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Tree biodiversity, land dynamics and farmers' strategies on the agricultural frontier of southwestern Burkina Faso

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Abstract. In the sub-humid part of Burkina Faso, population growth, migrations and new marketing opportunities have induced rapid land-use changes and social reorganization, leading to new approaches to natural resource management. The objective of this study was to evaluate tree biodiversity parameters in agroforestry parklands (scattered trees in crop land) as population increases and fallows become shorter. Out of about 100 tree species existing in the area, and 50 commonly found in traditional parklands, only 3 indigenous and 2 non-native species hold a significant importance for farmers, all for their fruits. No indigenous tree species are planted, but a few are protected when clearing the land. Planted cashew nut orchards develop rapidly and are seen as a land tenure guarantee and an important source of income. Given these facts, the perspectives for tree biodiversity management in farmers' land may appear bleak. Yet, the importance given by farmers to specific tree products demonstrates that trees do play a part in land development and farmers' strategies. Existing practices of farmers show potential for improved land-use and spatial patterning of the land, as revealed by emerging parklands and orchards. Our data do not confirm common statements that migrant farmers do not manage the land as sustainably as native farmers do. Rather than trying to conserve tree biodiversity as it is, researchers and developers should identify with farmers the complementarities between trees and farms and promote tree biodiversity through existing practices.

Introduction

In sub-humid West Africa, agricultural frontiers experience intense dynamics due to population pressure, migrations and changing marketing opportunities. Native farmers, herders and new settlers share a decreasing per capita land area. Rapid technological change (e.g. new crops, sedentary livestock rearing) creates previously unknown pressures on natural resources (Gray 1999; Gazel 2002; Augusseau et al. 2003; Petit 2003). In south-western Burkina Faso, tree biodiversity and traditional parklands (scattered trees in cropland) are under pressure, as fallow periods decrease and intensive cropping techniques develop. Yet trees play an important role in farmers' strategies, especially if they provide cash income. Tree biodiversity has thus to be looked at in terms of both traditional and modern farming practices in the context of changes in traditional practices and landscape structure.

Burkina Faso is renowned for its extensive parklands, especially those where the shea butter tree (''karité'', *Vitellaria paradoxa*, Sapotaceae) or *Faidherbia albida* (Leguminosae-Mimosaceae) dominate (Depommier 1996; Bayala et al. 2002). Karité is a popular fruit tree; the fruits are used in food preparations for their fat content and the fat is also used in the cosmetic industry. *Faidherbia* is widely used to provide fodder for livestock in the dry season and is a favourite species for tree–crop associations because it sheds its leaves during the cropping season and is known to improve soil fertility. Parklands are nevertheless diverse, with more than 50 tree species commonly recorded at village level (Boffa 1995). Preferred trees are protected when clearing and burning the original wooded savannah vegetation or when they naturally occur in farmland. A few exotics are planted. Some trees are tended according to farmers' needs and practices, e.g. by side pruning, pollarding for fodder collection (Petit 2003), and fruit or wood harvesting. Some parklands rely on long fallows (20 to 30 years) to regenerate a wooded vegetation.

A typical landscape in the area consists of fields with scattered trees above different crops (yam, millet, sorghum, maize, cotton), fallows of different ages and forest reserves. Animal husbandry (cattle, goats) relies on fallows and forest reserves during the cropping season and on field crop residues during the dry season. In this mosaic-like landscape, the agricultural frontier does not appear geographically distinct but is shaped by a series of factors determining where land clearing takes place, such as land availability, age of fallow, distance from village, soil and geomorphology, and vegetation type. With today's increased population pressure, other factors appear, such as human migrations and social dynamics linked to ethnicity, rangeland management and land tenure issues. Under intense social dynamics, new spatial land patterns and production practices emerge (Augusseau et al. 2003).

Fallow shortening and agricultural intensification have not necessarily resulted in land degradation and decreasing crop yields. As noted elsewhere (Mertz 2002), yields in shifting cultivation are not only influenced by fallow length but by a wide range of biophysical, socioeconomic and cultural factors. Agricultural change often occurs according to Boserup's agricultural intensification theory, with increased population pressure resulting in increasingly diversified labour input and sustained productivity in fields with shorter or no fallow period. Other examples from Africa provide evidence that, as population increases, the number of trees can also increase, especially on small farms (Tiffen et al. 1994; Backes 2001).

In this rapidly changing context, the objective of this paper is to examine tree biodiversity and its management at farm level. Farmers' strategies and decision making regarding trees are analyzed to explore linkages between farm dynamics and tree biodiversity. Based on a previous characterization of farming systems (Augusseau et al. 2000) and parkland structure (Nikiéma 2004), we elaborate on farmers' perception of land-use changes and tree roles, taking into account differences in farming practices and ethnicity.

Materials and methods

Site

Field research was implemented near the village of Torokoro in the Mangodara Department of the Comoé Province of Burkina Faso (4°25′ W; 10°03′ N). The elevation is 300 m above sea level and the landscape is flat. The site receives 1100 mm of rain per year (average 1995–2002) in a single rainy season extending from May to October. The mean maximum and minimum temperatures in Bobo Dioulasso (200 km to the North) are 32 and 22 °C respectively. Soils in the area are lixisols, deep and developed on granitic bed rocks.

The original vegetation is an open forest with an *Andropogon* grass layer where conspicuous tree species are *Isoberlinia doka*, *Daniellia oliveri* (Leguminoseae–Caesalpiniaceae), *Parinari curatellifolia* (Chrysobalanaceae), *Diospyros mespiliformis* (Ebenaceae), and several *Terminalia* species (Combretaceae). Outside protected areas, the forest has evolved towards a wooded savannah vegetation with smaller trees, due to repeated pastoral or agricultural use, and fire. Some native farmers own remote pieces of land which are actually very old fallows already influenced by repeated pastoral and agricultural use. Today's landscape has been shaped by human activity, with almost no natural forest left (Botoni 2003) and is a mosaic of dense or open woody vegetation and parklands with some riverine vegetation and, since 1999, cashew tree orchards (*Anacardium occidentale*, Anacardiaceae) (Nikiéma 2004). This includes woody fallows of different ages and crop fields under parkland tree cover of varying density, from very dense (yam cultivation, during the first year after land clearing) to low (cotton cultivation).

Population

The village of Torokoro was created a century ago by Dogossé migrants, who still have land authority: land tenure issues, especially for newcomers, have to be referred to the traditional Dogossé chiefs. Scantily populated until 30 years ago (4 persons km^{-2} in 1975), the Mangodara Department now experiences one of the highest migration pressures in Burkina Faso (7.5% year^{-1}). Since 1990, migrants have been coming from other parts of the country or from Ivory Coast. Torokoro had 790 inhabitants in 1985, all native farmers, but has now a population of more than 2700, of which native Dogossé farmers represent only 24%, while the dominant ethnic group are the Mossi, representing 41% of the population. Fulbe pastoralists started to settle about 10 years ago;

they are partly sedentary and reside in settlements outside villages. Current population density is about 20 persons km^{-2}.

Main farming practices

Native farmers have large farms of 80 ha on average (including fallows). Their main traditional practice is the selective clearing and burning of forest or fallow land, on which they grow yams for 1 to 2 years, followed by 3 to 5 years of cereals or a legume crop, after which the land is left to fallow. All crops are grown among scattered trees within parklands. Migrant farmers manage farms of about 10 ha, or less for those who arrived most recently. They clear sites similar to those cleared by native farmers but seldom grow yams, which require large areas. They seldom practice fallowing but maintain permanent parklands. They mainly grow cereals and sometimes cotton.

Data collection and analysis

Findings discussed in this paper are a combination of data obtained through aerial photographs, field surveys and farmer interviews. A total of 17 native and 21 migrant families were met in 2002 and 2003 for the characterization of farming systems and their dynamics (18 and 22 for biodiversity related data). Spatial patterns of land development were obtained through a diachronic analysis of aerial photographs from 1956, 1983 and 1998. Land-use and cover was recorded on fields during different seasons and the position of the fields was determined using a GPS.

Parkland structure and tree biodiversity were assessed at household level, differentiating between native and migrant families. Further differentiation was made between fallows and cultivated land, as well as between yam (native farmers only), cereal (both native and migrant farmers) and cotton (migrant farmers only) fields. Differentiation was also made according to the age of the field (years of cultivation) or fallow duration (years since last cropping season). In farmed areas, tree density parameters (presence, height, DBH > 10 cm) were recorded in plots of 0.25 ha (migrant farmers) to 1 ha (native and a few migrant farmers with large farms; Table 1a). Trees in fallows were sampled in 0.25 ha plots (Table 1b).

Tree biodiversity was assessed through the computation of species richness, S, Shannon's diversity index, H′, and Evenness index, J′ (see e.g. Begon et al. 1990). A standard analysis of variance was used to analyze the data. A level of $p < 0.05$ was chosen as the minimum for significance.

Farmers' strategies and perceptions about land-use changes and the importance of trees in landscape dynamics were assessed through individual or group interviews of farmers and resource persons. These were conducted with open-ended questions or with participatory techniques (matrix ranking), following a participatory research approach as described in Pretty et al. (1995).

Table 1. Tree sampling intensity (number of plots) as a function of field or fallow status and age, Torokoro, Burkina Faso, March 2003.

(a) *Field*	Field age (years)								
	1	2	3	4	5	6	7–8	9–11	Total
Native farmers	8	8	3	2	2	–	–	–	23
Migrant farmers	8	14	8	7	8	7	11	7	70
Total	16	22	11	9	10	7	11	7	93

(b) *Fallow*	Fallow age (years)						
	1	2	3	4	5–10	20–40	Total
Native farmers	1	3	4	3	2	4	17
Migrant farmers	–	–	2	–	–	2	4
Total	1	3	6	3	2	6	21

Semi-structured interviews addressed people's perception of land-use dynamics, tree functions and major farming problems and opportunities.

Matrix ranking was used to evaluate farmer perceptions of the potential of different existing land-use units to address the problems identified. A 2-entry matrix was designed to combine all possible land-uses and problems identified. Matrices were drawn on the ground on large paper sheets and people given seeds to rank priority. Care was taken to carefully explain the exercise in native language and the facilitation process was conducted with an "attitude" (Groot 2002) intended not to influence people, while giving them time to think, discuss, hesitate or change their mind before giving the final answer. Questions were asked in a neutral way; for instance "which land-use unit can help in avoiding fire problems?", not "do you think that this type of land-use unit is good to avoid fire problems?". In the case of groups (see below), time was given to interviewees to check and compare their answers and discuss their choices. Priority was assessed on a 0 to 5 scale, 1 being the lowest priority (0 = no relevance) and 5 the highest. 19 matrix exercises were performed, sampling both native (10) and migrant (9) farmers, individuals (13) or groups (6), women (2 groups, natives) or men (13 individuals, 3 groups), young men (1 group) or old men (1 group) and a mixed men and women group. No statistical analysis was performed on these data, which should be seen as indicating major trends only.

Results

Farm and social dynamics

In 1956, only 5% of the land in Torokoro was farmed, including 3% under fallow. This percentage reached 8.5% in 1983 and 29% in 1998. The amount of natural vegetation decreased proportionally, and changed from a roughly balanced proportion between open forest and wooded savannah to a strong dominance of savannah. Meanwhile, the length of the fallow phase decreased from 30 to 10–15 years or less and the area under fallow from 40 to 20%.

On-going dynamics reveal changes in land tenure and the emergence of socially patterned land areas. Recently arrived migrant farmers settle at the periphery of the main settlement area, separated from native farmers' fields. A major land-use change in the last 4 years has been the expansion of arboriculture (tree farming) of cashew trees for cash, a practice originally brought by migrants from Ivory Coast. These orchards have developed rapidly and now occupy 40% of the cultivated area. In native farms, this expansion occurs at the expense of fallows or even yam fields. Trees represent the centrepiece of this new agroforestry practice while cereals are associated to boost their growth. When renting out orchards from native farmers, migrants are allowed to grow cereals provided they tend the trees.

Originally a food crop for native farmers, yam became a cash crop in the 1980s with the availability of the new "florido" variety for urban markets. However, the area under yam has sharply decreased over the last 2 years. A shortage of fertile, fallowed land, and the cost of labour probably explain this trend. Three main alternatives to yams have appeared recently: (1) cashew orchards, (2) use of animals for land preparation and ploughing in order to intensify cereal or cotton production and (3) diversification into non-agricultural activities (shop-keeping, handicrafts, services, etc.).

The migrant farmers' objective is clearly one of long-term settling in the area while pursuing a strategy of investment in animal traction and cash generation. A strong determinant of migrant farm dynamics is the history of the migrant family: whether or not it arrives with some capital, ploughing equipment or specific skills and the structure and cohesion of the family itself. Other determining factors are land access, orchard development (average 40% of the area of the farm, an upper limit for small farms in order to be able to grow enough food crops) and animal traction (76% of all farms). Data from recently planted orchards reveal that tree planting density is half what it was a few years ago, showing that migrant farmers give priority to the production of crops rather than trees.

Increasingly limited land access has been associated with the recent appearance of land transactions, a formerly unknown practice locally. Thus, in-migration induces strong changes of the local system towards intensification.

Parkland structure and present tree biodiversity

A total of 101 tree species (from 39 plant families) were found in the cultivated area (fields + fallows). All fields and fallows are strongly dominated by karité (Table 2), but less so in old fallows. These old fallows belong mostly to native farmers who call them "forest reserves" since they look like the natural vegetation of the area, which has virtually disappeared (Botoni 2003). Thus, in

Table 2. The 10 main tree species in fallows and fields, Torokoro, Burkina Faso, March 2003 (% of total tree number).

Old fallows (> 20 years)	%	1-year old fields	%	Fields 2–5 year old	%
Vitellaria paradoxa	14.8	*Vitellaria paradoxa*	55.0	*Vitellaria paradoxa*	56.9
Maranthes polyandra	11.5	*Isoberlinia doka*	5.6	*Tamarindus indica*	8.1
Isoberlinia doka	8.6	*Lannea acida*	4.9	*Anacardium occidentale*	4.0
Daniellia oliveri	5.6	*Diospyros mespiliformis*	4.5	*Parkia biglobosa*	3.1
Parinari curatellifolia	5.6	*Manilkara multinervis*	3.4	*Diospyros mespiliformis*	2.7
Combretum sp2	5.3	*Tamarindus indica*	3.1	*Detarium microcarpum*	2.1
Monotes kerstingii	4.3	*Fagara xanthoxyloïdes*	2.2	*Combretum sp2*	1.3
Lannea acida	3.3	*Bombax costatum*	2.0	*Acacia dudgeoni*	1.3
Diospyros mespiliformis	3.0	*Combretum sp2*	2.0	*Isoberlinia doka*	1.1
Isoberlinia dalzielli	3.0	*Maranthes polyandra*	2.0	*Pterocarpus erinaceus*	1.1
Fields > 5 year old*	%	Young fallows (< 10 years)	%	Fallows 10–20 year old	%
Vitellaria paradoxa	50.3	*Vitellaria paradoxa*	67.7	*Vitellaria paradoxa*	26.5
Anacardium occidentale	11.0	*Diospyros mespiliformis*	4.6	*Parinari curatellifolia*	12.0
Parkia biglobosa	7.0	*Acacia dudgeoni*	3.8	*Combretum sp2*	9.4
Tamarindus indica	5.9	*Parkia biglobosa*	2.3	*Lannea acida*	6.8
Mangifera indica	5.8	*Combretum sp2*	1.5	*Maranthes polyandra*	6.0
Diospyros mespiliformis	1.6	*Ficus platyphylla*	1.5	*Pericopsis laxiflora*	6.0
Detarium microcarpum	1.4	*Ficus sur*	1.5	*Piliostigma thonningii*	5.1
Anogeissus leiocarpus	1.3	*Lannea acida*	1.5	*Pteleopsis suberosa*	3.4
Bombax costatum	1.1	*Maranthes polyandra*	1.5	*Bombax costatum*	2.6
Ficus platyphylla	1.0	*Monotes kerstingii*	1.5	*Hymenocardia acida*	2.6

*Migrant farmers only

managing parklands, farmers strongly modify the species diversity of natural vegetation or fallows towards a dominance of useful tree species.

As expected, tree biodiversity decreases with age of the fields (Figure 1). However, a strong variability is observed and changes over time should be

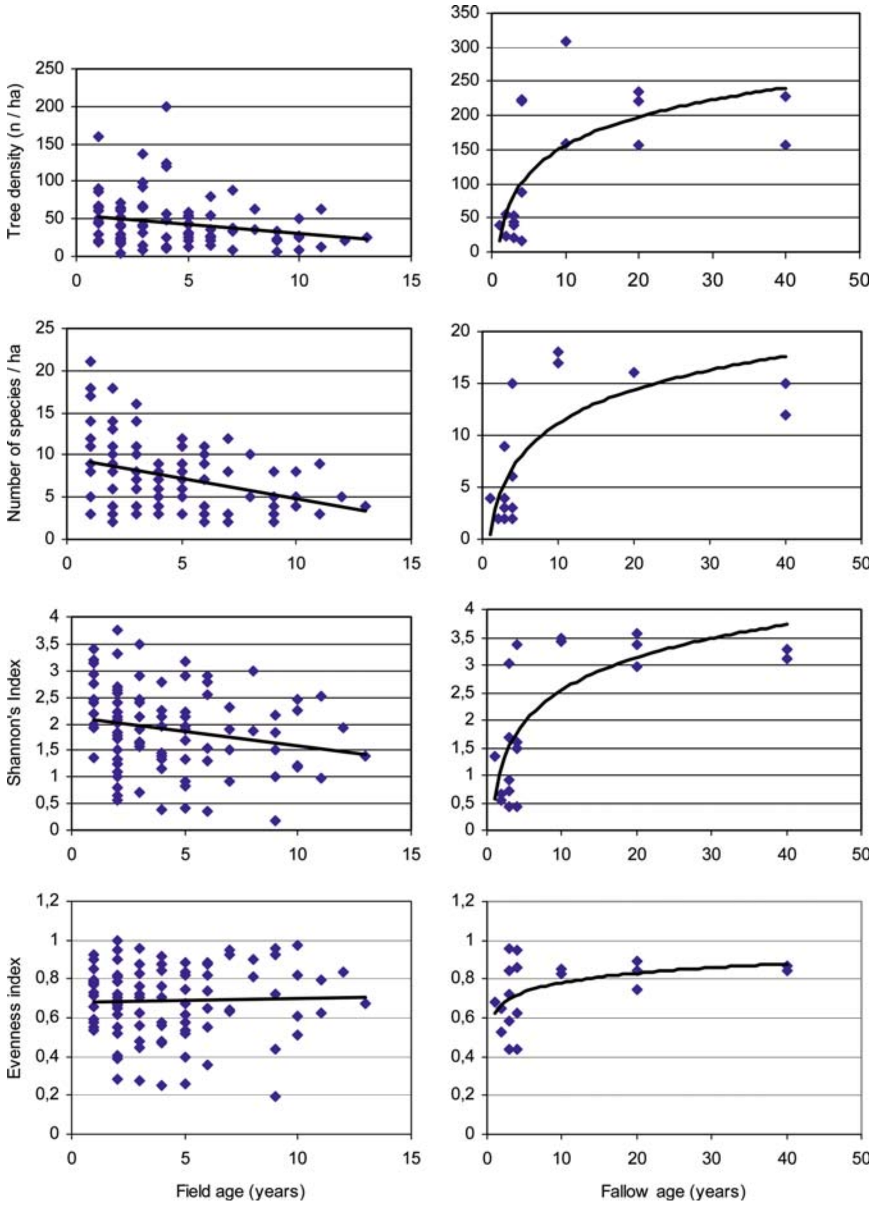

Figure 1. Tree biodiversity parameters as a function of field and fallow age, Torokoro, Burkina Faso, March 2003.

considered as trends only. As fields become older, tree selection by farmers leads to a dominance of fewer species, especially fruit trees (Table 2). Tree biodiversity data as a function of field type, land-use unit and farmers' social status confirm the above trends: yam fields (all in 1-year old clearings) appear different from both cereals and cotton fields, which do not differ among them (Table 3). As fields become older, tree biodiversity parameters first decrease, then increase during the fallow phase (Table 4). Low values in young fallows are probably explained by the choice of 10 cm as the minimum DBH size for sampling. No major differences can be found between native and migrant farmers' fields (all fields together, Table 5), except for richness, higher in the case of native farmers, probably because of a high proportion of yam fields (35%) where a lot of trees are kept as stakes for the yam vines. However, migrant farmers, who own small farms and do not fallow the land, conserve a high proportion of "useful" trees in their fields, as a strategy to establish permanent parklands. In 5-year old fields (owned by migrant farmers only, Table 2), such trees (without karité) account for 30% of total tree number, including 2 exotics (mango and cashew).

Land tenure and trees

Land access for migrants is provided through a long term loan which provides the right to use the land as long as the family stays in the village. Traditionally, tree products are shared between the landowner and the tenant farmer. Recently arrived farmers may secure annual land rents only without any rights on trees. Normally, access to wild tree products is free, but observations show that spouses of the landowners have more-or-less exclusive rights to harvest karité and néré (*Parkia biglobosa*, Leguminosae-Mimosaceae), thereby excluding the migrant land user. Thus, native and migrant farmers experience contrasting situations as far as parkland trees are concerned. However, it has to be noted that migrant farmers started to plant cashew trees without any land rights. Cashew orchards thus appear as an innovation readily adopted by farmers.

Table 3. Tree biodiversity in cultivated fields, Torokoro, Burkina Faso, March 2003.

Field type	Density (trees ha^{-1})	Richness (species ha^{-1})	Shannon index (H′)	Evenness index (J′)
Yams	64.3	11.8^{a}	2.5^{a}	0.72
Cereals	42.2	7.0^{b}	1.8^{b}	0.68
Cotton	36.3	5.7^{b}	1.3^{b}	0.68
	NS	$p < 0.01$	$p < 0.05$	NS

Mean values with different superscript in a column differ significantly at the probability level indicated in the lower part of the column; NS: not significant.
Aggregated average values for the plots sampled (Table 1).

Table 4. Tree biodiversity in land-use units, Torokoro, Burkina Faso, March 2003.

Land-use unit	Number of plots	Density (trees ha^{-1})	Richness (species ha^{-1})	Shannon index (H′)
Old fallows (> 20 years)	6	202.0	32.0	3.3
1-year old fields	16	54.6	12.1	2.5
Fields 2–5 years old	52	40.2	7.2	1.8
Fields > 5 year old (migrants)	25	31.0	5.9	1.7
Young fallows (< 10 years)	13	39.7	3.3	1.1
Fallows 10–20 years old	2	234.0	52.0	3.4

Due to unequal number of sampling plots in different land-use units, no statistical analysis was performed on these values. See text for major trends detected.
Aggregated average values for the plots sampled (Table 1).

Table 5. Tree biodiversity parameters as a function of farmers' social status (all fields together, see Table 1), Torokoro, Burkina Faso, March 2003.*

	Density (trees ha^{-1})	Richness (species ha^{-1})	Shannon index (H′)	Evenness index (J′)
Native farmers	44.0	9.2^a	2.0	0.64
Migrant farmers	43.2	6.3^b	1.8	0.70
	NS	$p < 0.01$	NS	NS

*Mean values with different superscript in a column differ significantly at the probability level indicated in the lower part of the column; NS: not significant.

Farmers' perception and strategies

All farmers declare that farming is done for subsistence. However, 93% (including most natives) grow cashew and 100% of natives grow yams (two cash crops which are only sold) and sell other fruits, excess crop or cattle in good years, or have off-farm income. Thus, although they rely on food they grow themselves, farmers also give much attention to earning cash.

Almost all farmers want their farm to develop, but very few farmers (25% of migrants and no natives) have investment projects in mind. Thus, it can be deduced that this increase is perceived in terms of extensification (via fallows and cattle), not intensification. About 50% of migrant farmers own land somewhere else and can expect earnings from it (e.g. cocoa in Ivory Coast) in order to invest. This is confirmed by the fact that migrant farmers have more farm implements (plough, weeder, draught animals, etc.) than do native farmers.

When asking farmers about major changes experienced as far back as they can remember (or since they arrived in the case of migrants), 56% mention decrease of woodland (probably combining fallows and wooded savannah) and human population increase. Their perception of soil fertility is that it is good, and that the area has water problems (mainly poor quality drinking water, but also lack – or decrease – of rain). Fifty percent of the farmers mention satisfactory harvests and adequate food security. When asked about a vision of their land in 10 years, 75% of the farmers mention high human population and land saturation. Only one farmer mentioned a likely decrease in tree cover. Lack of farm implements is mentioned by 62% of the native farmers and only one migrant.

Only five tree species are significantly important for all farmers, and of these only two are planted by all farmers. Both are exotics: mangos (in fields and around houses) and cashews (in orchards). Karité and néré are protected by all farmers, but never planted. Tamarind (*Tamarindus indica*, Leguminoseae–Caesalpiniaceae), an exotic introduced centuries ago which regenerates naturally, comes next. A few other trees are commonly protected by farmers (*Khaya senegalensis*, Meliaceae; *Diospyros mespiliformi*s, Ebenaceae; *Pterocarpus erinaceus*, Leguminoseae–Fabaceae; *Bombax costatum*, Bombacaceae; *Afzelia africana*, Leguminoseae-Caesalpiniaceae). The only consistent use of trees mentioned is the collection and sale of fruits, for earning cash. Wood was mentioned only once. Fodder was not mentioned. No management is performed on trees, except cashew tree pruning and orchard maintenance. Occasional side pruning is performed on trees in cropland. No difference was noticed between the perception of tree uses by native and migrant farmers.

When asked whether there are ''natural'' trees in their cropland, farmers did not answer. They considered all trees in their fields not to be natural, but to be there as a result of their action (planting or protection). As noted elsewhere (e.g. homegardens in Indonesia: Soemarwoto 1987), agroforestry systems, sometimes rightly described by scientists as mimicking natural environments (e.g. Joffre et al. 1999), are not perceived as natural by farmers, who see them as the result of their labour.

When asked about changes experienced as far as trees are concerned, a third of the farmers (mostly migrant farmers) responded that the number of trees had decreased. About 60% of the farmers felt that tree cover and production will have increased within 10 years, and only 12% were concerned about as possible decrease in tree numbers. However, women rank the decrease in tree cover as an important problem.

When asked about the potential of the different land-use units to address the problems identified, almost all native farmers mentioned fallow land as an important element of their strategy, while only 12% of migrant farmers did. Since the former control land tenure access for newcomers, they still own large land areas and can leave them to fallow for about 13–15 years while migrant farmers hardly achieve 3–5 years of fallowing, if at all. However, all farmers, including migrants, surprisingly identify fallow land as the most important land-use unit (see matrix ranking results, Table 6). The least preferred land-use unit to address the problems identified, again for everybody, is yam cultivation. Fallow land is again systematically mentioned as the preferred land-use unit to increase or maintain tree density. Field crops are mentioned as being incompatible with trees, as if parklands would not contain trees. Fertility improvement is not a reason mentioned by farmers to keep trees in cropland, but when adding farmers' answers on the potential of different existing land-use units to

Table 6. Ranking matrix: land-use units or activity vs. identified problems, Torokoro, Burkina Faso, March 2003[a].

	Yam fields	Cereal fields	Cashew orchards	Womens' groundnut plots	Fallow	Bushland	Livestock	Total
(a) *Migrant farmers*[b]								
Soil fertility decline	10	14	6	21	28	4	9	92
Fire problems	10	9	17	22	10	0	16	84
Disturbance by livestock	5	19	19	7	10	9	0	69
Rainfall irregularity	10	0	19	0	16	22	5	72
Land water shortage	0	0	7	0	7	10	2	26
Cropland shortage	0	22	5	10	14	15	15	71
Tree cover decrease	10	5	10	4	23	17	5	65
Total	45	69	83	64	108	77	42	
(b) *Native farmers*[c]								
Soil fertility decline	13	7	7	22	30	27	5	111
Fire problems	3	15	13	2	0	0	23	56
Disturbance by livestock	0	5	16	0	10	10	3	44
Rainfall irregularity	0	0	14	0	12	15	8	49
Land water shortage	5	10	10	5	10	15	10	65
Cropland shortage	0	5	10	5	14	4	10	48
Tree cover decrease	4	5	4	0	27	13	13	66
Total	25	47	74	34	103	84	72	

[a]The question asked was: which land-use unit or activity (x) appears to you the more appropriate to address the problem (y)? Priority was assessed on a 0 to 5 scale, 0 being the lowest priority (cannot address the problem in question) and 5 the highest. Figures should not be regarded as absolute values but rather indicate trends. Only strongly contrasting figures (e.g. very high vs. very low) are worth considering.
[b]9 interviews: 7 men, 1 mixed group men/women, 1 group elderly men.
[c]10 interviews: 6 men, 2 womens' groups, 1 group elderly men, 1 group young men.

address identified problems (Table 6), soil fertility ranks as the first problem, for both native and migrant farmers.

Discussion

Our observations show that it is the fallow phase which allows tree biodiversity to recover. Farmers' perception on how to address farming problems match with our findings about the importance of fallows. In today's changing land-use system at the agricultural frontier, with fallows of short duration, and an increasing importance of cash crops, this biodiversity restoration phase is altered. However, a decline in tree biodiversity also occurs during the various phases of cultivation (Tables 3 and 4). Tree biodiversity recovers to some extent during the fallow phase, either through invasion of the abandoned land through seed dispersal from surrounding trees, or through regrowth of stumps or germination and growth of residual seeds in the fields. The decreasing length of the fallows means less time for reinvasion and regrowth of trees, although most of the incoming species have established within the first 10 years (Figure 1). The increase in species during the fallow depends on (a) the intensity and duration of cultivation (and therefore the number of propagules – seeds, live root stocks – remaining in the soil), and (b) the presence of mature seed trees in surrounding land units, from which invasion of the fallow lands can take place. Thus, intensity of cultivation, duration of the cropping phase, and extent of the area under cultivation all impact on tree biodiversity.

Since one can postulate that the tree crop synergy observed in the parklands and during the fallow phase is beneficial to the environment and to farmers, an important question is: how can today's land management system allow tree biodiversity to stay at a level compatible with sound environmental management and farmers' needs? Can farmers achieve their production objectives, and still rely on parklands, with tree biodiversity as it is modified by the new land management system? As known in biodiversity assessments, changes in species diversity are influenced by variations at ecosystem level, especially in terms of habitat fragmentation (e.g. Weibull et al. 2003; Melbourne et al. 2004). Similarly, landscape patterns reflect the scale and organization of agricultural activities and their impact on biodiversity (Ernoult et al. 2003). In the last instance, it is not the number of species which matters; it is the ecosystems in which they can survive, i.e. in the case of agricultural land-use, the different land-use units which, in turn, determine ecological niches. It is the mosaic of different land units, each in a different phase of the clearance–cultivation–abandonment–recovery–clearance cycle, which is important in maintaining ecological niches and thus tree biodiversity overall. In another African agroforestry context, tree biodiversity was found to be dependent upon the maintenance of traditional land use practices and on the mosaic-like distribution of various land management units, including those with social and cultural significance (Backes 2001). Clearly, if biodiversity changes are suspected and are to be monitored and addressed, the diagnostic can be in terms of number of species, but the cure has to be in terms of [agro]ecosystem health.

Thus, in order to influence tree biodiversity in a way which could be compatible with farmers' objectives, actions could be implemented to favour the land-use units which traditionally harbour tree biodiversity (i.e. fallows and related woodlands). The objective would be to maintain a mosaic of land units among which land uses shift, alternately eliminating some species (when the land is cleared and cultivated) and allowing some recovery (when the land is temporarily abandoned). This landscape level management is the key to the maintenance of biodiversity in these systems (Finegan and Nasi 2004). Can this be achieved in today's context? At first sight, the answer is no. As population increases and more land is cropped, especially for cash crops or tree crops, fallows will inevitably decrease in area and duration, if not disappear altogether. In the wetter conditions of the Amazon, the reduction of fallow length from 10 to 2–4 years has been shown to change the landscape from a shifting mosaic in steady-state condition to a non-equilibrium landscape where secondary vegetation tends to disappear and agricultural areas expand (Metzger

2002). These secondary vegetation areas are precisely the zones where trees are regenerated for future parklands. Thus if trees are considered to be indispensable to maintain farming conditions, alternatives have to be found.

The little importance given by farmers to trees other than the three favourite native ones and the two common exotics is probably linked to the fact that forests and fallows are still widespread in southwestern Burkina Faso and that farmers so far have no problems in obtaining fuelwood or tree fodder. Although the data show a decrease in tree-bearing land-use units, this decrease is not yet sufficiently well perceived by farmers that they are prepared to modify their practices to maintain more tree cover.

Land use in Torokoro depends strongly on factors such as markets, labour, capital, tools, etc., and this will affect the proportion of the different land units. Land use in Burkina Faso today is characterized by a strong move towards commercial agriculture. A recent study shows that 40 to 50% of farmers are no longer subsistence farmers but are commercially oriented (Ducommun et al. 2004). In Torokoro, the cash crops yam, cashew nut and cotton are witnesses to this national trend and demonstrate that the progression of the agricultural frontier does not necessarily end up in land degradation. So the challenge to maintain parklands' tree biodiversity in "good" condition also needs to take into account the increasing commercialization of agriculture. Clearly, this trend is likely to continue and it can be asked whether parkland trees have a place in tomorrow's agriculture of Torokoro.

Most traditional agroforestry trees can be described as domesticated or semi-domesticated species (Simons and Leakey 2004). The protected trees in farmland are actually trees which have undergone a long traditional selection process (Leakey et al. 2004). The fact that farmers do not perceive trees of the parklands as natural confirms this and tells us that the greater challenge is how, in managing those species that people retain because they are useful, they can also enhance the potential to conserve the broader suite of species making up "natural biodiversity". Of course, it is highly unlikely that one will be able to conserve all of it, but surely the challenge is to conserve more and lose less. Without saying that natural biodiversity does not matter, it has to be acknowledged that it is this tree-[agro]biodiversity which matters to farmers. Such trees, among which karité is of utmost importance, will certainly keep a key place in farming practices, but it is likely that this place will not be equivalent to today's place in parklands. A more intensified tree management, perhaps similar to what is already being used for cashew trees, can be anticipated. The development of cashew tree orchards is a major trend observed elsewhere in the region (e.g. Ivory Coast: Dugué et al. 2003). As shown by the new practice of cereal cultivation within cashew nut orchards, agroforestry will probably evolve towards something closer to arboriculture than parkland. Agricultural research ought to be ready for this. Changes in agricultural policies need to be implemented as well (e.g. see Dugué et al. 2003, for a discussion on this in neighbouring Ivory Coast). Another important issue, beyond the objectives of the present study, concerns the viability of the livestock sector if the cultivated area expands and the fallow areas get smaller.

Spatial analysis and interviews in Torokoro have shown an amazing capability of farmers to transform and stabilize landscape units, be it in terms of parklands or orchards. From the migrant farmers' perspective, the landscape units they have created are new for this part of Burkina Faso and indicate a willingness for a sustainable management of permanent farms. In arguing for the role of agroforestry for biodiversity conservation, Huang et al. (2002) showed that functional groups, i.e. sets of tree species with similar impacts on ecosystem processes, can be identified. They identified ecological (soil erosion control, water management, N fixation), livelihood (food, cash) and conservation (wood, fruit, fodder, hunting) functional groups of trees and insist that farmer's needs can be satisfied only if all such groups are found in farmland. Otherwise, farmers will encroach into protected or other land to satisfy their needs. In parklands, the three groups are represented by scattered trees in the landscape. In a new, intensified, tree-based agriculture, different groups will probably occupy different niches. Agroforestry research needs to identify such niches and adapt tree improvement to them, e.g. fruits in upper storey trees in cropland, wood in boundary trees, soil and water conservation in hedges, etc. This pragmatic attitude, close to farmers' changing practices, will certainly yield more results than a plea for the continuation of present parklands at any cost.

However, the above trend may favour a tree-covered landscape, but not necessarily a landscape with a high tree biodiversity. For the latter to occur, fallows have to exist. Given the fact that farmers still perceive them as important land-use units (even if they do not own fallow land), there may also be a scope to enrich natural fallows with useful species and transform them into attractive land units on an economic point of view, not only as soil restoration mechanisms. Such an alternative would also benefit other types of biodiversity (e.g. birds, insects, soil flora and fauna, etc.). Unfortunately, it goes against present agricultural intensification trends and any effort towards this solution should be carefully evaluated keeping also in mind that it is a mix of fallows of different ages that will be able to retain a healthy natural biodiversity.

All opportunities should nevertheless be seized to make use of parklands' biodiversity potential to keep a tree-covered landscape. Some parklands, notably the *Faidherbia albida* parklands further north in Burkina Faso, function more or less like permanent fallows, with crops associated at times, but tree cover remaining as a permanent feature (Depommier 1996). In Torokoro, the continuous cropping by migrant farmers in a parkland/savannah landscape shows a similar pattern.

As shown elsewhere (e.g. Opdam et al. 2003) some landscape cohesion has also to be maintained for biodiversity persistence, for example corridors between landscape units and net-like structures in the landscape matrix. In agroecosystems, landscape heterogeneity at farm scale has also been found to favour species richness (Weibull et al. 2003). Intense farm dynamics and landscape patterning in Torokoro definitely show some potential for this.

Conclusion

The main message put forward in the present paper is that existing tree biodiversity in south-western Burkina Faso parklands is threatened by changing agricultural practices. This change is not the result of worsening farming conditions or poverty driven migrations, but the result of a dynamic, market oriented agriculture. It is not yet perceived by farmers to be a problem. They insist that soil conditions in their area are satisfactory and consequently do not appear concerned by shortening fallows which is the causal factor behind tree biodiversity decrease. Two research strategies can address this challenge. On the one hand, one might draw attention to the gradual disappearance of those land units that determine tree biodiversity and to the fact that parkland tree biodiversity will be more affected in the near future. This would lead to research on the 'how?' and 'why?' of present parklands/fallows and the conditions for their biological and social reproduction. This strategy is likely to fail as it does not take into account farmers' perception of soil fertility and willingness to benefit from emerging markets. On the other hand, our results can be analyzed to show that some innovation potential exists among farmers, including migrant farmers, and that this potential should be seized to introduce a new tree biodiversity challenge, through the management of permanent parklands. This challenge is that of an intensified agroforestry, relying on tree improvement and the promotion of specialized agroforestry niches, including in the context of arboriculture. All in all, the agricultural frontier should not be seen as a negative process but as an opportunity for new sustainable development alternatives combining farmers' know-how with changing external factors.

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