level and landscape levels (Franzel et al., 2001). An understanding of interactions among diverse tenure systems is critical to agroforestry, as practices of individual farmers (deforestation, on-farm species selection) have very direct effects on common property resources such as water (Le Maitre et al., 2000). There also tends to be a direct relationship between access to forest resources and agroforestry practices (Meinzen-Dick et al., 2002). The second sense of integration is critical in understanding the role of institutional and policy mechanisms in minimizing conflict, enhancing sustainability (Ostrom, 1998; Pandey and Yadama, 1990; Scoones and Thompson, 2003), and managing trade-offs in species selection (putting the right trees in the right places so as to enhance the positive and minimize the negative impacts). Market solutions may also be required to find alternatives to economically sound but otherwise problematic species.

Methodology

BENCHMARK SITES

The sites selected for this study are highland micro-watersheds with smallholder farming systems, high population density and evidence of natural resource degradation found within the eastern African highlands. These sites are pilot sites of AHI where new approaches to integrated natural resource management are first developed and tested, enabling regional comparative research and subsequent dissemination of lessons applicable to the region at large.

Ginchi site is located in Western Shewa Zone, Ethiopia. The high altitude (> 2200 masl) presents a constraint on the range of tree species that can adapt well to the area (Shelton, 1998). Indiscriminate cutting of remnant trees and contiguous forest, due largely to shifts in political regimes and the resulting ambiguity in tenure systems (Bekele, 2003), has contributed to large areas of landscape devoid of tree cover. Forest cover in the highlands reduced from 40% to 6% between the turn of the century and 1988 (Omiti et al., 1999). Limited access to tree products has led to an increased labor burden on women and children who must walk long distances to collect firewood, and negative impacts on soil nutrients due to the sharp increase in the use of dung for fuel in recent decades (Omiti et al., 1999). Loss of tree cover and cultivation of water-demanding trees around springs have led to the degradation of springs (water quality and quantity), the sole source of water for both humans and livestock. Despite a short history of afforestation programs in the area, farmers already perceive the negative impacts of some species on crops and water.

The second site is located in Lushoto District, Tanzania. The German and British colonial policies increasingly marginalized the local population from once-revered forest resources, which continued with post-colonial policies of forest conservation and commodity production favoring exotic species (Conte, 1999). These policies marginalized local residents from state-managed protected areas and timber plantations, and gave impetus to afforestation programs introduced in the 1950s. In addition to resulting in a dramatic increase in tree cover on-farm, the long history of interaction with both indigenous and exotic tree species has led to a wealth of ethnobotanical knowledge on the diverse impacts of these species, both positive and negative. In addition to the critical importance of trees to livelihood, farmers believe certain tree species are responsible for the drying of springs and reductions in crop yields on neighboring farmland. Given the declining size of agricultural plots and the almost sole reliance on local springs and surface water for domestic use and irrigation, these impacts are seen as highly significant. Such impacts results not only from afforestation by smallholders, but by the large-scale cultivation of exotic species by missions, tea estates and government departments governing district and national forest reserves.

RESEARCH METHODS

Watershed Diagnostics

To identify local motives for improved NRM at landscape level, focus group discussions with diverse social groups (women and men, youth and elders, poorer and wealthier, and from different landscape locations) using semi-structured interview techniques were used to identify the key concerns of different actors (Bernard, 1994). A single list of issues was then compiled at village or watershed level, and key informants (again stratified by gender, wealth, age and landscape position) were asked to rank these issues according to their relative importance.

An important component of the methodology was to fine-tune and triangulate questions asked to farmers, so that diverse types of issues could be effectively identified. The elicitation frame captures diverse dimensions of landscape-level NRM and cooperation: the primary livelihood impacts of land use and landscape change, trans-boundary influences between neighboring farms and villages, issues that could benefit from collective decision-making and solutions, problems associated with the management of common property resources (CPR), and existing sources of conflict. While the questions posed to farmers limited the inquiry to natural resource management-related issues, diagnostic methods that go beyond agroforestry ensure that the identification of tree-related problems is not an artifact of the method alone.

Identification of Trade-Offs in Species Selection

A second stage in the methodology emerged due to problems identified by farmers in the area of agroforestry, including negative social and environmental repercussions of the cultivation of exotic tree species in certain niches. Focus group discussions were held with groups of farmers knowledgeable about both indigenous and exotic trees in Lushoto and Ginchi. These interviews generated three types of information: a) landscape niches where trees are or could be grown, b) a robust list of tree species elicited on the basis of their cultural and economic importance, harmful characteristics, and compatibility with identified niches; and c) a list of species' characteristics generated by asking informants to express the reasons for species selections.

An item-by-feature matrix (D'Andrade, 1995) consisting of a master list of tree characteristics (n = 35 and 19 for Lushoto and Ginchi, respectively) and tree species (n = 30 and 18) was then compiled in MS Excel. Key informants were then asked to rate each species in the matrix according to the degree to which it exhibits each feature (2 = "yes exhibits feature", 1 = "exhibits feature somewhat" and 0 = "does not exhibit feature"). The matrix was then imported into a multi-dimensional scaling program (PC-ORD), which uses a function minimization algorithm to evaluate different configurations to maximize the goodness-of-fit, detect meaningful underlying dimensions of the matrix, and allow the researcher to explain observed similarities or dissimilarities (distances) between the investigated objects (Kruskal and Wish, 1978). Under the current application, multi-dimensional scaling reduced the complexity of the original matrix (the observed distances between tree features and species) to enable a 3-dimensional view of local perceptions of tree species and their characteristics. Observed patterns in the resulting scatterplot offer insight into the relationships between tree species or tree characteristics in the minds of local residents. Transposing the matrix enables the graphing of the perceptual similarities among species, or among species characteristics. The scatterplot of tree characteristics (depicted below) is particularly useful in illustrating the trade-offs inherent in species selection.

Identification of Niches and Niche-Compatible Species

To move from diagnosis of trade-offs to niche-compatible agroforestry, it is important to understand the niches where trees are or could be grown and characteristics that make tree species compatible with each niche, as illustrated above. Direct elicitation of tree species compatible with different niches is the simplest way to identify niche-compatible species, our experience shows that additional species can be identified by averaging species ratings across all criteria claimed to be important for each niche. In other words, a sub-set of species characteristics is lumped by niche, and the average values used to assess niche compatibility. The species identified as niche- compatible during semi-structured interviews and those identified numerically are then compared, and discrepancies fed back to informants. This enables corrections to be made to either: a) the list of species considered compatible with each niche (where highly-ranked species are also considered niche compatible); or b) the niche compatibility criteria of each niche (where highly-ranked species are nevertheless considered niche-incompatible). This stage of the method provides outputs that can be used in afforestation efforts, either to reform tree dissemination strategies to foster greater niche compatibility (publicizing negative properties of certain species, targeting species for specific niches) or to formulate policies which minimize the social and environmental trade-offs in species selection. See German et al. (in press) for a discussion of multi-stakeholder engagement processes to enhance niche compatibility.

Results

AGROFORESTRY-RELATED PROBLEMS IDENTIFIED THROUGH LANDSCAPE LEVEL DIAGNOSIS

Landscape-level NRM problems identified by local residents in Lushoto and Ginchi include issues that are both directly and indirectly related to agroforestry (Table 1). Problems of direct relevance to agroforestry include limited access to tree products, negative impacts of trees on neighboring cropland (competition with crops, negative impact on soil fertility, and enhanced run-off), and effects of certain tree species on the taste of spring water. Another set of issues related to water supply and management is indirectly related to agroforestry in the sense that water-demanding tree species are one component of an integrated problem. Causal factors include individual ownership of land around springs and waterways (undermining effective governance of water),

Table 1. Watershed Problems Related to Agroforestry in the AHI Pilot Sites

Identified NRM Problems	**Ginchi Site**	**Lushoto Site**
Problems Directly Related to Agroforestry:		
Negative impact of boundary trees on (neighbouring) crops and soil, reducing available cropland and yields	√	√
Deforestation and loss of indigenous tree species	√	√
Theft of crops, trees	√	√
Shortage of fuel wood	√	
Impact of exotic trees (primarily Eucalyptus) on springs	√	√
Enhanced run-off through impermeable layers of leaf litter		√
Impact of certain trees on water taste	√	
Problems Indirectly Related to Agroforestry:		
Drying and contamination of watering points & spin-offs (conflict, disease, labour)	√	√
Periodic drought & drying of valley bottoms	√	√
Limited access to irrigation water (poor management, limited quantity)	(√)[a]	√
Individual ownership of land around springs	√	√

[a] Parentheses are used to denote problems not identified by farmers during diagnostic activities, yet nevertheless known to be true for the site.

contamination of drinking water (from cultivation of these areas and contamination with pesticides, run-off and human waste) and drying of water resources (springs, valley bottoms, irrigation channels) due to deforestation and cultivation of water-demanding trees. Yet when farmers were asked to indicate the most important cause of water resource decline, the planting of exotic tree species – most notably Eucalyptus – was highlighted. Agroforestry-related problems are similar despite the marked historical, economic and agroclimatic differences between the two sites, suggesting that this methodology could have broad geographical relevance.

IDENTIFICATION OF TRADE-OFFS IN SPECIES SELECTION

Trade-offs in species selection were identified through an analysis of ethnobotanical knowledge of tree species identified by local residents in each research site. Informant ratings of each species according to the degree to which it exhibits each identified tree characteristic enables systematic analysis of the degree to which species exhibiting strong positive characteristics also exhibit other negative characteristics. Multidimensional scaling of the data in the form of tree species – tree characteristic matrices produced 3-dimensional graphical representations of how locally-salient tree characteristics co-vary within the available species (Figures 1 and 2). While each axis represents all tree species to a certain degree, axes represent some species much more strongly than others. This reduces 30-dimensional space (30 species each with its own unique assemblage of characteristics) to 3 dimensions, enabling the visualization of relationships among species characteristics and the trade-offs inherent in species selection.

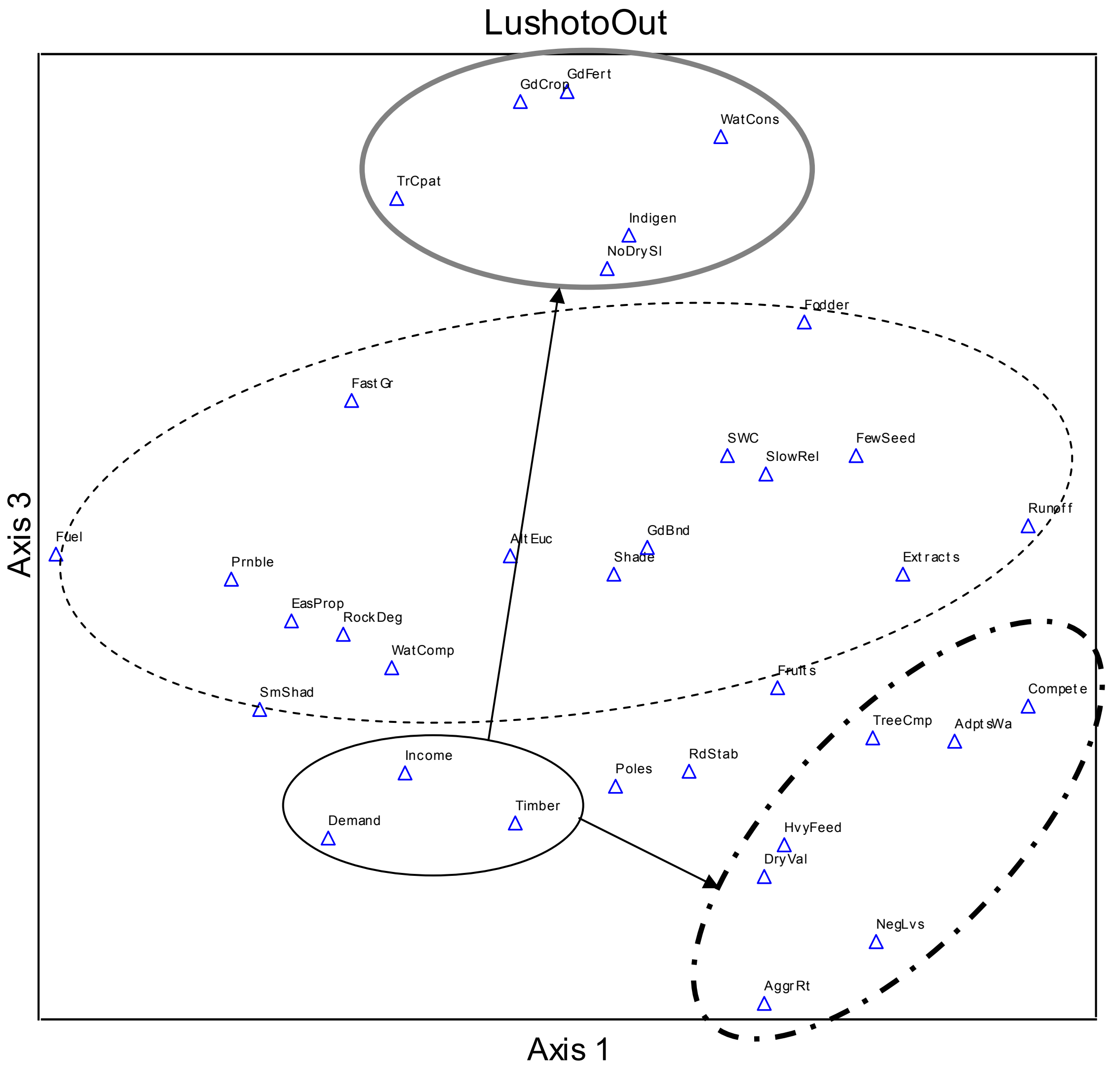

Figure 1. Clusters of Tree Species Characteristics in Multidimensional Space, Lushoto Site[a]

[a] Analysis based on 30 species.

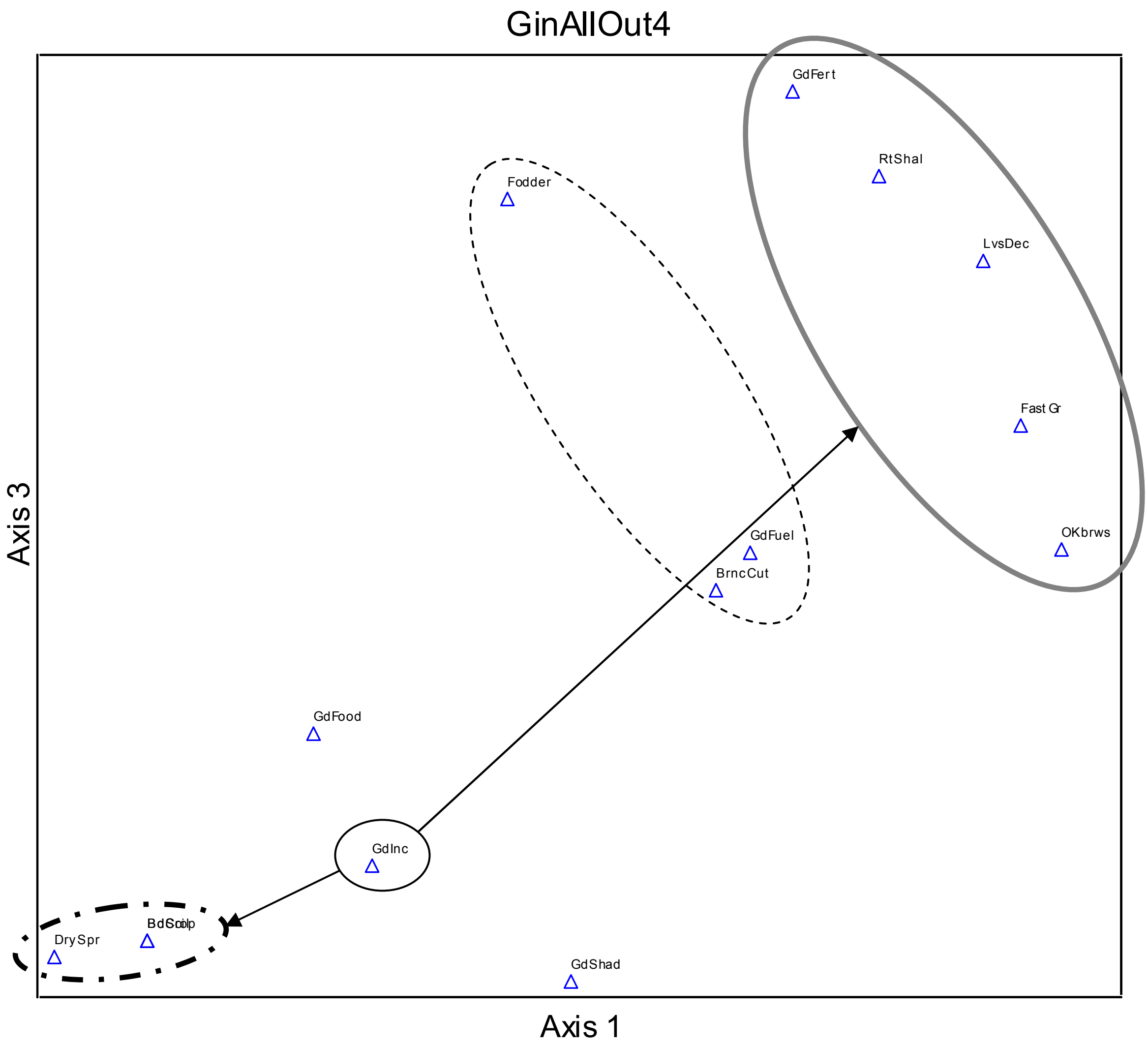

Figure 2. Clusters of Tree Species Characteristics in Multidimensional Space, Ginchi

[a] Analysis based on 18 species.

In both Lushoto and Ginchi (Figures 1 and 2, respectively), tree characteristics fall into distinctive clusters based on the tendency for single species to embody either favorable environmental characteristics (thick gray lines), negative environmental characteristics (thick dotted black lines), or favorable economic characteristics (thin black circles). This suggests that there is a strong tendency for species exhibiting one positive environmental characteristic to also exhibit others, and the same for negative impacts. This suggests that there are clear trade-offs in the species chosen in terms of their environmental impacts, whether positive or negative.

A second observation relates to the proximity of the "income" cluster to the two "environmental impact" clusters. In each site, species seen as best for income generation (thing solid black lines) are closer to those species exhibiting negative than those exhibiting positive environmental impacts. This is equally apparent from Tables 2 and 3, where species with the closest "fits" to each cluster are listed and a high degree of overlap in the species with favorable economic and negative environmental characteristics is seen. Clearly there is a second trade-off between economic and environmental benefits, the latter a precursor to niche compatibility. If evaluated in terms of diverse benefits from trees (fodder, fuel, food, etc.) rather than just income, as illustrated by thin dotted black lines, the trade-offs are less apparent. Yet the strong impetus for cultivating high-value (largely exotic) trees in a region characterized by very low household incomes suggests that farmers will continue to select trees with less favorable environmental impacts.

Clearly, strategies to minimize the trade-offs in species selection are sorely needed. The detailed nature of ethnobotanical knowledge of trees suggests that it is not a gap in knowledge that hinders farmers from

Table 2. Properties of Identified Clusters and Species with Closest Fit, Lushoto Site

Cluster	Cluster Characteristics	Species with Closest Fit
Negative Environmental Impacts	· Heavy feeder on water · Dries valley bottoms · Aggressive root system · Leaves bad for crops and soil · Out-competes other tree species · Competes with undergrowth · Adapts to water-logged conditions	*Eucalyptus saligna* *Eucalyptus robusta*
Income & Market Demand	· Good source of income · Has steady market demand · Produces good timber	*Eucalyptus saligna* *Eucalyptus robusta*
Positive Environmental Impacts	· Good for soil fertility · Has positive effect on crops · Conserves water · Does not dry soil · Compatible with other tree species · Is indigenous	*Cyanthea manniana* *Ficus benjamina* *Ficus thonningii* Unkn. (local name Mapofo)

Table 3. Properties of Identified Clusters and Species with Closest Fit, Ginchi Site

Cluster	Cluster Characteristics	Species with Closest Fit
Negative Environmental Impacts	· Causes drying of springs · Has a negative effect on soil · Has adverse effect on adjacent crops	*Cupressus lusitanica* *Eucalyptus globulus* *Olea africana* (springs only)
Income	· Is a good source of income	*Cupressus lusitanica* *Eucalyptus globulus* *Olea africana*
Diverse Tree Products	· Serves as feed for livestock · Is a good source of fuel wood · Its branches may be cut for fuel	*Buddleja polystachya* *Chamaecytisus palmensis* *Dombeya torrida* *Hagenia abyssinica* *Hypericum quartinianum* *Maesa lanceolata* *Salix subserata* *Erica arborea*
Positive Environmental Impacts	· Has beneficial effect on soil fertility · Has a shallow root system · Its leaves decompose easily · Is fast-growing · Young trees survive browsing	*Buddleja polystachya* *Chamaecytisus palmensis* *Dombeya torrida* *Hagenia abyssinica* *Hypericum quartinianum* *Maesa lanceolata* *Senecio gigas* *Vernonia auruculifera*

cultivating species with more favorable environmental characteristics, but a strong economic incentive to do otherwise. Given that many of the aforementioned negative impacts affect not only the landowners themselves but also neighboring farmers and water users, there is a need to integrate social and policy interventions into what is currently seen as a predominantly technical endeavor – the dissemination of trees into smallholder farming systems. There is also a need to legitimize local knowledge in the face of external research and extension systems whose criteria for evaluating and promoting select tree species may diverge substantially the criteria utilized by local communities.

TREE NICHE ANALYSIS: TOWARD NICHE COMPATIBILITY IN AGROFORESTRY

Given the strong incentive to cultivate trees with negative environmental impacts, the next step was to determine where different trees could be cultivated on the landscape so as to enhance the positive and minimize the negative social and environmental impacts. The characteristics that make tree species desirable or undesirable for specific niches clearly differ by niche (Tables 4 and 5), offering an opportunity for more optimal integration of culturally important trees in more appropriate niches. The data presented in this section offer insights into how greater niche compatibility might be fostered in agroforestry research and practice.

Niches identified by farmers where trees are or could be cultivated have similarities and differences as a function of the farming system and the particular species causing problems in each site. While problems associated with farm boundaries (incompatibilities with crops) and springs and waterways (incompatibilities with water) are common across sites, other niches are site-specific (Tables 4 and 5). Residents of Lushoto mentioned protected area boundaries and roadsides as niches requiring improved management due to the incompatibilities of particular species (*Acrocarpus fraxinifolius, Eucalyptus* spp. and *Olea europaea*). Residents of Ginchi, on the other hand, mentioned outfields due to the relative absence of cultivated trees in these areas and the role of seasonal open access grazing in hindering tree establishment and incentives for investment. They also mentioned degraded areas due to the need for trees to halt soil fertility decline and gulley formation, and the need to find an appropriate niche for *Eucalyptus* – a genus that is economically important but seen as incompatible with most niches.

Niche compatibility criteria in similar niches also share similarities across sites. On farm boundaries, farmers stress tree compatibility with crops (nutrient, shade and water interactions) and the provision of diverse tree products. Around springs and waterways, farmers mention only those characteristics influencing species compatibility with water (despite the multiple uses characterizing these areas), demonstrating the critical importance given to water resources. Water compatibility is expressed in terms of the ability of trees to enhance water recharge (Lushoto only), minimize water loss (both sites), or preserve water taste (Ginchi only). In most other niches, compatibility with crops is a major concern of farmers – with the exception of degraded areas in Ginchi, where the niche's unsuitability to crops enables a wider range of criteria to be applied (as illustrated by the lack of incompatible species).

While the divergence in species assemblages makes site comparison of species difficult, several related observations can nevertheless be made. First, *Eucalyptus* species tend to be key culprits in niche incompatibility for both crop and water interactions. It is critical that we understand how to manage this species so as to minimize its negative impacts on certain system components (water, soil, crops) and users (neighboring farmers, water users). Second, *Ficus* spp. were identified as having an important water conservation function by farmers in both sites (and are additionally considered sacred in Lushoto), but are not listed in Table 5 (Ginchi site) because *Ficus* are absent at this altitude. Finally, while most negative effects stem from exotic species in Ginchi, negative effects were identified with both indigenous and exotic species in Lushoto. Data from Lushoto nevertheless obscure problems associated with the intensity of effects from different species, such as species-specific impacts or densities. Here, *Eucalyptus* spp. and Black Wattle (*Acacia mearnsii*) are most salient in their detrimental effects due to economic forces (high market price for both species and a local processing plant for Wattle) encouraging their cultivation.

Clearly, managing trees is not a "plot-level" issue requiring minimal collective action, as depicted by some authors (Knox et al., 2002). Rather, it requires an understanding of the impacts of individual behavior on other users, and multi-stakeholder negotiations and policy reforms to ensure that individual goods are not the sole operating motive in land use decision-making. While farmers have clear understanding of the features that trees should exhibit in different landscape niches, they often lack the policy and organizational mechanisms to ensure that positive synergies exist between landscape components (tree-crop, tree-water) and users.

Table 4. Perceived Compatibility of Different Tree Species with Different Locations on the Landscape, Lushoto Site

Landscape Location	Compatibility Criteria	Least Compatible[1]	Most Compatible	
1. Farm Boundaries	· Compatible with crops · Adds nutrients to the soil · Does not take much water from the soil · Creates small shady area	· *Allanblackia stunlamannii* · <u>*Eucalyptus*</u> spp. · <u>*Persea americana*</u> · *Olea europaea* subsp. *africana* · *Ocotea usambarensis* · *Solanecio mennii*	· <u>*Acrocarpus fraxinifolius*</u> · *Albizia schimperiana* · *Cyanthea manniana* · *Ficus benjamina* · <u>*Gravillea robusta*</u> · <u>*Markhamia obtusifolia*</u>	· *Morus* spp. · *Prunus persica* · *Psidium guajava* · Unkn. (local name Mapofo)
2. Springs and Waterways	· Keeps the area wet (conserves moisture) · Does not take much water from the soil	· <u>*Acacia mearnsii*</u> · <u>*Eucalyptus*</u> spp. · *Ocotea usambarensis* · *Olea europaea* · <u>*Mangifera indica*</u> · *Parinari curatslifolia*	· *Albizia harveyi* · *Allanblackia stunlamannii* · *Cyanthea manniana* · *Ensete ventricosa*[3] · *Ficus benjamina* · *Ficus thonningii*	· *Hallea rubrostipuleta* · *Myrianthus holstii* · *Plectranthus laxiflorus*[3] · *Solanecio mennii* · Unkn. (local name Mapofo)
3. Forest Boundaries	· Does not inhibit growth of trees or crops · Does not take much water from the soil · Not indigenous · Branches may be cut for fuel	· <u>*Eucalyptus*</u> spp. · *Olea europaea* subsp. *africana*	· <u>*Acrocarpus fraxinifolius*</u> · *Eriobotrya japonica* · <u>*Gravillea robusta*</u> · <u>*Mangifera indica*</u> · <u>*Markhamia obtusifolia*</u> · Unkn. (local name Mapofo)	
4. Roadsides	· Not harmful to crops · Branches do not break in wind · Strong roots good for road stabilization · Does not break the road	· <u>*Acrocarpus fraxinifolius*</u>[2] · <u>*Eucalyptus*</u> spp. · *Olea europaea* subsp. *africana*	· <u>*Acrocarpus fraxinifolius*</u> · *Azadiracta indica* · <u>*Gravillea robusta*</u> · <u>*Markhamia obtusifolia*</u> · Unkn. (local name Mapofo)	

[1] Underlined species are exotics.
[2] Note that farmers strongly disagree on the suitability of Agrocarpus for roadside stabilization.
[3] While these species are not trees, they are mentioned by informants due to cognitively salient niche compatibility characteristics.

Table 5. Perceived Compatibility of Different Tree Species with Different Locations on the Landscape, Ginchi Site

Landscape Location	Compatibility Criteria[1]	Incompatible Species[2]	Most Compatible Species
1. Farm Boundaries	· **No adverse effect on adjacent crops** · Branches can be cut for fuel wood · Good for soil erosion control · Serves as feed for livestock · Good for shade · Makes a good fence · Good source of income	· <u>*Eucalyptus globulus*</u> · <u>*Cupressus lusitanica*</u> · *Senecio gigas* · *Rahmnus prinoides* · *Podocarpus gracilor* · *Juniperus procera* · *Olea africana* · *Erica arborea*	· *Buddleja polystachya* · *Dombeya torrida* · *Hagenia abyssinica* · <u>*Acacia decurrens*</u> · <u>*Chamaecytisus palmensis*</u> · *Maesa lanceolata* · *Hypericum quartinianum*
2. Springs and Waterways	· **No negative effect on spring discharge** · **Does not change the taste of water** · Has a shallow root system · Creates a good shade	· <u>*Cupressus lusitanica*</u> · <u>*Eucalyptus globulus*</u> · *Olea africana* · *Senecio gigas* · *Vernonia auruculifera*	· *Salix subserata* · *Juniperus procera* · *Hagenia abyssinica* · *Maesa lanceolata* · *Olea africana* · *Podocarpus gracilor*
3. Outfields	· **No negative effect on crops** · Good for soil fertility · Has shallow root system · Good source of income · Has a good shade · Good for soil erosion control · Young trees survive browsing	· <u>*Cupressus lusitanica*</u> · <u>*Eucalyptus globulus*</u>	· *Dombeya torrida* · *Hagenica abyssinica* · *Juniperus procera* · *Podocarpus gracilor*
4. Degraded Areas	· Has beneficial effect on soil fertility · Deep rooted · Fast growing · Not suitable for other niches		· *Buddleja polystachya* · *Dombeya torrida* · <u>*Eucalyptus globulus*</u> · *Hagenica abyssinica* · *Vernonia auruculifera*

[1] Compatibility criteria in bold font are those critical to other stakeholders or system components, and therefore the only criteria used to assess incompatibility. The most compatible species were identified through consideration of all identified compatibility criteria.
[2] Underlined species are exotics.

Discussion

Taking a regional perspective, the negative impacts of agroforestry show strong similarities in different sites, and may be summarized by three basic interactions: a) interactions between trees and water, b) effects of trees on soil, and c) interactions between trees and crops or other tree species, due to either competition or allelopathic effects. Local stakeholders involved in the first of these include owners of land around springs and waterways whose land use practices (deforestation, cultivation of water-demanding trees and/or failure to protect water from contamination), and water users who depend on a clean, reliable source of water for domestic use and irrigation. The consequence of leaving this first problem unabated is substantial given the large number of people affected by declines in water quality and quantity. The last two impacts, while widespread, are generally limited to neighboring landowners – whether two smallholder farmers, several smallholders and a larger religious, educational or commercial institution, or farmers and the government (as in the case of forest reserves). While most actors benefit from the cultivation of tree species known to have negative environmental repercussions, emphasis on landowners' use rights within regulatory schemes obscures the impacts that individual land use practices have on others. Negatively affected are farmers whose crops neighbor woodlots and tree lines of incompatible species on adjacent farms, and downstream users whose water supply is degraded from the cultivation of water-demanding species in valley bottoms and upper catchments.

Causal factors behind these negative interactions are also similar across sites. The properties exhibited by certain tree species is itself a cause, given the significant trade-offs they embody. This is illustrated by the tendency for trees of high value to more closely correlate with trees exhibiting negative rather than positive environmental impacts. If landowners aim to maximize their income from trees, then negative economic, social and environmental impacts will follow. A second cause is the tendency to emphasize individual over collective goods and immediate over long-term benefits in the absence of an effective regulatory environment (Meinzen-Dick et al., 2002; Ostrom, 1990; Pandey and Yadama, 1990) and when traditional governance functions break down, as evidenced a tendency to maximize household income from trees and crops over the community's long-term water supply. The prevalence of negative interactions between components (trees and crops, trees and water), neighboring farmers, and tenure regimes (individually-owned farmland vs. communal springs) indicates that effective negotiation among stakeholders and policies regulating the actions of individuals in the area of agroforestry are sorely lacking.

The findings of this research demonstrate the importance of discrediting the common misconception that more trees on the landscape is better for both livelihoods and environment, as well as the need for a knowledge-based strategy for integrating trees into appropriate niches within agricultural landscapes. This is particularly important for the tree component of agricultural systems, for which impacts can only be seen medium- to long-term (Knox et al., 2002) and the cost of technological change (i.e. species modifications or relocation of tree lots) is high. Given the tendency of development organizations to downplay the importance of species' characteristics and local knowledge in afforestation programs and to disseminate that which is readily available rather than what is logical in each cultural and agroecological context (Brandi-Hansen, personal communication), dissemination of this methodology could go a long way in minimizing the negative outcomes of afforestation activities. However, it will be important to consider the familiarity of local residents with different tree species, in particular within efforts to integrate exotic trees into the system. More systematic ethoecological research on tree impacts within different agroecologies where exotic trees have been present for longer periods of time would enable cross-site sharing of information. It would also enable more ethical agroforestry interventions, in that farmers would be given more rigorous information from which to make decisions on unfamiliar species.

The methodology would then be applied to the design of afforestation programs, and to guide stakeholder engagement and local-level policy reforms around identified agroforestry problems. In landscapes where trees are already prevalent, the open-ended diagnostic tool for participatory identification of natural resource management problems beyond the farm level and tree niche analysis can be jointly used to understand where regulatory interventions are needed. The first can be used to target niches for intervention, and the latter for generating a list of species compatible and incompatible with this niche. In landscapes where no substantial agroforestry is currently practiced, evaluation of species' compatibility in different landscape niches from sites with similar agroecological characteristics can serve as a basis for informing farmers on the pros and cons of different species from the outset. The open-ended tool for diagnosing landscape-level NRM problems can be used to understand the current concerns of local residents (i.e. spring recharge, soil conservation, fodder production), and the potential role of trees in addressing these. The tree niche analysis can then be carried out on species already known to farmers and integrated with ethnoscientific knowledge on species from similar agroecological zones. This will provide farmers with a robust list of tree species adaptable to the area, and information on the potential of these species to address farmers' concerns and to be compatible with existing landscape niches.

Under either scenario, the niche compatibility study can be channeled into two different forms of intervention. In cases where failure to cultivate niche-compatible species stems from non-availability of more compatible species, landowners (alone or in groups) can be given lists of *only those species considered by farmers to be compatible with different niches* to choose from during community nursery and afforestation efforts. For such surveys, only those niches where individual landowners have decision-making authority (farm boundaries, within farmland, around springs and waterways) are included, as decisions on the management of government property such as roads and protected area boundaries can only be made through negotiations with the relevant authorities.

The other intervention is designed for the management of species or environmental processes (deforestation, water resource degradation) considered harmful by at least one stakeholder (individual landowner, government ministry, common property resource users). For encouraging individual stakeholders to take decisions that consider the interests of multiple parties, multi-stakeholder negotiations, by-law reforms or strengthening of traditional governance functions will be required. We are working on an approach for identifying stakeholders in specific landscape niches where tree incompatibility is a problem, ensuring problem are diagnosed and niche compatibility criteria elicited from each stakeholder, and negotiating more "optimal" species and management processes for the niche in question. This process involves distilling the list of niche compatibility criteria to the most critical ones (those causing conflict or risks to livelihood), and negotiating species acceptable to both the landowner and affected groups. For a more detailed description of these multi-stakeholder negotiation processes, see German (in press). For the few species causing widespread concern across a range of stakeholders and landscape niches (for example, the species identified as *most incompatible* from the third column of Tables 4 and 5), local-level policy reforms that attempt to balance the needs of the landowner with collective goods (i.e. reliable water supply) may be needed.

Conclusions

Results of the watershed diagnostic activity carried out in AHI benchmark sites clearly illustrate the problems emerging from the lack of niche-compatible afforestation strategies and policies. Tree niche analysis is a promising approach both for anticipating and avoiding such problems during the planning stage of afforestation programs, as well as for addressing them once they occur. While identified problems may seem intractable to local users due to the strong trade-offs that exist and the divergence between individual and common interests, solutions to identified problems become much less elusive when broken down into their component parts. These include diagnosis of landscape-level NRM problems, identification of tree niches and niche-compatible species, afforestation strategies that make niche compatibility explicit, and multi-stakeholder negotiations and policy reforms to enable more socially-optimal solutions for managing species considered harmful by certain stakeholders. Widespread application of this methodology can generate a body of knowledge and stakeholder perceptions about the conditions under which negative impacts from different species emerge, and strategies most appropriate for engaging stakeholders in different types of niches due to the relative risks and gains involved for each party, particular system characteristics or other pertinent factors.

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Bibliography

Akbar, G., Ahmad, M., Rafique, S. and Babar, K.N.: 1990, 'Effect of Trees on the Yield of Wheat Crop', *Agroforestry Systems* 11, 1--10.
Ardayfio, E.: 1986, *The Rural Energy Crisis in Ghana: Its Implications for Women's Work and Household Survival*, World Employment Programme Research Working Paper No. 39, ILO, Geneva.
Arnold, J.E.M.: 1992, *Community Forestry: Ten Years in Review*, FAO, Rome.
Bachrach, P. and Baratz, M.S.: 1970, *Power and Poverty: Theory and Practice*, Oxford University Press, New York, 220 pp.
Becker, B.: 1986, 'Wild Plants for Human Nutrition in the Sahelian Zone,' *Journal of Arid Environments* 11, 61--64.
Bekele, M.: 2003, 'Forest Property Rights, the Role of the State and Institutional Exigency: The Ethiopian Experience', *Ph.D. Thesis*, Swedish University of Agricultural Sciences, Uppsala, 220 pp.
Bernard, R.H.: 1994, *Research Methods in Anthropology: Qualitative and Quantitative Approaches*, 2nd Ed, Altamira Press, Walnut Creek, CA, 588 pp.
Bonnard, P. and Scherr, S.: 1994, 'Within Gender Differences in Tree Management: Is Gender Distinction a Reliable Concept?,' *Agroforestry Systems* 25, 71--93.
Caveness, F.A. and Kurtz, W.B.: 1993, 'Agroforestry Adoption and Risk Perception by Farmers in Senegal', *Agroforestry Systems* 21, 11--25.
CGIAR: 2002, 'Putting Integrated Natural Resource Management into Action', Proceedings of the 4th INRM Workshop, Aleppo, Syria, September 2002, 98 pp. Aleppo: ICARDA.
Conte, C.A.: 1999, 'The Forest Becomes a Desert: Forest Use and Environmental Change in Tanzania's West Usambara Mountains', *Land Degradation & Development* 10, 291--309.
D'Andrade, R.G.: 1995, *The Development of Cognitive Anthropology*, Cambridge University Press, Cambridge, 286 pp.
Denning, G.: 2001, 'Realising the Potential of Agroforestry: Integrating Research and Development to Achieve Greater Impact', *Development in Practice* 11(4), 407--416.
FAO: 1976, *Forests for Research and Development*, FAO, Rome.
FAO: 1986, *Restoring the Balance: Women and Forest Resources*, FAO, Rome.
Fernandes, E.C.M.: 1990, 'Alley Cropping on an Acid Soil in the Peruvian Amazon: Mulch, Fertilizer and Hedgerow Root Pruning Effects', *Ph.D. Thesis*, North Carolina State University, Raleigh, NC.
Franzel, S., Cooper, P. and Denning, G.: 2001, 'Scaling Up the Benefits of Agroforestry Research', *Development in Practice* 11(4), 524--534.
German, L., Tolera, T. and Charamila, S.: in press, 'Managing Trade-Offs in Agroforestry: From Conflict to Collaboration in Natural Resource Management,' in A.S. Klappa and D. Russell (eds.), *Cultured Trees: Transformations in Agroforestry Systems*.
Gutteridge, R.C. and Shelton, H.M.: 1993, 'The Scope and Potential of Tree Legumes in Agroforestry,' *Agroforestry Systems* 23(2-3), 177--194.
Ivory, D.A.: 1990, 'Major Characteristics, Agronomic Features and Nutritional Value of Shrubs and Tree Fodders', in C. Devendra (ed.), *Shrub and Tree Fodders for Farm Animals: Workshop Proceedings*, Denpasar, Indonesia, July 1989. Ottowa, Canda: IDRC.
Kang, B.T., Reynolds, L. and Atta-Krah, A.N.: 1990, 'Alley Farming', *Advances in Agronomy* 43, 315--359.
Knox, A., Meinzen-Dick, R. and Hazell, P.: 2002, 'Property Rights, Collective Action, and Technologies for Natural Resource Management: A Conceptual Framework,' in R. Meinzen-Dick, A. Knox, F. Place and B. Swallow (eds.), *Innovation in Natural Resource Management: The Role of Property Rights and Collective Action in Developing Countries*, Johns Hopkins University Press, Baltimore, pp. 12--44.
Kruskal, J.B. and Wish, M.: 1978, *Multidimensional Scaling: Quantitative Applications in the Social Sciences*, Sage Publications, Newbury Park, CA, 96 pp.
Larsson, U.: 1990, *Trees as Cash Crops: Commercial Value of Trees and Forests in Babati District*, Swedish University of Agricultural Sciences, Uppsala.
Le Maitre, D.C., Versfeld, D.B. and Chapman, R.A.: 2000, 'The Impact of Invading Alien Plants on Surface Water Resources in South Africa: A Preliminary Assessment', *Water SA* 26(3), 397--402.
Lundgren, B.O.: 1982, Cited in Editorial: 'What is Agroforestry?', *Agroforestry Systems* 1, 7--12.
Lwakuba, A., Kaudia, A.A. and Okorio, J.: 2003, 'Agroforestry Handbook for the Montane Zone of Uganda,' Technical Handbook No. 31, RELMA, Nairobi.

Meinzen-Dick, R., Knox, A., Place, F. and Swallow, B.: 2002, *Innovation in Natural Resource Management: The Role of Property Rights and Collective Action in Developing Countries*, IFPRI, Washington, D.C., 317 pp.

Munk Ravnborg, H. and Ashby, J.A.: 1996, 'Organising for Local-Level Watershed Management: Lessons from Rio Cabuyal Watershed, Colombia', *AgREN Network Paper* 65, 14.

Nair, P.K.R.: 1984, *Soil Productivity Aspects of Agroforestry*, ICRAF, Nairobi, Kenya, 85 pp.

Nair, P.K.R.: 1993, *An Introduction to Agroforestry*, Kluwer Academic Publishers, Dordrecht, 499 pp.

Omiti, J.M., Parton, K.A., Sinden, J.A. and Ehui, S.K.: 1999, 'Monitoring Changes in Land-Use Practices Following Agrarian De-Collectivisation in Ethiopia', *Agriculture, Ecosystems and Environment* 72, 111--118.

Ostrom, E.: 1990, *Governing the Commons: The Evolution of Institutions for Collective Action*, Cambridge University Press, Cambridge, UK, 298 pp.

Ostrom, E.: 1998, 'The Institutional Analysis and Development Approach,' in E.T. Loehman and D.M Kilgour (eds.), *Designing Institutions for Environmental and Resource Management*, Edward Elgar Publishing, Chelthenam, UK, pp. 68--90.

Pandey, S. and Yadama, G.N.: 1990, 'Conditions for Local Level Community Forestry Action: A Theoretical Explanation', *Mountain Research and Development* 10(1), 88--95.

Pellow, D.N.: 1998, 'Negotiation and Confrontation: Environmental Policymaking through Consensus', *Society & Natural Resources* 12, 189--203.

Rocheleau, D. and Edmunds, D.: 1997, 'Women, Men and Trees: Gender, Power and Property in Forest and Agrarian Landscapes,' *World Development* 25(8), 1351--1371.

Russell, D. and Harshbarger, C.: 2003, *Groundwork for Community-based Conservation: Strategies for Social Research*, Altamira Press, Walnut Creek, CA, 322 pp.

Schroeder, R. A.: 1993, 'Shady Practice: Gender and the Political Ecology of Resource Stabilization in Gambian Garden/Orchards,' *Economic Geography* 69(4), 349--365.

Scoones, I and Thompson, J.: 2003, 'Participatory Processes for Policy Change', *PLA Notes* 46, 100 pp.

Shelton, H.M.: 1998, 'Environmental Adaptation of Forage Tree Legumes', in R.C. Gutteridge and H.M. Shelton (eds.), *Forage Tree Legumes in Tropical Agriculture*, CAB International, Wallingford, UK, pp. 120--131.

Ssekabembe, C.K. (ed): 2004, *Agroforestry Approach to Land Use: A Training Manual for Extension Agents*, Makerere University Press, Kampala, 229 pp.

Wittayapak, C. and Dearden, P.: 1999, 'Decision-Making Arrangements in Community-Based Watershed Management in Northern Thailand', *Society & Natural Resources* 12, 673--691.

Young, A.: 1989, *Agroforestry for Soil Conservation*. CAB International, Wallingford, Oxford, UK, 284 pp.

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