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Plant biodiversity and vegetation structure in traditional cocoa forest gardens in southern Cameroon under different management

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Abstract Floristic surveys were performed in 17 traditional cocoa forest gardens under different management regimes in the humid forest area of southern Cameroon, to assess the impact of intensification on plant biodiversity. This impact was evaluated by analyzing species richness, vegetation structure, carbon sequestration and above ground biomass. We hypothesize that: (a) plant (tree and herbs) species richness is negatively correlated to management intensity and (b) vegetational density predictably change with management intensity. Our results show that management as practiced in traditional cocoa forest gardens in southern Cameroon following a gradient of intensification from extensive cocoa forest gardens with high floristic diversity to intensive ones strongly impacts plant diversity, plant biomass and to some extend carbon storage with possible negative consequences on biodiversity. Great differences in species richness, species composition, and, for trees, diameter at breast height and basal area were evident among the five types of traditional cocoa forest garden systems investigated. In terms of plant species richness, we found a decreasing gradient of plant species numbers from extensive forest gardens to intensive ones. This study also highlights the importance of the Management Index for quantifying differences in the management; this index could be used to standardize certification procedures and assess conservation progress and success. Our findings support the idea that traditional cocoa forest gardens can help to protect many forest species, sustains smallholder production and offer more scope for conservation of biodiversity, at both species-level and landscape-level. Moreover, diverse traditional cocoa forest gardens may help in regulating pests and diseases and allow for efficient adaptation to changing socioeconomic conditions.

Keywords Agroecology · Biodiversity conservation · Cocoa agroforest · Intensification · Management index · Management regime · Southern Cameroon

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Introduction

Agroforestry involves either the incorporation of trees in agricultural cropping systems or the incorporation of crops in forest systems. Traditionally, agroforestry research has focused on the first development pathway (the incorporation of trees in agricultural cropping systems) with less attention on multi-strata cropping systems that mimic the structure of natural forests (Lefroy et al. 1999; Muschler and Beer 2001). In southern Cameroon the structure of the landscape is characterized by natural rainforest, forest gardens (mixed tree plantations surrounding or at some distance from villages, usually less intensively tended than homegardens and they include a higher percentage of native trees (Wiersum 2004), homegardens and annual field crops (Degrande and Duguma 2000). Several research projects have focused on homegardens with little attention to other types of agroforests such as traditional forest gardens (TFGs) (Guyer 1984; Ruf and Schroth 2004). It is only since several years that these "intermediate" management systems (Michon and De Foresta 1997) are gradually receiving increasing interest (Laird et al. 2007; Sonwa et al. 2007). In such systems tree composition is adapted to local needs, and their structure is close to that of natural forests. Their management practices are influenced by their relationship to the other components of the land-use system and are oriented at using a combination of multiple forest resources (Sonwa et al. 2001; Schroth et al. 2004; Perfecto et al. 2005). Their adaptive nature offers options for combining biodiversity conservation and production for human benefits (Greenberg et al. 2000; Reitsma et al. 2001; Perfecto et al. 2004; MCNeely and Schroth 2006; Gordon et al. 2007; Steffan-Dewenter et al. 2007). TFGs are developed as a result of the interactions between local communities and forests and reflect various forms of human creativity in dealing with forest resources. They could be regarded as a mixture of natural forest tree species such as fruit tree species, timber species, semi-cultivated woody plants (*Elaeis guineensis*) and cultivated plants (cocoa and bananas), presenting a high level of plant diversity, and potentially be of high conservation value (Zapfack et al. 2002; Bobo et al. 2006; Merijn et al. 2007; Sonwa et al. 2007). They form a dynamic component of an integrated local land-use system, providing supplementary products such as fruits, cash crops, firewood and/or medicines. Moreover, TFGs provide opportunities in developing new approaches in conservation of tropical rainforests and biodiversity, as well as increased recognition of indigenous land-use systems as a possible way for sustainable development (Gordon et al. 2007; Steffan-Dewenter et al. 2007).

This paper aims to demonstrate the impact of management intensity on plant diversity and vegetation structure of TFGs in southern Cameroon. This impact can be evaluated by analyzing species richness, vegetation structure, carbon sequestration and above ground biomass. We hypothesize that: (a) plant (tree and herbs) species richness and management intensity are negatively related (b) vegetational density predictably change with management intensity.

Methods

Study sites

Our surveys were conducted in the semi-deciduous rainforest region in five major cocoa-growing regions within 17 cocoa farms in southern Cameroon. The study areas are located between 2°35′N and 4°15′N and 11°48′ and 11°15′E. The altitude varies between 450 and 715 m above sea level and is characterized by a subequatorial climate, with a bimodal rainfall regime. The mean annual temperature is around 25°C with a relatively small thermal variation. The mean annual rainfall is around 1,900 mm. The soils are Oxisols/Ultisols, which make up about 80% of the soils in the humid forest region of Cameroon and the pH of the soil varies from 4.29 to 5.43 (Kotto-Same et al. 1997; Kanmegne et al. 2006).

The five regions may be characterized as follows: (1) Ngomedzap is in the south around the Mbalmayo forest reserve, which is partially logged due to a low-population density with old cocoa forest gardens (~50 years and more) near the forest margin or in the dense forest; (2) Obala in the center, with no original forests remaining because of very high human population density and relatively old cocoa forest gardens (~40 years and more), located in strongly degraded semi-deciduous forest near houses and villages; (3) Bakoa and (4) Kedia in the northern extreme west with old (~30 years and more) and young (~8–15 years) cocoa forest gardens, respectively, in forest galleries at the forest-savannah transition zones; and (5) Talba in the northern extreme east with mature cocoa forest gardens (~15–20 years) in or near the forest. The Ngomedzap area is considered by cocoa farmers to be less technified (more dense and diverse shade, fewer chemical inputs) and could be compared to the "rustic" cocoa areas (Greenberg et al. 2000) reported in Latin America. The Kedia and Talba areas are considered to be more technified (less dense and diverse shade, high-chemical inputs) and are seen as the pioneer front in cocoa cultivation in southern Cameroon.

Five Union of GICs (Common Initiative Group) and four federations of cocoa farmers within the five regions were identified and selected for the study, regrouping 41 GIC with a total of 2,597 cocoa farmers. In each region, the process started with a community meeting with the help of ASPA (Appui aux Stratégies Paysannes et à la Professionnalisation de l'Agriculture) of the Ministry of Agriculture and Rural Development (MINADER) to inform all cocoa farmers and the respective "Common Initiative Group" (GIC) about the objectives of the study and to ask for their participation and action planning. During the pilot phase, 20 cocoa farms were inspected per union. We selected the farms according to a land-use intensity gradient based on density, plant diversity, height of shade trees, percent of shade and herb cover and the age of cocoa trees (Philpott et al. 2006). The selected farms represented individual land holdings. Ngomedzap was considered as an extensively managed old traditional cocoa forest garden (EO), Bakoa as an extensively managed young traditional cocoa forest garden (EY), and Obala as a home garden cocoa forest (HG), because all plantations are located very close to the houses in the village. Talba was considered to be an intensively managed mature traditional cocoa forest gardens (IM) and Kedia as an intensively managed young traditional cocoa forest gardens (IY). The management practices in Bakoa were similar to that of Ngomedzap, but with less dense and diverse shade and moderate chemical inputs. Farmers in Bakoa claimed to have trained those of Talba in proper management of their cocoa plantations that resulted in their higher production. The rate of pesticides application, insecticides applied, the main used of plant species and intentionally introduced tree species were assessed through individual interviews with selected farmers. In all our study sites cocoa production was the main cash crop, occupied most of the landscape and accounted for more than half of the total cocoa production in southern Cameroon, with 28% of the total production of the whole country (Annon 2002).

Plant survey and estimation of tree biomass

The ecological survey was performed between July and December 2005 in five cocoa growing regions in the humid forest area of southern Cameroon, which include both evergreen and deciduous rainforest. We selected 17 cocoa plantations (sites) within five types of traditional cocoa forest gardens (TFGs) namely EO, EY, HG, IM, and IY as follows: two EO (Ngomedzap), four EY (Bakoa), IM (Talba), and IY (Kedia), respectively, and three HG (Obala). Vegetation characteristics were determined within 600 m^2 plots (20 $\times$ 30 m) in each site. For each site, all non-cocoa trees with diameter at breast height (dbh) $\geq$10 cm were individually counted, numbered, identified and their density per plot estimated. Their crown class, dbh, as well as their full height was measured and the basal area (BA) was calculated. The BA per quadrate (600 m^2) was calculated as follows: BA (m^2/ha) = $\Sigma 0.00007854D^2$, where D is the dbh per tree. The BA is included to give a rough approximation of plant biomass production, which usually increases with age (Carrière et al. 2002). The above ground tree biomass was calculated using the equation $\ln B = -3.375 + 0.948 \times \ln (D^2 \times H)$ (Steffan-Dewenter et al. 2007), where B is the aboveground biomass, D is the dbh, and H is the total tree height, respectively.

Herb species were sampled and counted in 15 quadrates of 2 $\times$ 1 m^2 in each plot per TFG. Scientific and vernacular names (the latter given by local cocoa farmers and local traditional practitioners) were recorded. The uses of each species (nutritive, timber, medicinal plants, fertilizers, etc.) were also determined. Species that could not be identified in the field were collected, pressed in between newspaper for later identification at the National Herbarium of Cameroon (Yaoundé). Also, within each site, cocoa tree parameters (i.e., spacing between cocoa trees, tree density, cocoa tree height, girth, crown depth and width, height of branching, and the number of chupons per tree, respectively) were monitored to assess management practices. These 17 study sites had a minimum size of 1 ha and a minimum distance to the nearest neighbor of 500 m. Sampling was standardized and performed on a spatial unit size comparable to typical management unit to avoid correction of richness data by rarefaction or through estimators. Diurnal temperature (°C) and relative humidity (%) were measured under standardized conditions (sunny days, 8–10 a.m.) in each plot. A combine Electronic hand-held hygro-thermometer (TECPEL CO LTD, Taiwan: Model DTM 321_ DTM 322) was used to measure temperature and relative humidity while daily rainfall was measured using a plastic pluviometer (Littoclime S.A, France). Canopy cover was measured at ten points per site using a hand-held spherical densiometer (R.E. Lemmon Forest Densiometers, USA) to estimate shading intensity.

A management index (MI) (Mas and Dietsch 2003; Philpott et al. 2006) was used to summarize vegetation variables per site in each region whereby all variables subjected to be affected by management were converted to a scale from 0 to 1 and then summed. We divided values for each variable in each site by the highest overall value, and then subtracted this from 1. All values were summed for a total possible of 7 (since seven vegetative variables were included in the index), where 7 is most and 0 is least-intensively managed site.

Diversity indices and statistical analysis

The number of species S (species richness) (Samways 1984; Krebs 1989), the Shannon index of diversity H' (Colwell and Huston 1991), the Berger-Parker index of dominance d

(Magurran 1988), and index of evenness *E* (Shannon and Weaver 1949) were selected to examine α –diversity within all sites and habitat (TFG). We also used the Jaccard index (1) of plant similarity to examine β-diversity among the habitats.

$$J_I = S_{ij} / \left(S_i + S_j - S_{ij} \right), \tag{1}$$

where S_{ij} = shared species; S_i = richness in first site; and S_j = richness in second site.

Data were analyzed using either Systat 11 or SPSS Version 11.0 (SPSS Inc. 2004).

When necessary, logarithm, arcsine-square or square root-transformed variables were used to achieve normal distribution. We analyzed diversity data by comparing measures of α-diversity per site to estimate heterogeneity. A two-factor (sites, habitats) unbalanced nested design was used for an ANOVA on each of the dependent variables (*S*, *H*, *d*, and *E*). The unbalanced design was necessary as a result of different numbers of sites for each habitat type. Diversity was compared within sites and sites nested within habitats. When the model found statistically significant differences in habitats and sites, Tukey's post hoc tests were used to determine which were significantly different. Data on species richness were analyzed by simple polynomial regression against canopy, aboveground biomass and herbaceous cover, respectively.

Results

General description

A total of 102 non-cocoa (companion) tree species and 260 herbaceous species were identified within the five traditional cocoa forest gardens. Species sampled belonged to 169 plant families; 56 families of trees, and 113 families of the herbs. The richest families were Moraceae (11 species) and Mimosaceae (6) in trees and the Acanthaceae (23 species), Commelinaceae (12), Poaceae (10), Araceae (8), Rubiaceae (6), and Asteraceae (4) in the herbs. There was a significant difference ($p < 0.01$) in the average number of tree ($F = 7.30$, $df = 4$) and herbaceous ($F = 15.97$, $df = 4$) families observed per TFG with HG recording the highest number of families from both plant groups and IM the lowest (Table 1). The most common tree species were *Albizia adianthifolia* and *Ficus exasperata* (17% of the total species, respectively) followed by *Ficus mucuso* and *Discoglypremna caloneura* (11%) in EO; *Ceiba pentandra* in IY; *F. exasperata* and *Newbouldia lewis* in EY; *Terminalia superba* in IM and *Pterocarpus soyauxii* in HG. Most of them were intentionally introduced as shade trees specifically in EY and IY.

Herbaceous species were dominated by *Nephrolepis bisserata* (Nephrolepideae) in EO; *Chromolaema odorata*, *Oplismenus hirtellus*, *Laportia avalifolia*, and *Commelina* sp in IY; O. *hirtellus*, *L. ovalifolia*, and *Dicliptera verticillata* in EY; *Commelina* sp, *Acanthus montanus*, *Cythula prostata*, *Desmodium abscendens*, and *L. ovalifolia* in IM and *Psychotria* sp and *O. hiertellus* in HG. All the herb species sampled depend on the period of the year because weeding is practiced throughout the cropping season.

Floristic diversity and habitat description

The plant species richness, Shannon–Weaver index, Shannon evenness and the Berger–Parker index of dominance for each TFG are presented in Table 1. A significant difference

Table 1 Floristic (Non-cocoa tree and herbaceous) species diversity indices in the different traditional cocoa forest gardens (*TFG*)

	Tree species					Herbaceous species				
	EO	EY	HG	IM	IY	EO	EY	HG	IM	IY
H'	2.23	1.54	1.98	1.68	1.24	3.10	2.87	2.85	2.45	2.93
E	0.93	0.95	0.97	0.93	0.91	0.90	0.89	0.89	0.90	0.91
D	0.23	0.33	0.21	0.32	0.32	0.11	0.11	0.17	0.17	0.12
S	18	20	24	23	17	53	54	55	37	61
Mean richness (SE)**	11.0 (1.0)c	6.5 (0.6)b	9.0 (0.6)bc	7.5 (0.6)b	5.3 (0.8)a	33.0 (9.0)c	25.8 (2.4)b	25.0 (2.5)b	17.3 (2.9)a	25.5 (1.8)b
Family mean (SE)**	6.5 (1.0)b	3.5 (0.7)a	6.3 (0.3)b	4.0 (0.5)a	3.30 (0.3)a	18.0 (1.4)c	14.3 (0.5)b	16.7 (2.5)c	11.3 (0.5)a	12.8 (0.5)ab
Total	9	10	15	9	13	22	22	28	18	23

EO Extensive manage old cocoa forest gardens, *EY* Extensive manage young cocoa forest gardens, *HG* Home garden cocoa forests, *IM* Intensive manage mature cocoa forest gardens, *IY* Intensive manage young cocoa forest gardens, *S* Species richness, *H'* Shannon–Weaver Index, *E* Shannon evenness, *D* Berger–Parker index of dominance. Letters show significant differences between regions based on Tukey's post hoc tests

**$p < 0.01$

($p < 0.01$) was observed between TFGs when analyzing tree species and herbaceous species richness, respectively. The average tree species richness was twofold higher in EO (11.0) as compared to IY (5.3). IM recorded the lowest herbaceous species richness and herbaceous cover. The Shannon–Weaver index between TFGs ranged from 1.54 to 2.23 for tree species and from 2.45 to 3.10 for herbaceous species. A significant difference was observed between TFGs for both two variables. Nevertheless, EO was the most diverse TFGs when considering the plant diversity indices (Table 1).

When taking into consideration the Jaccard Index (JI), the floristic similarity between TFGs decreased with increasing intensification (Table 2). Therefore, β-diversity was lower between sites under different land-use management. However, the highest similarity in floristic composition occurred between EY and IY.

When looking at the management practices in different TFGs, we observed that spacing between cocoa trees varied from 1.3 m (SE = 0.1) in HG to 2.1 m (SE = 0.0) in IM (Table 3). Spacing significantly differed ($p < 0.01$) between TFGs. The average cocoa tree height ranged from 6.4 m (SE = 0.0) in EO to 8.6 m (SE = 0.5) in IM. Tree height did not show any significant difference between TFGs as did tree girth, crown width and height at branching. However, a significant difference ($p < 0.01$) was observed between TFGs on crown depth of cocoa trees and the mean number of chupons per cocoa tree. This value ranged from 0.1 (SE = 0.0) in EO to 0.9 (SE = 0.2) in HG while crown depth ranged from 2.6 m (SE = 0.3) in EO to 5.7 m (SE = 1.0) in HG. There was a significant difference ($p < 0.01$) in cocoa tree density between TFGs with HG having the highest density and IM the lowest with 1,075 tree/ha (Table 3). The rate of pesticides application per cropping season significantly differed ($p < 0.001$) between TFGs with the extensive cacao production systems having fewer pesticide applications as compared to the intensive ones (Fig. 1). Insecticide application was found to be significantly different ($F = 17.21$, $df = 4$, $p < 0.001$) between TFGs with EO applying less insecticides (Fig. 1). Of the insecticides applied 43% were Organochlorine, 20% Carbamate, 17% organophosphate, 14% nicotinoid, and 4% pyrethroids.

Vegetation structure

Based on a one-way-ANOVA, density of non-cocoa tree significantly differed ($p < 0.001$) among TFGs with the density recorded in EO twofold higher than that observed in IY

Table 2 Percent similarity in non-cocoa (companion) trees species for all traditional cocoa forest gardens (*TFG*)

	Non-cocoa tree species				
TFG	EO	EY	HG	IM	IY
EO		17	12	11	12
EY			12	15	33
HG				14	15
IM					19
	Herbaceous species				
EO		34	27	10	16
EY			28	25	28
HG				17	16
IM					25

Table 3 Management practices applied and cocoa trees parameters in different TFG

Locality	DCC (m)	ATH (m)	TG (m)	CW (m)	CD (m)	AHB (m)	NBT	ATD (tree/ha)
EO	1.7 (0.2)b	6.4 (0.0)	0.3 (0.0)	2.2 (0.0)	2.6 (0.3)a	1.5 (0.1)	0.2 (0.0)a	1,250 (50)ab
EY	1.8 (0.2)c	9.4 (0.7)	0.5 (0.0)	2.5 (0.2)	5.6 (0.5)c	0.5 (0.2)	0.5 (0.1)ab	1,183 (80.5)a
HG	1.3 (0.1)a	9.9 (0.8)	0.5 (0.1)	2.5 (0.2)	5.7 (1.0)c	1.1 (0.6)	0.9 (0.2)b	1,600 (208.2)b
IM	2.1 (0.0)c	8.6 (0.5)	0.4 (0.0)	2.4 (0.3)	5.5 (0.4)c	1.6 (0.2)	0.3 (0.1)a	1,075 (96.8)a
IY	2.0 (0.1)c	7.6 (0.8)	0.4 (0.0)	2.6 (0.2)	3.7 (0.3)a	1.3 (0.1)	0.1 (0.1)a	1,095 (69.10)a
p	**	NS	NS	NS	**	NS	**	**

EO Extensive manage old cocoa forest gardens, *EY* Extensive manage young cocoa forest gardens, *HG* Home garden cocoa forests, *IM* Intensive manage mature cocoa forest gardens, *IY* Intensive manage young cocoa forest gardens, *DCC* Distance between two consecutives cocoa tree, *ATH* Average tree height, *TG* Tree girth, *CW* Crown width, *CD* Crown depth, *AHB* Average height at branching, *NBT* Number of chupons per cocoa tree, *ATD* Average tree density per farm. Values are mean (SE) and *NS* Not significant. Letters show significant differences between regions based on Tukey's post hoc tests

$^{**}p < 0.01$

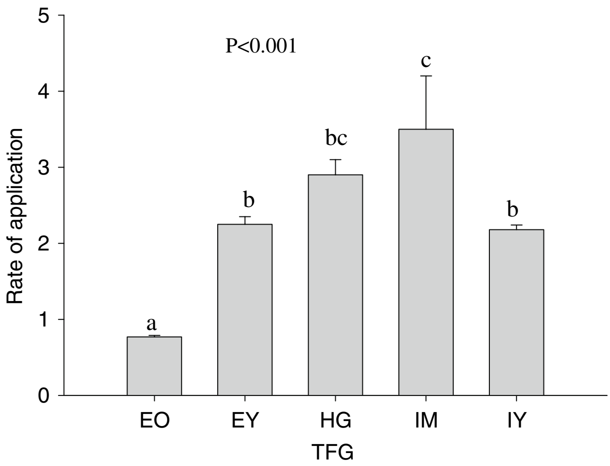

Fig. 1 Rate of Insecticides application in different traditional cocoa forest gardens ($F = 17.21$, $df = 4$, $n = 17$)

(Fig. 2). Dbh and tree height of non-cocoa trees in TFGs are summarized in Fig. 3. Both parameters significantly varied ($p < 0.001$) between TFGs. Mean dbh ranged from 62.25 cm (SE = 2.90) in EO to 135.85 (SE = 13.46) in IM. Mean dbh was 93.49 cm (SE = 1.47) in EY, 124.42 cm (SE = 10.91) in HG and 115.97 cm (SE = 5.86) in IY. Average height value of non-cocoa was higher in older systems than in younger ones. This value was 43.90 m (SE = 3.35) in EY, 44.16 m (SE = 1.51) in IY; 55.50 m (SE = 3.26) in EO, 64.04 m (SE = 3.61) in HG and 65.64 m (SE = 2.91) in IM. Finally, we found a weak, although non-significant relationship between dbh and tree height.

Basal area (BA) and biomass production

Management had a significant ($p < 0.001$) effect on BA with IY recording the lowest BA (9.5 m^2/ha). IM recorded the highest BA-value (46.7 m^2/ha). Mean BA in HG was about

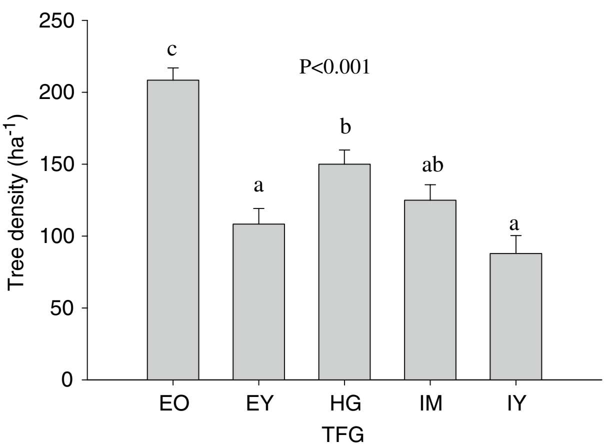

Fig. 2 Average tree density (ha^{-1}) in different traditional cocoa forest gardens

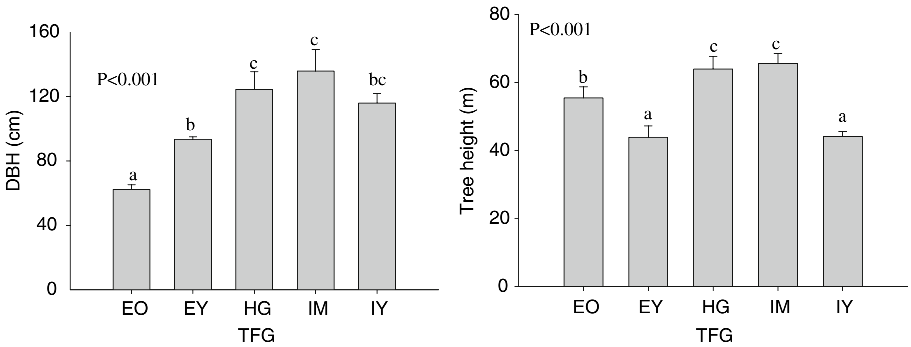

Fig. 3 Diameter at breast height (cm) and tree height (m) of non-cocoa trees in five land-use systems of traditional cocoa forest gardens in southern Cameron

twofold that of EY (Fig. 4). Standing tree biomass significantly ($p < 0.001$) decreased with intensification, with IY recording fourfold lower trees biomass than IM and EO, respectively. IM recorded the highest mean biomass per standing tree species with 374 kg/tree (Fig. 4). We observed a positive relationship between standing non-cocoa tree biomass and canopy cover ($R^2 = 0.37$, $p < 0.05$). We also found a positive relationship between standing non-cocoa tree biomass and tree species richness, however this relationship was not statistically significant.

Ethnobotany

Farmers normally preserve either medicinal species, fertilizers, nutritive and/or timber species in their TFGs. Many non-timber forest products were observed in the TFGs analyzed. These included the Sterculiaceae from plant genus *Cola*, used as “Kola” and aphrodisiacs. *Ricinodendron heudelotii* (Euphorbiaceae) and *Mondia whitei* (Periplocaceae) are used as spices. Fruits of several tree species, such as *Voacanga africana, R. heudelotii, Dacryodes edulis, Irvingia gabonensis*, *Mangifera indica*, and *Psidium guayava* are sold to the local market. A few plant species, such as *Gnetum africanum* (Okok) (specifically in HGs) are also preserved for local consumption as a staple vegetable. About

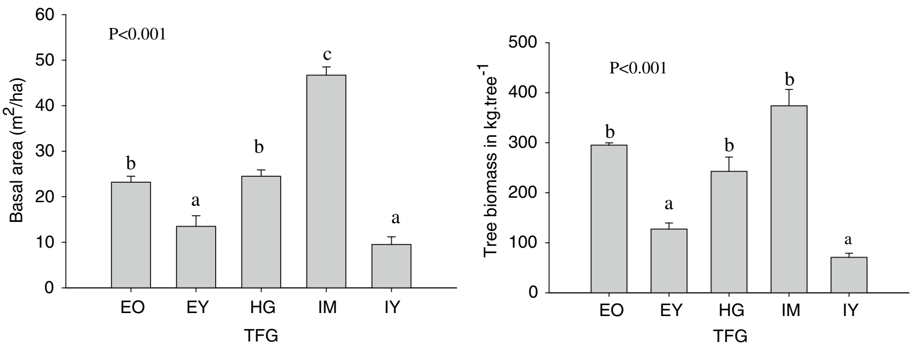

Fig. 4 Basal area (m^2/ha) and tree biomass (kg/tree) of non-cocoa tree species in five TFG

Table 4 Management index (*MI*) from vegetation characteristics sampled in five cocoa forest gardens regions

Vegetation variables	EO	EY	HG	IM	IY
Tree species richness (no)	0.48	0.69	0.57	0.64	0.75
Herbaceous species richness (no)	0.46	0.58	0.59	0.74	0.58
Canopy cover (%)	0.12	0.27	0.16	0.24	0.56
Herbaceous cover (%)	0.15	0.22	0.78	0.92	0.67
Tree height (m)	0.46	0.57	0.38	0.36	0.57
Number of chupons	0.95	0.89	0.77	0.93	0.97
Cocoa tree density (tree/ha)	0.38	0.41	0.20	0.46	0.45
Total Management Index (MI)					
(A)	2.98a	3.63b	3.45b	4.29c	4.55c**
(B)	1.67	2.33	2.48	2.90	3.13

A high MI shows more intensive cocoa management. Letters show significant differences between regions based on Tukey's post hoc tests. *A* MI using seven variables, *B* MI using five variables

**$p < 0.01$

60% of the bark of tree species in EO, 45% in EY, and 1% in IM, IY and HG, respectively, are peeled off for medicinal purposes.

Management index (MI)

The one-way ANOVA of the mean MI-values for each TFG revealed statistically significant differences among the five management systems ($F_{4,16} = 7.94$, $df = 4$, $p < 0.002$) (Table 4). A Tukey's multiple comparison test indicated EO to be significantly different as compared to the other four systems. IY contained the least shaded cacao production sites while EO contained the most shaded; HG and EY were intermediate. Based on the MI we found that plant diversity and biomass of standing tree species significantly decreased with intensification.

Discussion

Floristic diversity and habitat description

Our study documents that management as practiced in traditional cocoa forest gardens in southern Cameroon following a gradient of intensification from extensive cocoa forest gardens with high floristic diversity to intensive ones strongly impacts plant diversity, plant biomass and to some extends carbon storage with possible negative consequences on biodiversity (Kotto-Same et al. 1997; Greenberg et al. 2000; Reitsma et al. 2001). Great differences in species richness and composition were evident among the five traditional cocoa forest gardens. In terms of plant species richness, we found a decreasing gradient of plant species numbers from extensive forest gardens to intensive ones. However, the species richness in cocoa forest home gardens (HG) exceeds all other numbers in the study area. What could be currently observed is the proliferation of pioneers or early secondary trees and poor conditions for the establishment of late secondary and climax species, resulting, consequently, in a lowering of tree diversity. This could be explained by the current management practices, specifically where undergrowth is cleared out twice annually in extensive systems and more in intensive ones. Such clearing are not selective, and all regenerating trees are eliminated and only a few arboreal plants happen to escape the cuttings. On the other hand, this could also be explained by the fact that before the cocoa crisis (Duguma et al. 2001), cocoa farmers were encouraged by the Societé de devéloppement du Cacao (SODECAO) to plant leguminous tree species such as the *Albizia* spp in cocoa plantations to enhance soil fertility. *Ficus* spp., *C. pentandra*, *T. superba*, and *Milicia excelsa* actively kept by the farmers, promote quick shading of the cocoa trees and are refuge for birds (Greenberg et al. 2000); beneficial insects (Philpott and Armbrecht 2006) and mammals (Rolim and Chiarello 2004). The young systems (EY and IY) present even higher densities of exotic tree species (*Khaya senegalensis*). On the other hand, the presence and conservation of secondary forests species in traditional cocoa forest gardens suggest that TFG could help to maintain biodiversity in landscapes where forest habitat is decreasing due to land-use pressure or may help to conserve endangered species (Zapfack et al. 2002; Schulze et al. 2004; Asare 2006; Bobo et al. 2006).

Herb species diversity was dominated by light-demanding herbs, specifically Acanthaceae, Commelinacea, Poaceae, and Asteraceae in patches and may function as indicators of the type of management.

The relatively low Jaccard Indices suggest a high β-diversity due to a high-species turnover. This is exemplified by the low proportion of shared species among the traditional cocoa forest gardens, specifically between EO and IY.

Vegetation structure

The average density of non-cocoa trees with dbh $\geq$ 10 cm in traditional cocoa forest garden may be considered low (126 $\pm$ 41.7 trees/ha) as compared to the less disturbed forest as reported by Zapfack et al. (2002). However, if compared to other cocoa systems such as the cabruca system in Brazil (Rolim and Chiarello 2004), this value is high. According to other studies (Steffan-Dewenter et al. 2007), planting of cocoa is economically viable at low tree density and thinning. Such practices may explain the type of land-use applied in intensive young systems (IY) resulting in poor plant diversity. However, farmers in these systems are concerned about the importance of tree as shade but lack appropriate technology in tree domestication or are not able to identify appropriate trees for shade.

The value of dbh in extensive TFGs were the lowest as compare to other TFGs and could be explained by a massive and selective logging during the cocoa crisis and the fall in market prices after 1992 (Duguma et al. 2001). Food diversification in HG (a combination of diverse fruit tree species in cocoa plantations), of similar age, has helped in preventing massive logging and plantations still possess timber tree species with significant dbh.

Basal area (BA) and biomass production

Basal area of timber species present in traditional cocoa forest gardens clearly decreased from young to old systems. The basal area of 46.7 m^2/ha from our mature systems, was higher than what was found by Zapfack et al. (2002) (i.e., 39.2 m^2/ha) and close to the value (i.e., 48.7 m^2/ha) recorded by Bobo et al. (2006) in primary forests in Southern Cameroon. It was also higher than the values (11.9–20.5 m^2/ha) obtained in cocoa plantations in Indonesia by Merijn et al. (2007) or elsewhere in the South province of Cameroon (29.7–42.6 m^2/ha) where some large trees (e.g. dbh = 143 cm) can still be found despite ancient selective logging activities (van Gemerden 2004). Our results suggest a good stock of remnant forest tree species such as *T. superba*, *M. excelsa*, *Mansonia altissima*, *Entandrophragma cylindricum* and planted multi-purpose trees such as oil palms *E. guineensis*, plum *D. edulis* and kola *Cola acuminate* in TFGs.

The large differences in above ground tree biomass among old and young TFGs are a good indication of the rate of intensification where farmers aimed at maximum cocoa productivity. Such practice may results in a significant loss of carbon (Kotto-Same et al. 1997; Steffan-Dewenter et al. 2007). According to Steffan-Dewenter et al. (2007) the removal of shade trees increased soil surface temperature by about 4°C and reduced relative air humidity at 2 m above ground by about 12%. These factors may have significant impact on the incidence of pests and diseases. We can also predict that the rate of biomass accumulation will probably decline as stands age because the dominant tree species are of economic importance and could be sold if there is a drastic drop of cocoa price at the international market. But TFGs will be profitable and sustainable if diversification of both crop and non-crop commodities such as non-timber forest products and fruit tree species is advocated (Zapfack et al. 2002; Bobo et al. 2006; Sonwa et al. 2007).

Management index (MI) and vegetation variables

The results of vegetative sampling and analysis of the MI (Table 4) clearly demonstrate that significant and measurable differences of MI can be quantified between different management systems of traditional cocoa forest gardens. Richness of non-cocoa tree species, herbaceous species, the average tree height, percentage of canopy and herbaceous cover were the principal variables explaining these differences. These results suggest the importance of TFGs as refuge areas for biodiversity, and subsequent structural diversity.

Three significantly different management systems could be identified among the traditional cocoa forest gardens studied: (1) The extensively managed cocoa forest gardens (EO), with the lowest MI and higher shade cover, as well as tree species richness; (2) the intermediate forest gardens (EY and HG) with intermediate MI; and (3) the intensively managed systems (IM and IY) with the highest MI and lowest shade cover and tree species diversity (Tables 1, 4). Such approach using a MI could be used for research and certification in the cocoa growing regions of the tropics, specifically in West and Central Africa where such indices do not exit. Traditional cocoa forest gardens in southern Cameroon are protected land-use systems where medicinal and edible plants, timber species and non-timber forest products are collected.

Conclusion

The results of this study demonstrates that management as practiced in traditional cocoa forest gardens in southern Cameroon following a gradient of intensification from extensive cocoa forest gardens with high floristic diversity to intensive ones strongly impacts plant diversity, plant biomass and to some extends carbon storage with possible negative consequences on biodiversity. However, domestication of forest species within the TFGs is one of the best options for satisfying certain social and economic needs and sustains smallholder production for increased social, economic, and environmental benefits. Such multi-resource land-use practices that create new landscape elements offer more scope for conservation of biodiversity, at both species-level and landscape-level, may help in regulating pests and diseases and allows for efficient adaptation to changing socioeconomic conditions. This study also highlights the importance of the MI for quantifying differences in the management of shade-grown cocoa. MI in relation to biodiversity, productivity and net income was assessed and we argue that MI could be used to standardize vegetation sampling protocols in certification and biodiversity evaluations and monitoring or to measure conservation progress and success. Such a certification scheme is well established for shade-grown coffee in Mesoamerica (Dietsch et al. 2004; Perfecto et al. 2005, Gordon et al. 2007) but does not exist for cocoa in West and Central Africa. Therefore, it would be very useful to combine the application of this MI with data on the faunal richness (birds, mammals, and beneficial insects) to assess the impact on pests and diseases as well as for the conservation of biodiversity based on the type of management.

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