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State and trends of woody vegetation cover in the cotton-based farming system zone of Western Burkina Faso

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ABSTRACT

This study was carried out in Bala, a village located in the cotton-based farming system zone of Western Burkina Faso. The objective was to assess the effect of increased cotton cultivation on the spatial dynamics and structural characteristics of the woody vegetation. Using aerial photos, an analysis of the land use for the years 1952, 1981 and 1999 was carried out. An inventory covering 25 smallholders' fields and fallows as well as the vegetation of a protected area (biosphere reserve of hippopotamus ponds) was carried out to evaluate the gradients of tree species richness and density. The results showed drastic changes in land use in Bala between 1952 and 1999. Cultivated areas which covered only 10% of the total land surface of the village in 1952 increased to 48% in 1999. A total of 44 woody species from 34 genera and 26 botanic families were recorded, out of which, 31 species were found in the protected area, 15 species in relatively recent fallows and 12 species in cultivated lands. Tree density in cultivated areas decreased as farmers' level of mechanization shifted from manual cultivation to partial ploughing, complete ploughing and motorized farming. On the other hand, tree species richness and density were higher both in the protected area and fallows than in cultivated lands confirming the key role that protection and fallowing play in the reconstitution of woody vegetation. Management of woody vegetation should take into account the level of mechanisation and the needs of farmers in order to sustain the production of indigenous trees on farms while allowing the intensification of the production of annual crops.

Keywords: Land use, cotton, farm, fallow, tree, Burkina Faso

INTRODUCTION

Many countries in the semi arid of West Africa are experiencing profound changes due to rapid population growth, migrations and changing marketing opportunities with associated pressures on natural habitats and their flora and fauna (Söderstrom et al., 2003). The growing population and the subsequent increasing demand for food, has ultimately led to conversion of natural woody vegetation to farmed parkland (INERA, 1998).

In the Upper Mouhoun valley in western Burkina Faso, the population density was estimated at about 30 inhabitants per km^2 in 1985, with a yearly growth rate averaging 5.5%. Over 82% of the population was rural and dependent on agriculture and animal husbandry (Söderstrom et al., 2003). The success in the control of the river blindness and trypanosomes allowed increased use of this area by farmers and herders migrating from more densely populated regions, thus creating a pressure on the natural resources (Gray, 1999). Furthermore, the introduction of cotton cultivation during the past four decades has resulted in widespread deforestation to create more farmland. The removal of woody vegetation, the shortening of fallowing period, and poor farming practices are known to cause soil erosion, thus raising questions about the sustainability of the system. Changes in land use are recognized as important causes of natural resources degradations (Gazel, 2002). Land use changes may have a negative effect on woody species population structure.

The current study aimed at assessing the evolution of woody vegetation cover and investigating the influence of land use types on woody species richness and tree population structure in the cotton-based farming system zone of Burkina Faso. We hypothesised that the development of cotton cultivation, change in the level of mechanization and duration of continuous cultivation of fields have adverse effects on woody vegetation cover, tree population structure and species richness.

MATERIAL AND METHODS

Study site location

This study was carried out at Bala, a village located within the cotton-based farming system zone of Western Burkina Faso, at 4°01' longitude west and 11°33' latitude north. The village covers an area of about 7575 hectares (Laine et al., 1990) and is located at 65 km north of Bobo-Dioulasso. Based on floristic and climatic features, Bala is within the South-Sudanian zone (Monod, 1957; Guinko, 1984). The characteristic of natural vegetation in this zone is tree and shrub savannah with sparse forests. Anthropogenic vegetation is widespread, characterized by the so-called traditional agroforestry parklands (scattered trees on farmlands), dominated by few tree species such as *Vitellaria paradoxa*, *Parkia biglobosa, Tamarindus indica* and *Lannea microcarpa*. Fallow lands are also common and are characterised by species such as *Combretum* spp, *Diospyros mespiliformis, Piliostigma thonningii, Entada africana Terminalia* spp. and *Daniellia oliveri*. The village is delimited in its north-western part by a biosphere reserve that covers a total area of 16354 ha, encompassing a permanent hippopotamus' pond of 660 ha which has been integrated to UNESCO's network of biosphere reserve in 1978 (Taïta, 2001).The landscape of the village is flat. Two types of soils are encountered in the village Regesols and Luvisols. Average monthly temperatures ranged between 27 and 33.2 °C. The annual rainfall ranged between 957 and 1100 mm, with 4 to 5 months of cropping period (May-September).

Cartography

In order to assess spatial patterns of land-use/ land-cover changes in Bala between 1952, 1981 and 1999, an analysis was carried out by interpreting aerial photographs collected from 'Institut Géographique du Burkina' (IGB).The choice of these reference years was done in relation with the development of cotton cropping in the area: 1952 corresponded to the year before cotton crop was introduced in the area; 1981 the year when cotton cultivation started expanding significantly; and 1999 which was the year of large scale expansion of cotton cultivation.

Woody vegetation inventory

Three land use types were taken into account for woody species inventory: (i) cultivated lands, (ii) fallow of short duration (less than 5 years), (iii) protected forest that is the vegetation of UNESCO's "Biosphere reserve of hippopotamus pond". Fallows aged more than or equal to 20 years were not present in the village at the time of the study, justifying why they were excluded from the sample.

In cultivated lands, a further subdivision of field types was made, based on two criteria: level of mechanization and field ages (Table 1). Then, twenty-five (25) smallholders involved in cotton growing were randomly selected within the village. Four categories of smallholders were distinguished with regard to their level of mechanization: Manual Smallholders (MS); Partially Mechanized Smallholders (PMS), using animal traction (with a plough) to perform some cropping operations while the others are still done manually; Completely Mechanized Smallholders (CMS) with all cropping operations being performed by means of animal traction; and Motorized Cultivation (MC) using a tractor. With respect to field age or cultivation duration, three categories of fields were identified: fields aged between 1 and 10 years of continuous cultivation, fields of age ranging between 11 and 20 years and fields of over 20 years of continuous cultivation.

Quadrants (inventory plots) were laid out within each land use type, totalling 48 quadrants in cultivated area, 16 quadrants in fallows <5 years. Quadrant sizes were 100 m x 100 m (1 ha) in uncultivated areas and 50 m x 50 m (0.25 ha) in cultivated areas. Quadrant sizes in uncultivated and cultivated areas were different because vegetation in cultivated lands generally has lower tree density than that of uncultivated lands.

The inventory consisted in identifying all woody species of stem circumference between 20 cm and 1.30 m. For each individual tree, the stem circumference, the height and the crown diameter were measured. Tree crown diameter was measured in two directions (East-West and Nord-South) and the resulting mean diameter was used to estimate the basal projection of the canopy. Trees with stem circumference lower than 20 cm were considered as part of regenerating trees.

Data analysis

SIG ATLAS GIS (windows and DOS versions) was used to estimate the diversity and surfaces of the different land use types identified from interpretation of aerial photos. The following categories of woody vegetation units were used to characterize the landscape: (i) anthropogenic vegetation including farmlands and fallows; (ii) tree and shrub savannahs; (iii) gallery forests or vegetation along watershed; (iv) artificial vegetation or plantations; and (v) settlements.

After drawing draft maps, field checking was done. Quantitative analysis of woody vegetation was carried out using SPSS version 12. Summary statistics were used to provide information on species richness, frequencies, and densities. Arithmetic means of tree density as well as percentage of crown groundcover were computed for each land use type. Histograms of tree circumference and height classes were plotted to analyze tree population structures of the different vegetation types.

The generated variables (tree density and crown cover) per quadrant were also subjected to an analysis of variance (One-way ANOVA) using Minitab release 14, considering land use types, farm level of mechanization and field ages as main factors.

RESULTS

Characterization of land use and land cover changes between 1952 and 1999

In 1952 more than 89% of the land surface of Bala was covered with four major types of vegetation: tree savannah, shrub savannah, gallery forests and fallow land (Table 2, Figure 1). Cultivated lands represented less than 10% of the village total area. In 1999, cultivated areas had increased drastically, covering approximately half (48%) of the village area. The rate at which cultivated lands increased was estimated at 93% from 1952 to 1981. This rate shifted to 175.4% between 1981 and 1999 and reached 430.8% between 1952 and 1999. The results showed that this expansion of cultivated areas was followed by a marked reduction of the other types of vegetation, mainly

Table 1: Number of quadrants (100 m x 100 m) as a function of field cultivation duration and equipment level, Bala, 2000, Burkina Faso.

Fields Cultivation Duration	Number of quadrants by category of smallholding				
	Manual Smallholding (MS)	*Partially Mechanized Smallholding (PMS)*	*Completely Mechanized Smallholding (CMS)*	*Motorized Cultivation (MC)*	**Total**
1 -10 years	3	5	5	3	**16**
11 - 20 years	3	5	5	3	**16**
> 20 years	3	5	5	3	**16**
Total	**9**	**15**	**15**	**9**	**48**

Table 2: Land use/ land cover in years 1952, 1981 and 1999 in Bala, Burkina Faso

	Area (ha)			Cover rate (%)		
Land-use/ land cover types	1952	1981	1999	1952	1981	1999
Cultivated land	781.1	1505.5	4146.6	9.1	17.5	48.3
Fallow land	220.3	727.9	170.7	2.6	8.5	2.0
Tree savannah	4518.2	1747.7	1121.6	52.6	20.3	13.1
Savannah with shrubs	2017.5	3237.0	2058.2	23.5	37.7	24.0
Shrub savannah on cuirass soil	320.7	635.8	356.1	3.7	7.4	4.1
Gallery forest	734.3	734.3	734.3	8.6	8.6	8.6
Plantation	0.0	3.6	4.6	0.0	0.1	0.1

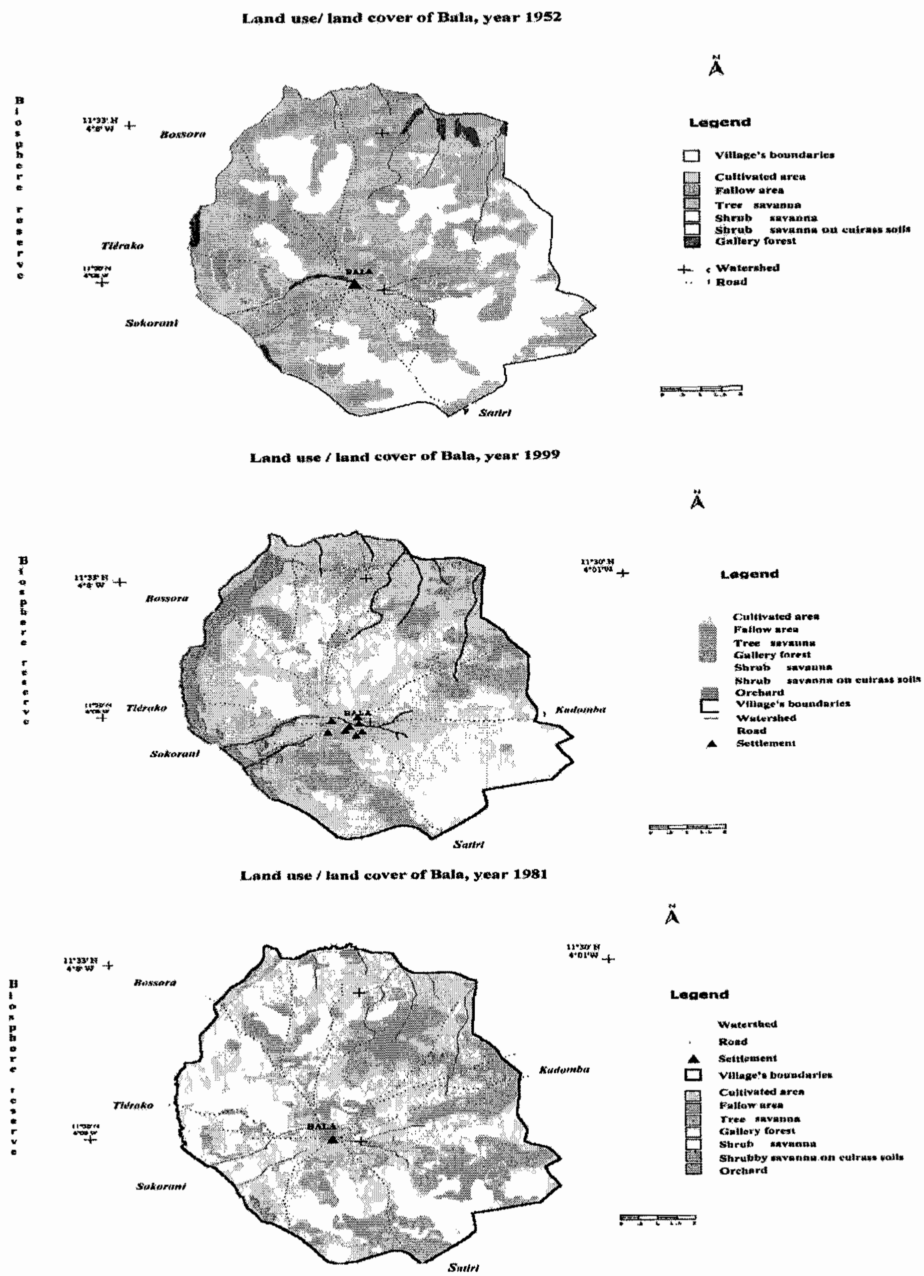

Figure 1: Maps of Bala showing the land use/ land cover in 1952, 1981, and 1999

savannahs with trees and shrubs. From 1952 to 1999 (47 years), the area with tree savannah was reduced at a drastic rate of 75.2%.

Tree planting or traditional agroforestry parkland enrichment was not observed in the village in 1952 (Figure 1). Analogously to the trend observed in cultivated areas between 1952 and 1981, fallows showed a high increase in term of land cover, with an extension rate being estimated at about 230.4%. Similarly, the areas covered with shrub savannah also increased at a rate of 98.3% between 1952 and 1981. The area allocated to plantations did not increase much between 1981 and 1999 and was only confined to an area close to the village settlement.

Land use and tree species composition

A total of 44 tree species was recorded, out of which 31 species were within the biosphere reserve (old fallow), 15 species in young fallow and 12 species in cultivated areas (Table 3). The species belong to 34 botanic genera and twenty six (26) families.

Forty six percent of the trees in the three land use types were leguminous plants, composed by following the families: *Caesalpiniaceae*, *Mimosaceae* and *Fabaceae*. The tree species richness was two folds higher in the biosphere reserve than in cultivated areas and recent fallows.

The species *Acacia albida, Azadiratcha indica, Cordia myxa, Diospyros mespiliformis, Sclerocarya birrea, Lannea microcarpa,* and *Ficus spp* were specific to cultivated areas.

Almost all species encountered on cultivated lands were useful trees preserved during field clearing. The most common were fruit trees, namely *Vitellaria paradoxa, Parkia biglobosa, Tamarindus indica, Diospyros mespiliformis* and some fodder trees like *Pterocarpus erunaceus.* Only one species was exotic (*Azadiratcha indica*) and confined to cultivated areas (Tables 3 and 4).

Tree population structural characteristics

Results showed that the vegetation in the biosphere reserve and in recent fallows was mainly composed of small sized trees, while farmland vegetation was dominated by medium to large sized trees. Indeed, figure 2A shows that 91% of trees in the biosphere reserve and 89% of the trees in recent fallows had their stem circumferences ranging between 20 and 60 cm while in cultivated areas, only 17% of trees fell into this category. In cultivated areas, the majority of the trees (70%) were of medium size, having their stem circumferences ranging between 60 and 150 cm (Figure 2A).

With regard to tree height classes, Figure 2B shows that the woody vegetation both in cultivated land and recent fallows were dominated (94% and 85%, respectively) by trees ranging between 5 and 15 m of height while in the biosphere reserve, most of the trees (98%) had their height less than or equal to 10 m.

High density of trees was recorded in biosphere reserve with an average of 377 trees ha^{-1}. This density fell to 120 trees ha^{-1} and 10 trees ha^{-1} on recent fallows and cultivated land, respectively. Similarly to the density of trees, the rate of tree canopy basal projection proportionally decreased from the biosphere reserve (44.2%) to recent fallows (13%) and cultivated area (6.1%) (Figure 3A).

In cultivated areas, as shown in Figure 3B, tree density was lowest in fields cultivated between 21 to 30 years. Indeed, it was recorded a mean density of 12.0 trees ha^{-1} in fields aged between 1 and 10 years, 10.2 trees ha^{-1} in fields aged between 11 and 20 years and 7.6 trees ha^{-1} in fields over 20 years of age. Contrary to tree density, the rate of tree crown cover recorded in each category of field age, namely fields aged from 1 to 10 years (6.1%), 11 to 20 years (7.0%) and over 20 years (5.0%) showed no statistical difference (P= 0.190).

Taking into account the farmer's level of mechanization based on tools used to perform cropping operations, results showed a significant decreased (P= 0.020) in tree density from manual farmers' fields (13.4 trees ha^{-1}) to partially mechanized farmers' fields (11.6 trees ha^{-1}), completely mechanized farmers' fields (8.5 trees ha^{-1}) and motorized farmers' fields (7.9 trees ha^{-1}). The mean crown cover rate recorded in manual farmers' fields was higher than in the other equipment classes; even though these differences were not statically different (Figure 3A).

Table 3: Tree species recorded by land use type

		Land use			
	Tree species	**All the land uses**	**Biosphere reserve**	**Recent fallow** (< 5 years)	**Cultivated land**
1	*Acacia albida Del.*				+
2	*Acacia dudgeoni Craib.*		+	+	
3	*Acacia seyal Del.*			+	
4	*Annona senegalensis Pers.*		+	+	
5	*Azadirachta indica Juss*				+
6	*Combretum molle R. Br.*		+		
7	*Combretum nigricans Lepr.*		+	+	
8	*Cordia myxa*				+
9	*Crossopterix febrifuga (Afz.) Benth*		+		
10	*Daniellia oliveri (R.) Hutch.* et *Dalz.*	+			
11	*Detarium microcarpum G.* et *Perr*		+		
12	*Dichrostachys glomerata (Forsk.)*		+		
13	*Diospyros mespiliformis Hochst*				+
14	*Entada africana G. et Per*		+	+	
15	*Feretia apodanthera Del.*		+		
16	*Ficus sp*				+
17	*Gardenia erubescens Stapf.*		+		
18	*Gardenia ternifolia K. Schum.*		+		
19	*Grewia bicolor Juss.*		+		
20	*Heeria insignis (Del.)O Kze.*		+		
21	*Hymenocardia acida Tul.*		+		
22	*Lannea acida A. Ric*		+	+	
23	*Lannea microcarpa Engel et krause*				+
24	*Lannea velutina A. Rich*		+	+	
25	*Maytenus senegalensis (Lam.)Exell*		+		
26	*Ostryoderris shuhlmanii Taub. Dunn*		+		
27	*Parinari exelsa Sabine*		+		
28	*Parkia biglobosa (Jacq.) Dc*	+			
29	*Piliostigma thonningii (Sch.) Miln.*		+	+	
30	*Prosopis africana (G. et Per) Taub*		+	+	
31	*Pteleopsis suberosa Engel.* et *Perr*		+	+	
32	*Pterocarpus erinaceus Poir.*		+		+
33	*Pterocarpus lucens Lepr.*		+		
34	*Sclerocarya birrea (Rich) Hochst.*				+
35	*Securidaca longipedunculata Fer.*		+	+	
36	*Sterculia setigera Del.*		+		
37	*Strychnos innocua Del*		+		
38	*Strychnos spinosa Lam*		+		
39	*Tamarindus indica L.*				+
40	*Terminalia macroptera G. et Per.*		+	+	
41	*Terminalia avicennioides G.et Per.*			+	+
42	*Terminalia laxiflora Engel*		+	+	
43	*Vitellaria paradoxa Gaerth*			+	+
44	*Vitex doniana Sw*		+		+
	Total number	**2**	**31**	**15**	**12**

+ = Specie present in the land use

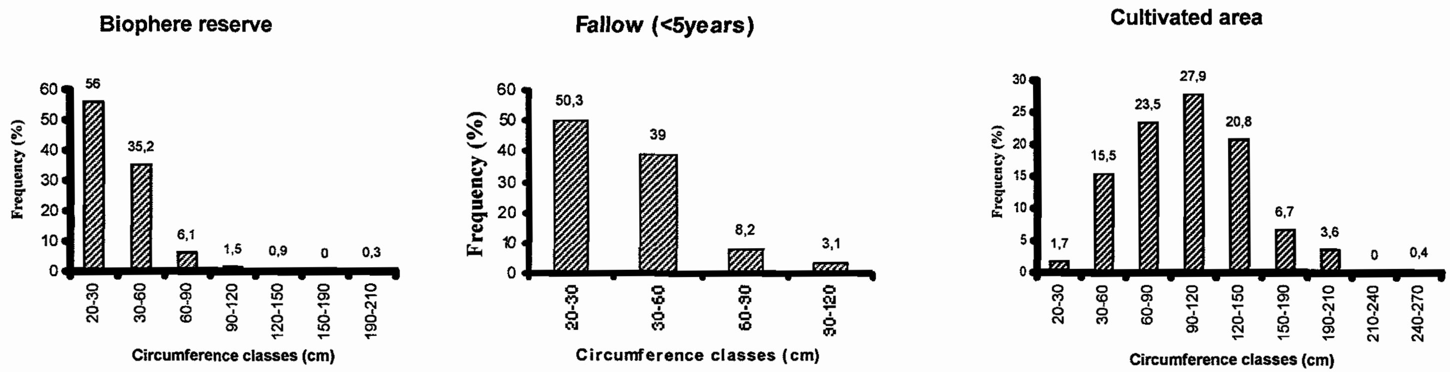

Figure 2A

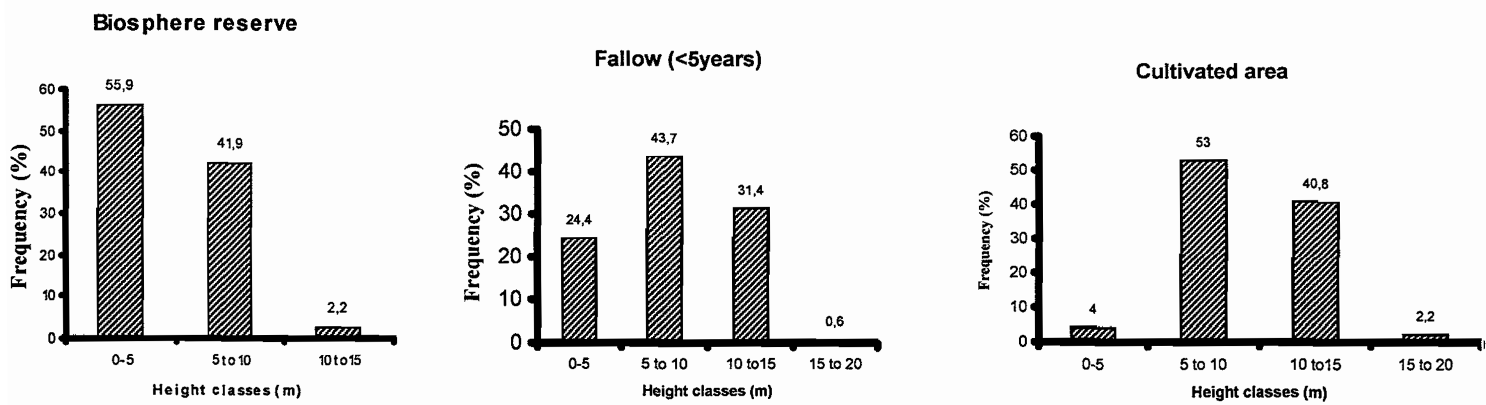

Figure 2B

Figure 2: Distribution of tree population by land use type: (**A**) Circumference classes; (**B**) Height classes.

Table 4: Tree species recorded as a function of the level of mechanization

	Tree species	Level of mechanization				
		All equipment level	**Manual cultivation**	**Partial ploughing**	**Complete ploughing**	**Motorized cultivation**
1	*Acacia albida Del.*				+	
2	*Azadirachta indica Juss*				+	
3	*Cordia myxa*		+			
4	*Daniellia oliveri (R.) Hutch.* et *Dalz.*				+	
5	*Diospyros mespiliformis Hochst*				+	
6	*Ficus sp*			+		
7	*Lannea microcarpa Engel et krause*		+			
8	*Parkia biglobosa (Jacq.) Dc*	+				
9	*Pterocarpus erinaceus Poir.*		+			
10	*Sclerocarya birrea (Rich) Hochst.*		+			
11	*Tamarindus indica L.*		+	+		
12	*Terminalia avicennioides G.*et *Per*		+			
13	*Vitellaria paradoxa Gaerth*	+				
14	*Vitex doniana Sw*				+	+

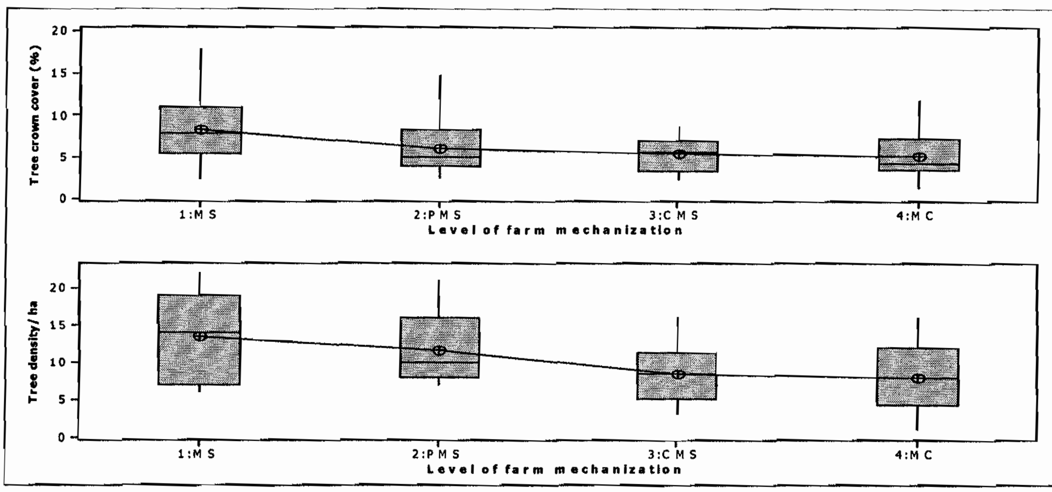

Figure 3A

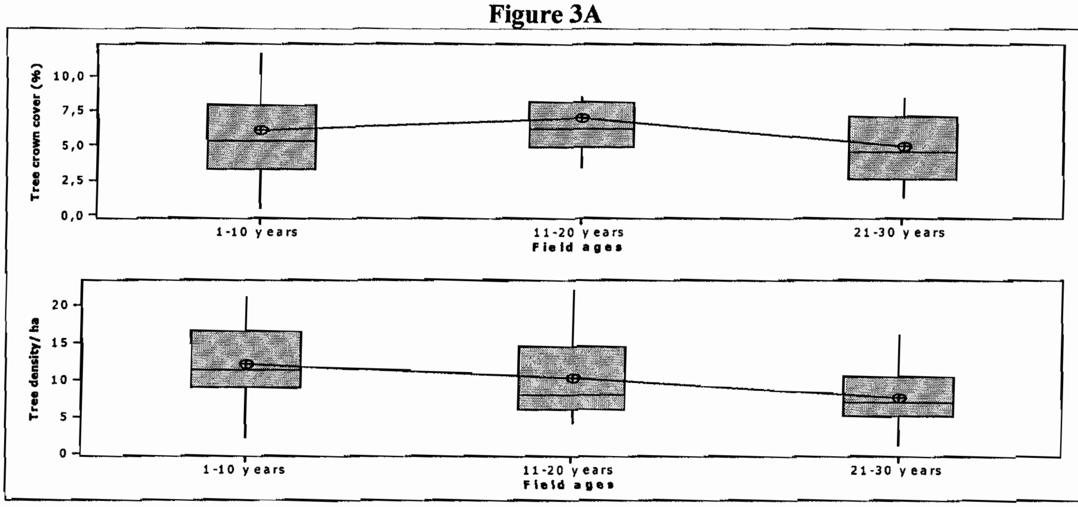

Figure 3B

Figure 3: Trends of (**A**) tree crown cover and (**B**) tree density according to field ages and levels of mechanization: Manual Smallholders (1:**MS**); Partially Mechanized Smallholders (2:**PMS**); Completely Mechanized Smallholders (3:**CMS**); and Motorized Cultivation (4:**MC**)

DISCUSSION

Results showed a strong shrinkage of areas covered both by tree and shrub savannahs between 1952 and 1999 and a drastic expansion of cultivated lands. During the 1950s, most if not all smallholders were manual, using only simple farm tools and implements to perform farm work. This technical constraint associated with the low population explained the low agricultural pressure observed at that period.

The acquisition of more efficient farming tools (ploughs and tractors) during the 1980s allowed farmers to cultivate more lands. The 1980s also showed an increase of the village population due to both the natural growth of the population and migration into the more fertile areas of the country. According to Bélem (1985) and Schwartz (1993), that period corresponded to the increase of smallholders' family sizes. Moreover, in order to refund credits for agricultural inputs given to smallholders involved in cotton cultivation by the cotton company (SOFITEX) and to make substantial profits from their farm produce, the only way out for most smallholders was to extend their farm lands. The combined effects of these phenomena resulted in a great increase of cultivated areas in the village.

The removal of trees during field clearing resulted in an impoverishment of tree species richness in farmlands in which only comestible fruit trees (*Vitellaria paradoxa, Parkia biglobosa, Tamarindus indica, Vitex doniana,* etc) and fodder trees (*Pterocarpus birrea, Ficus sp*) were preserved. On the contrary, the greater number of woody species encountered in recent fallow lands implied that fallow phase has favored the regeneration of tree species. This supports the findings of Nikièma (2004) who inventoried 90 woody species in fallow lands and 65 species in cultivated land of Torokoro, in South-western Burkina Faso.

Tree density in cultivated lands was reversely proportional to both the smallholder's level of mechanization and the duration of continuous cultivation, agreeing with the findings of Bayala and Lamien (1997). Field clearance was purposely done not only to remove non desired trees, shrubs and grasses within the plots before cultivating but also to protect fields from bush fires. According to Boffa (1995) and Nikièma (2004), during field establishment, farmers do not only eliminate trees which do not offer tangible services but also prune useful tree species to reduce the tree crown cover to a minimum.

The results indicated that trees occurring in cultivated lands were mostly of medium to large sizes in comparison to those in recent fallows or in the biosphere reserve. The decline of tree density in farmlands as a result of a drastic removal of trees during the clear-cut of cropping areas (Lamien *et al.*, 2004) ultimately leads to a reduction of competition between species for growth factors such as light, water and nutrients, not to mention the fact that trees might also benefit from mineral and organic fertilizers used for cotton cultivation. Consequently, trees tend to grow larger in cultivated land than in fallows and natural vegetation. Another possible explanation is that smaller trees are removed systematically throughout the cultivation and that only the largest remain in the end of cultivation.

The lack of young trees in cultivated lands is a sign of ageing tree population while recent fallow and the biosphere reserve vegetations were characterized by a predominance of small individual trees. The high proportion of small sized trees in fallow lands suggested that fallowing played a vital role in tree regeneration. However, the dominance of medium to large trees in cultivated areas was an indication of tree aging but your explanation about the possible removal of small trees in cultivated areas is valid here. These findings corroborate those of Taïta (1997) and Bayala et al., (2000) who showed evidence of reduced tree densities, low regeneration and aging tree population in traditional agroforestry parklands in Burkina Faso. The low level of regeneration of trees in cultivated lands associated with the regular (yearly) removal of re-spouts from tree stumps and roots as well as the uprooting of some tree stumps during cultivation phase were mentioned in previous reports (Boffa et al., 1994; Yaméogo, 1997; Bayala and Lamien, 2000).

The significant decrease of tree density with field age implies that even after field establishment, some trees initially preserved are gradually cut down in order to allow a better development of crops and make agricultural work easier. As trees grow larger in older farmed lands, their crowns consequently expand thereby explaining why no significant difference was found in the tree canopy cover with field cultivation duration. In general, the rate of tree crown basal projection on the ground was smaller in mechanized fields than in fields cultivated manually. The lowest densities of trees recorded in motorized and completely mechanized smollholders' fields suggest that the use of mechanized implements (ploughs) and tractors were less compatible with parkland development. Indeed, all mechanized and motorized smallholders were actively involved in cotton cultivation, and it is well known that successful cultivation of cotton crop requires among other growth conditions, plenty of sunshine (heliophyte plant).

Conclusion

This study revealed that cultivated land in Bala has increased rapidly at the expense of tree and shrub savannahs. Results also showed drastic changes in woody vegetation characteristics (density and species richness) in close relation with land use types, agricultural intensification (mechanization) and cultivation duration of fields. Tree density and diversity were significantly lower in cultivated land than in recent and old fallows. Manual and partially mechanized farmers conserved more trees in farmlands, whereas completely mechanized and motorized farmers seemed to remove more trees.

The main cause of natural resources degradation in the cotton-based farming systems was not related to the cultivated crop species but to farming practices. The efficiency of farming tool and continuous cultivation were the key factors of woody vegetation degradation.

These findings would help conceiving short, medium and long-term planning to protect the environment from irreversible degradation. Improved agronomical techniques such as balanced fertilization, residue management and cultivation practices that conserve soil organic matter need to be developed to maintain soil fertility (Bayala et al., 2005). These agronomic practices have to be supplemented with agroforestry technologies like contour plantings, improved tree fallows (using atmospheric nitrogen fixing trees) and enrichment plantings on farmed land.

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