# Management of tree diversity in agricultural landscapes around Mabira Forest Reserve, Uganda

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## Abstract

As natural forests contract, farming systems become increasingly important to landscape biodiversity conservation, yet assets and limits of their contribution are insufficiently documented. A sound understanding of farmer strategies in the management of on-farm tree biodiversity is also critical to landscape approaches for biodiversity conservation and livelihood improvement. Diversity and management of woody species were surveyed in 105 farms around Mabira Forest in South-Central Uganda. Farms were selected according to distance to forest, landscape axis, gender, wealth, and specialized forest use of household heads. Farmer management has a strong influence on tree diversity in the coffee–banana systems around Mabira Forest. This is reflected in the relatively high number of planted and exotic species at the levels of farm niche, farm and landscape. Both the number of years under cultivation and farmer involvement in specialized forest use were conducive to higher species diversity. Gender, wealth and tenure status did not influence tree diversity. Variation in on-farm species richness was noted between landscape axes radiating out of the forest rather than concentric distance categories. Farming systems around Mabira Forest Reserve provide a key complementary rather than substitute tree diversity refuge and can be managed to enhance overall landscape biodiversity.

*Key words:* agroforestry, forest dependence, landscape biodiversity conservation

## Introduction

Biologically diverse land use systems provide a range of goods and services that are critical to farmers' pursuit for sustainable livelihoods. Farmers maintain and plant trees in farming landscapes that enhance food, fuel and medical security, especially for low-income rural people and during hungry periods, diversify income, lower production risk and optimize the management of their resources (Arnold & Dewees, 1995). As natural forests decline in surface area and vegetation quality, the contribution of these agroforestry systems to overall tree canopy cover in the landscape increases significantly over time (Place & Otsuka, 2000). At the same time, biodiversity promoted through wild habitat in agricultural landscapes can have significant and sometimes underemphasized costs to farmers in the form of pests, health risks, increased labour and foregone benefits to resource conservation. These factors influence farmer incentives to maintain a diversity of tree and other species in their systems.

There is increased recognition that conservation should look beyond protected areas and take place at the scale of landscapes to maintain ecological processes and the production of goods and services to a variety of actors. Compared with natural systems, the role of agricultural areas for the conservation of landscape biodiversity has received little attention. Trees in landscape mosaics enhance the ecological quality of the landscape matrix and provide habitat and greater landscape connectivity through buffer zones, corridors, and stepping stones for dispersal of plant and animal species (Perfecto & Vandermeer, 2002; Schroth *et al.*, 2004).

By promoting farm diversification, agroforestry can also contribute to reducing pressure of local communities on adjacent forest areas (Murniati, Garrity & Gintings, 2001). Relations between investment in agroforestry and reduced protected area resource use on one hand, as well as spatial tree diversity patterns in forested agricultural landscapes on the other need to be better understood, if the potential of agroforestry for conservation of landscape biodiversity is to be realized.

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With the higher goal of assessing constraints and opportunities for enhancing the role of agroforestry and system diversification towards landscape-level biodiversity conservation, the primary objectives of this study were to (i) analyse differences in tree species diversity among farms; (ii) identify farm and farmer parameters which influence on-farm tree diversity and its management; and (iii) assess the contribution of agroforestry farming systems surrounding the Mabira protected area to overall landscape tree diversity.

## Materials and methods

### *Study area*

The study was conducted in Mukono district, Central Uganda, bordering Lake Victoria, an area of high to medium agricultural potential. Altitude there ranges between 1150 and 1300 m above sea level (Nielsen, Guinand & Okorio, 1995). Rainfall ranging from 1200 to 1400 mm is bimodal with two seasons in March–May and September–November. The area south of Mabira Forest Reserve (FR) has relatively good market access through the road linking the two largest towns of Uganda, Kampala and Jinja to the west and to the east, respectively of the study area. Probably because of its proximity to these urban centres, the area has been subject to human migration, the rise of land prices and deforestation for agriculture and logging.

The district has a number of sugarcane and tea plantations. Outside of these industrial plantations, coffee and banana smallholder farming systems have traditionally prevailed. Main intercrops include cassava, sweet potato, maize, beans and groundnuts. Vanilla and less commonly cocoa are also found (Oduol & Aluma, 1990; Mrema, Wafula & Agaba, 2001). Decreasing tree crop yields in traditional coffee–banana because of declining soil fertility and increased pest and disease pressure, as well as the replacement of perennials with annual crops point to the degradation of these land use systems (Sserunkuuma, Babigumira & Abang, 2001). An assessment of agricultural tree diversity and associated farmer tree management practices can help inform the improved management of these agricultural landscapes.

All farms studied are located around the Mabira FR. Extending over 300 $km^2$, this forest is the largest and only block of medium altitude moist semi-deciduous forest in Central Uganda. Compared with 65 other Ugandan forests, the Mabira FR stands out for its high butterfly species richness and the uniqueness of its bird and butterfly assemblage, but has been greatly influenced by human activities (Davenport, Howard & Baltzer, 1996). Given its close location to Kampala and Jinja, Mabira FR has a strong potential for ecotourism.

### *Village and farmer selection*

To identify a possible influence of the forest on-farm tree diversity, fifteen villages were selected along five axes (Southwest, Southeast, East, Northeast and Northwest) in each of three distance categories of 0–1, 5–7 and 12–19 km relative to Mabira FR. The fifteen villages were randomly selected from a complete list of villages located in the eleven target administrative subcounties. In each village, a stratified random selection of farms was conducted with village chairmen according to gender and wealth categories. An indicative list of criteria, describing the low, middle and high ends of household types with regards to wealth, which was previously developed through focus group discussions, was provided to the chairmen. An additional farm was randomly selected from a list of village forest specialists which included herbalists, fuelwood or timber dealers, craft makers, and seed or honey collectors. In each village, a meeting was held to introduce the objectives and methodology of the study to village chairpersons and selected farmers.

All woody plants including trees and shrubs were tallied and information collected on species, number, niche, establishment method (planted, retained from natural regeneration and pre-existing at onset of cultivation). Household variables measured included family size, land tenure, off-farm employment, use of labour, house type, number and type of livestock. Data were analysed using generalized linear models (GLM) of the quasi-Poisson family and ANOVA (Analysis of deviance) using the Biodiversity.R software developed by Kindt & Coe (2005). The significance level of terms entered in the ANOVA was based on Wald tests of ANOVA type-II. The ecological classification of tree species developed by the Uganda Forestry Department for the biodiversity assessment of Mabira FR (Davenport *et al.*, 1996) was used to characterize species found in the farm survey.

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## Results

### *General results*

The majority of farmers in the survey area cultivate a single plot of land with an average farm size of about 2 ha. The average number of tree species per farm was 27.4 (ranging 7–71) with 208 trees per farm (ranging 22–1464). On the 105 farms surveyed, 21,803 trees were encountered belonging to 238 species and 61 families. Genus and or species were not identified for sixteen species. Estimation of total species richness for the survey area ranged from 270 (bootstrap estimation) to 359 species (second-order jackknife estimation) (Kindt & Coe, 2005). Together with the shape of the accumulation curve (not shown here), these statistics indicate that more species would be expected if a larger number of farms were visited. The number of species planted was 127 or 54% of all encountered species, and 37 species (16% of total species) occurred in an exclusively planted state.

Most species have low abundances (Fig. 1). Ten species of highest abundance (4% of the total number of species) contained 50% of all trees. For 14.7% of the species, only one individual tree was encountered, whereas 52.5 % of them had ten or fewer individuals. Out of the ten most abundant species (abundance >550), the abundance of five of them was predominantly because of planting (*Jatropha curcas* L.: 94%, *Ficus natalensis* Hochst.: 73%, *Carica papaya* L.: 82%, *Artocarpus heterophyllus* Lam.: 61%, *Maesopsis eminii* Engl.: 61%). The species with the highest abundance also occurred on a large number of farms. In total, 37.7% of all trees surveyed were planted. Close to half of planted trees (48.5%) were found associated with cropland. Other farm niches where planted trees were frequent included external boundaries (26.3%) and around the homestead (15.8%).

### *Landscape distribution of species richness*

Species accumulation curves constructed separately for each distance category show that farms at intermediate distance from Mabira forest were characterized by the lowest overall species richness. Size of farms in this distance group was also smaller than in the other distance categories. However, when adjusting for farm size, species richness was still lower in farms at intermediate distance from the forest compared with the other two distance categories (Fig. 2). Despite differences in value, however, regression analysis provided no evidence for significant differences at the 0.05 level in species richness per farm between distance categories (Table 1).

Accumulation curves constructed separately for each axis radiating out from the centre of Mabira FR showed that total species richness is the largest on the southwestern sides, and in decreasing order on the northwestern and northeastern sides. On a per farm basis, regression analysis (GLM with log link function and quasi-Poisson variance function, Kindt & Coe, 2005) also indicated significant differences in species richness between axes (Table 1). Farms located on the northeastern side of Mabira Forest showed a significantly lower species richness for all tree categories but a higher species number for planted

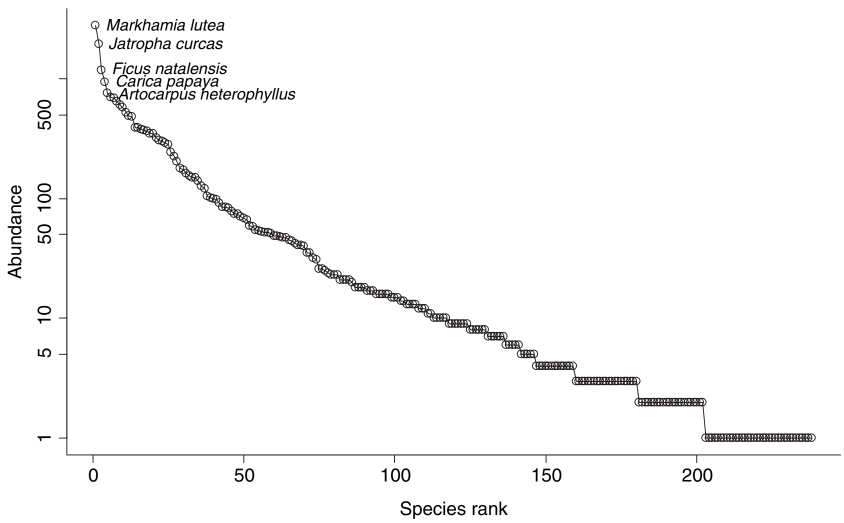


**Fig 1** Rank abundance curve (logarithmic scale) of inventoried species in the Mabira farming landscape

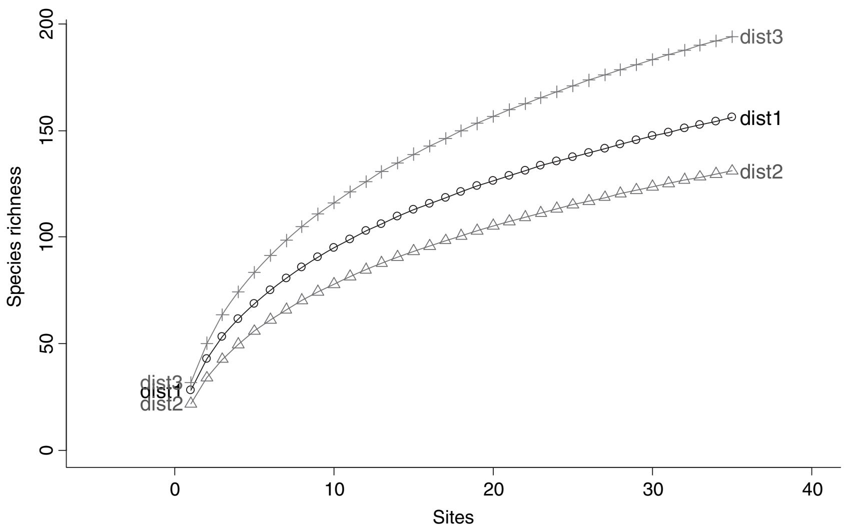


**Fig 2** Species accumulation curve pooling farm sites scaled on their average farm size

trees. The southeastern, eastern and northeastern axes contained fewer total species than the southwestern radius, with no evidence for planted trees, however. Patterns in the northwest segment were not very different from the southwest axis. Tree abundance did not show any significant variation between axes or distance categories.

### *Influence of farm parameters on species richness and abundance*

Tree species richness for all tree management categories increased significantly with the number of years the farm had been cultivated (Table 1), which ranged from 2 to 60 years with an average of 24 years in this study. Farm size had a positive effect for all trees and retained trees. Increments in species richness for larger farms become smaller, as one would expect naturally. This pattern had been observed in results of exploratory GLM models that inspired the second-order polynomial for farm size. Also, farmers known to be specialist forest users also had a greater diversity species on their farm. This effect could clearly be observed for all species, as well as forest interior and forest-dependent species ($P < 0.05$). ANOVA analyses confirmed that main differences in deviance were related to differences in farm size, number of cultivated years and being a forest user (Table 2). There was little evidence of differences among axes for all trees and planted trees.

Regression coefficients indicate that farm size was the major contributing factor to abundance of all trees and retained trees on farm; it did not contribute to the number of planted trees. Tree abundance had a positive relationship with the number of children in the family for the total number of trees and planted trees, and a negative association for retained trees with the presence of a zero-grazing unit. ANOVA results confirmed results of the regression coefficients. Surprisingly, gender, wealth and land tenure status did not appear to influence species diversity or abundance.

The cropland niche which was found on virtually all farms and represented the largest proportion of the farm's total surface area hosted the largest number of species (Table 3). Both the cropland and homestead niches had the highest and fairly similar percentage of planted and exotic species. However, the proportion of planted species relative to total niche richness was twice as high on homesteads as on cropland. Niches with higher number of species per farm also had higher total richness in the landscape. While few farms displayed tree fallow, grazing land and natural forest niches, tree richness was relatively much higher there than in other more common tree niches such as internal boundaries or woodlots (Table 3).

### *Forest dependence of tree species*

Farming landscapes were rich in forest species, but tended to reflect more open habitat characteristics. A total of 144 or 46% of the woody species inventoried in Mabira FR were also found in the surrounding agricultural landscape (Table 4; Davenport *et al.*, 1996). These did not include any of the nine species of Mabira Reserve cited as restricted-range species by Davenport *et al.* (1996), besides

**Table 1** Coefficients of GLM (log link and quasi-Poisson variance functions) explaining species richness by farm characteristics

| | All trees | | Planted trees | | Retained trees | | Non-forest dependent | | Forest dependent | | Forest interior | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Coefficient | *P*-value | Coefficient | *P*-value | Coefficient | *P*-value | Coefficient | *P*-value | Coefficient | *P*-value | Coefficient | *P*-value |
| (Intercept) | 2.92 | <0.001 | 1.48 | <0.001 | 2.72 | <0.001 | 1.89 | <0.001 | 1.82 | <0.001 | 0.52 | |
| ha | 0.12 | <0.001 | −0.05 | | 0.20 | <0.001 | 0.15 | <0.001 | 0.20 | <0.001 | 0.18 | <0.1 |
| ha$^2$ | 0.00 | <0.01 | 0.00 | | −0.01 | <0.01 | −0.01 | <0.01 | −0.01 | <0.01 | −0.01 | <0.1 |
| Distance$^2$ | −0.20 | <0.1 | −0.11 | | −0.24 | | −0.19 | | −0.24 | | −0.38 | |
| SE axis | −0.33 | <0.01 | −0.16 | | −0.39 | <0.1 | −0.38 | <0.05 | −0.39 | <0.1 | −0.37 | |
| E axis | −0.29 | <0.05 | 0.09 | | −0.48 | <0.05 | −0.28 | | −0.65 | <0.01 | −0.79 | <0.05 |
| NE axis | −0.22 | <0.05 | 0.36 | <0.05 | −0.43 | <0.05 | −0.25 | | −0.60 | <0.01 | −1.11 | <0.01 |
| NW axis | −0.21 | <0.1 | 0.07 | | −0.31 | <0.1 | −0.25 | <0.1 | −0.35 | <0.1 | −0.65 | <0.05 |
| Forest user | 0.29 | <0.01 | 0.24 | | 0.28 | | 0.21 | | 0.52 | <0.01 | 0.61 | <0.05 |
| No. cultivated years | 0.01 | <0.01 | 0.01 | <0.05 | 0.01 | <0.05 | 0.00 | | 0.01 | <0.05 | 0.02 | <0.05 |
| Brickwall house type | 0.18 | | 0.43 | <0.1 | 0.08 | | 0.20 | | 0.07 | | 0.09 | |
| No. local cows | 0.02 | | −0.05 | <0.1 | 0.05 | <0.1 | 0.02 | | 0.02 | | 0.01 | |

Only variables for which coefficients were significant in at least one of the regression analyses are shown. Four landscape axes shown are analysed with reference to the SW axis which is not shown.

**Table 2** ANOVA table for regression results expressed as percentage of total deviance estimated by model II regression where the respective variable is added to the model last

| | All trees | | Planted trees | | Retained trees | | Nonforest dependent | | Forest dependent | | Forest interior | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Coefficient | *P*-value | Coefficient | *P*-value | Coefficient | *P*-value | Coefficient | *P*-value | Coefficient | *P*-value | Coefficient | *P*-value |
| All variables | 74.0 | <0.001 | 48.8 | <0.001 | 65.8 | <0.001 | 57.8 | <0.001 | 72.9 | <0.001 | 66.0 | <0.001 |
| ha | 23.3 | <0.001 | 1.4 | | 21.3 | <0.001 | 18.5 | <0.01 | 20.1 | <0.001 | 5.8 | <0.1 |
| I(ha$^2$) | 14.1 | <0.01 | 0.3 | | 13.3 | <0.01 | 11.2 | <0.01 | 14.5 | <0.01 | 4.7 | <0.1 |
| Distance | 12.1 | <0.05 | 0.7 | | 6.5 | | 4.4 | | 6.2 | | 5.5 | |
| Axis | 14.8 | <0.1 | 15.3 | <0.1 | 10.4 | | 8.5 | | 18.8 | <0.05 | 21.2 | <0.05 |
| Forest user | 13.2 | <0.01 | 3.8 | | 3.8 | | 3.2 | | 13.2 | <0.01 | 6.9 | <0.05 |
| Wealth | 8.9 | <0.1 | 1.8 | | 4.8 | | 2.4 | | 8.5 | <0.1 | 6.9 | |
| Cultivated | 11.8 | <0.01 | 6.9 | <0.05 | 10.4 | <0.05 | 1.0 | | 9.1 | <0.05 | 9.6 | <0.05 |
| Collection in Mabira | 0.2 | | 0.2 | | 0.3 | | 0.1 | | 4.4 | <0.1 | 2.5 | |
| No. local cows | 1.2 | | 4.9 | <0.1 | 4.7 | <0.1 | 1.1 | | 1.0 | | 0.2 | |

Only variables with significant results have been included. 'All variables' is the deviance explained by all variables.

**Table 3** Species richness relative to farm niches

| Farm niche | No. farms | No. species | No. species planted | No. exotic species |
|---|---|---|---|---|
| Cropping plots | 104 | 193 | 83 | 43 |
| Homestead | 86 | 112 | 92 | 45 |
| External boundary | 90 | 97 | 35 | 21 |
| Tree fallow | 23 | 92 | 14 | 13 |
| Grazing land | 5 | 66 | 13 | 10 |
| Natural forest | 6 | 64 | 0 | 6 |
| Internal boundary | 14 | 44 | 11 | 7 |
| Woodlot | 2 | 14 | 1 | 3 |

External boundaries are boundaries between the farm and neighbouring land plots; Internal boundaries provide boundaries between different land uses located within the farm.

*Elaeis guineensis* Jacq., which is found elsewhere in and outside Uganda. Ninety four species (39%) observed in our survey, of which 63% are exotic, were not observed in the Mabira FR. In a similar pattern to Mabira Forest, for species whose ecological classification was available, the agricultural landscape hosted a far larger percentage of forest-dependent species (38%) than that of nonforest dependent species (21%). However, tree abundance in both categories of species at the landscape level was similar. Among the forest dependent species, richness was larger for forest interior species than forest edge species, while the opposite was found for their relative abundance. Within each ecological category, the ratio of species found exclusively on farm relative to those found both on farm and in the forest increased from the forest dependent category to forest nondependent category and to the open habitat species group.

In the agricultural landscape, the proportion of species with higher ecological forest dependence such as forest-dependent and forest interior species was lower than the proportion of those in the FR. This difference between the two environments was less marked for nonforest dependent species and was reversed for species characteristic of open habitat (Table 4). Yet, the number and abundance of open habitat species on farm was small, suggesting that most tree species present in these agroforestry systems occupy at least some forest habitat.

Larger and older farms had a higher richness of forest dependent trees (Table 1). The fact that farms of forest specialist users were significantly richer in forest dependent and forest interior species, but not in planted or retained trees indicates that the richer farm tree cover probably dated back to the time of farm establishment.

**Table 4** Richness, abundance and frequency of tree species found on farm and in Mabira Forest Reserve according to ecological category as defined by Davenport *et al.* (1996)

| Location | Agricultural landscape | | | | | Mabira forest | |
|---|---|---|---|---|---|---|---|
| Species type | No. species | % of species | No. trees | % of trees | % of farms | No. species | % of species |
| Exotic species on farm only | 59 | 24.8 | 7008 | 32.1 | 100 | – | – |
| Indigenous species on farm only, no ecological classification | 5 | 2.1 | 163 | 0.7 | 32.4 | – | – |
| Forest dependent species[a] | 91 | 38.2 | 6860 | 31.5 | 99.0 | 189 | 60.6 |
| Both on farm and in Mabira forest | 82 | 34.4 | 6780 | 31.1 | 99.0 | – | – |
| On farm only | 9 | 3.8 | 80 | 0.4 | 20.0 | – | – |
| Forest generalist | 40 | 16.8 | 1344 | 6.2 | 81.9 | 65 | 20.8 |
| Both on farm and in Mabira forest | 35 | 14.7 | 1314 | 5.7 | 81.0 | – | – |
| On farm only | 5 | 2.1 | 30 | 0.4 | 9.5 | – | – |
| Forest interior | 34 | 14.3 | 1684 | 7.7 | 81.0 | 98 | 31.4 |
| Both on farm and in Mabira forest | 32 | 13.4 | 1653 | 7.2 | 81.0 | – | – |
| On farm only | 2 | 0.8 | 31 | 0.5 | 5.7 | – | – |
| Forest edge | 14 | 5.9 | 3640 | 16.7 | 99.0 | 22 | 7.0 |
| Both on farm and in Mabira forest | 13 | 5.5 | 3637 | 16.6 | 99.0 | – | – |
| On farm only | 1 | 0.4 | 3 | 0.0 | 1.9 | – | – |
| Riverine and lakeshore | 2 | 0.8 | 176 | 0.8 | 21.0 | 3 | 1 |
| Both on farm and in Mabira forest | 2 | 0.8 | 176 | 0.8 | 21.0 | – | – |
| On farm only | 0 | 0.0 | 0 | 0.0 | 0.0 | – | – |
| Dry forest | 1 | 0.4 | 16 | 0.1 | 4.8 | 1 | <1 |
| Both on farm and in Mabira forest | 0 | 0.0 | 0 | 0.0 | 0.0 | – | – |
| On farm only | 1 | 0.4 | 16 | 0.1 | 4.8 | – | – |
| Nonforest dependent species[b] | 51 | 21.4 | 6727 | 30.9 | 100 | 85 | 27.2 |
| Both on farm and in Mabira forest | 43 | 18.1 | 6514 | 29.5 | 100 | – | – |
| On farm only | 8 | 3.4 | 213 | 1.3 | 23.8 | – | – |
| Open habitat species[c] | 24 | 10.1 | 331 | 1.5 | 45.7 | 18 | 5.7 |
| Both on farm and in Mabira forest | 12 | 5.0 | 265 | 1.0 | 39.0 | – | – |
| On farm only | 12 | 5.0 | 66 | 0.6 | 20.0 | – | – |
| Undetermined species | 8 | 3.4 | 714 | 3.3 | 61.9 | 20 | 6.4 |
| Both on farm and in Mabira forest | 7 | 2.9 | 713 | 3.2 | 61.0 | – | – |
| On farm only | 1 | 0.4 | 1 | 0.0 | 1.0 | – | – |
| Total | 238 | 100 | 21803 | 100 | 100 | 312 | 100 |

[a]Forest-dependent species include all species that occupy at least one of the following forest habitats: forest interior, forest edge, dry forest and riverine/lakeshore; forest generalist species occupy more than one forest habitat.
[b]Nonforest dependent species are plants that occupy at least one of the forest types and at least one nonforest habitat such as woodland, grassland, rocky places, bush/thickets, dry scrub, swamp, and moorland.
[c]Open habitat species are species that occupy any of the nonforest habitat types.

## Discussion

The strong influence of farmer management on tree diversity patterns in farms and agricultural landscapes surrounding Mabira Forest was demonstrated in several ways. First, planted species and trees including exotic species in the Mabira agricultural landscape represented a high proportion of their respective totals both at the landscape and farm levels. Comparatively, the proportion of planted trees was lower in South-Central Uganda (38%) than in the more densely inhabited and degraded Kigezi Highlands (close to 50%), thus indicating that investment in land management may be reinforced under conditions of high human population density or land degradation (Boa *et al.*, 2005). Starting with an overall higher species richness than in southwestern Uganda, farming systems around Mabira Forest also had a higher number of species planted (55%) than in the Kigezi (41%). Second, in the

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'cropland' niche, the most frequently found on-farm tree niche in the survey, 43% of occurring species are planted. Around the homestead, a less diverse niche at landscape level, this proportion rose to 83% (Table 3). Also, the study provides evidence that in these agroecological conditions, farmer management tends to promote woody species richness ($P < 0.01$) and abundance ($P < 0.1$) over time. Farmers therefore seek to optimize tree products and services by enhancing species diversity on their available land resources.

The representation of many species with only few individuals in the farming systems points to their low density and isolation, as well as the risks of reduced geneflow and curtailed ability for long term survival (Boshier, 2004). However, similar observations have been made in natural East African tropical forests (Huang *et al.*, 2002).

Specialist forest users with more direct livelihood involvement with forest products had higher overall on-farm species richness. This supports the fact that farmers invest in farm tree management even in the relative proximity of a major forest, possibly because availability or cost of access to specific products favours their integrated production on farm. It also illustrates the potential impact of enhancing farmer knowledge on tree utilization for promoting their diversity in agroforestry systems. Limitations in local knowledge coupled with limitations in availability of reproductive material are likely to result in smaller tree diversity on farms. Indeed, lack of planting material and lack of knowledge were expressed as the dominant constraints to tree planting by 30% and 15% of survey farmers respectively.

The absence of impact of land tenure on tree planting and species richness was not expected. Kibanja farmers, who form the largest (nearly 50%) tenure group in this study, derive land use rights from an informal agreement with a Mailo land owner who generally maintains ownership rights over trees (Nielsen *et al.*, 1995). The lack of correlation in this study indicates that this land tenure arrangement may afford nonrestricting tree access to Kibanja farmers and as currently practiced may not be such an important constraint to active tree management on farm.

Differences in farm tree species richness or tree abundance in the three distance categories sampled in this study were not statistically significant. This shows that the spatial concentric model of forest-farm interactions in the Mabira forest landscape does not apply simplistically within the 20-km radial scale considered and may be compounded by other processes. The increasing forest resource use by farming households with proximity to Mabira Reserve (Jourget, 2001) did not translate into observable variations of species and tree characteristics on farms in our sample. Rather than varying by distance from the forest, species richness showed significant differences between axes or segments of the agricultural landscape around Mabira, indicating the involvement of multiple locations and processes at play rather than a single source of variation linked to the forest. The lower species richness in the eastern and southeastern axes may relate to the occurrence of extensive tea and sugarcane plantations, the resulting change in land use over time and reduced tree diversity in this part of the district. Such differences between axes point to the need to refine the analysis of forest and land use patterns in these locations.

Farm size was positively correlated with species richness and the number of trees on a farm. This pattern was expected and has been observed in various natural and domesticated ecosystems. The rate of increase in species richness diminished for larger farm sizes, however. Such a pattern points to the interaction of scale and land use diversity, with a diversity of small farms contributing more to overall tree diversity and abundance in the landscape than fewer larger farms (Kindt, Simons & Van Damme, 2004).

Farming landscapes in this study displayed a significant species richness that was common to the forest environment. However, low forest dependence, high proportion of exotic species and absence of rare species also prevailed among tree species exclusively found in smallholder agriculture. These results indicate that farming systems around the Mabira FR provide a key refuge for tree diversity, but one that is complementary rather than substitutable to forest tree biodiversity. Naidoo (2004) also found that smallholder agricultural systems adjacent to Mabira had significantly different songbird community composition from the forest, but that increasing tree densities in agricultural areas would contribute to enhancing community similarity towards forest communities within a short distance from the forest. While the forest and farming environments respectively hosted 312 and 238 tree species separately, the two environments combined hosted 406 tree species or a 30% increase in the number of species, supporting the advantage of encompassing both environments in conservation planning. At the scale of landscapes, conservation and management of biodiversity will be optimized by a combination of various degrees of agricultural intensification. Therefore, management practices in both smallholder farming and forest systems should not only be geared towards improved productivity of these respective systems but also target the enhancement of overall landscape biodiversity.

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