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Long-term dynamics of cocoa agroforests: a case study in central Cameroon

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Abstract The sustainability of cocoa growing systems in the humid tropics is debatable. Socio-economic and technical data were obtained from 1,171 cocoa farmers and 1,638 cocoa plantations to assess the long-term dynamics of cocoa agroforests in central Cameroon since the beginning of the twentieth century. On-site, we estimated the age of the cocoa trees and measured their density in a sub-sample of 402 cocoa plantations. We inventoried associated woody species in 45 cocoa plantations from this sub-sample. Our results revealed a high Shannon index for the cocoa plantations (2.6) and showed that an average of 25 tree species per cocoa plantation had been planted with the cocoa trees at a density of 120 trees ha^{-1}. Surveys indicated that there had been no mineral fertilization. Nearly 70% of the cocoa agroforests were over 40 years old, and all farmers continuously regenerated their cocoa tree stands. Irrespective of the cocoa plantation age, the cocoa tree density remained over 1,000 plants ha^{-1}, and fermented dried cocoa yields were 255 kg ha^{-1} on average. Cocoa agroforests occupied 60% of the cultivated area on farms and cocoa sales accounted for 75% of total farm income. Almost a third of the farmers were from the area and under 40 years old. In conclusion, our results show that the farmers' agroforestry practices, in addition to the fact that the cocoa tree stands were continuously regenerated and passed down between generations of farmers, could explain the long-term dynamics of cocoa agroforests in central Cameroon.

Keywords Agroforestry systems · Sustainability · Agrobiodiversity · Management · Regeneration practices · Cocoa yield · Cocoa farm · *Theobroma cacao* L.

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Introduction

Cocoa growing has been classified as 'tree crop shifting cultivation' since the early twentieth century (Knapp 1920) since new cocoa stands have always been planted on cleared forest land (Ruf 1987). Cocoa plantations set up in this way are usually managed in accordance with agricultural research recommendations, in monocultures or under uniform lighting and shade (Enriquez 1985; Willson 1999), but not always in compliance with fertilization recommendations. After 30–40 years of cultivation, these cocoa plantations are often hampered by the biological decline in the cocoa trees, and the loss of soil fertility, and thus they have to be regenerated (Jolly 1955; Lanfranchi 1971; Montgomery 1981). Due to high labour and input costs, however, regenerating senescent cocoa plantations is more expensive than setting up new cocoa plantations on cleared forest land (Trivedi 1992; Ruf et al. 1994, Petithuguenin 1995). Consequently, old cocoa plantations are usually abandoned and farmers plant new stands after forest clearing, as is common practice in Côte d'Ivoire (Ruf et al. 1994). They may also be reconverted into annual crop plots (e.g. in Togo and Haiti), grazing land (e.g. in Brazil), or into rubber tree or oil palm plantations (e.g. in Côte d'Ivoire; Harwich 1992; Ruf 1995).

Paradoxically, in Cameroon, cocoa agroforests are still being cultivated after a century, which would tend to show that a sustainable cocoa growing model is possible. Cameroon has been producing cocoa since the beginning of the nineteenth century and central Cameroon is the oldest production region (Champaud 1966; Assoumou 1977). In this area, the many cocoa agroforestry based farms are often passed down from generation to generation, thus enabling young farmers to start out. Cocoa growing is also spreading into theoretically less suitable areas for its development, such as forest–savannah transition zones (Jagoret and Malézieux 2007). Cocoa growing systems in central Cameroon, however, have developed differently with respect to the models usually recommended by agricultural research—farmers combine cocoa trees with a broad range of forest or fruit species in complex agroforests, as described by certain authors (Duguna et al. 2001; Zapfack et al. 2002; Sonwa et al. 2007).

Some cocoa growing systems of the same type have been described in Nigeria (Degrande et al. 2006; Oke and Odebiyi 2007), Côte d'Ivoire (Herzog 1994), Ghana (Asare and Tetteh 2010) and Brazil (Ruf and Schroth 1995), but these studies did not provide any insight into all of the agro-ecological and socio-economic aspects of the long-term dynamics of such systems. Moreover, there is little information available on the technical management and performance of cocoa tree stands. In addition, the long-term evolution of such systems is poorly documented, as such studies would require measurable indicators that could be used to monitor changes in different variables over time (Francis et al. 1990; Rodrigues et al. 2009).

As complex agroforestry systems (AFS) are hard to characterise, we decided to study cocoa agroforests in central Cameroon over several decades by focusing specifically on cocoa tree stands. Data, including technical variables on cocoa plantations, were gathered in a survey involving 1,171 farmers. Our study covered the three main cocoa growing zones in central Cameroon that were representative of the north–south soil–climate gradient characterizing that production region.

Materials and methods

Sites and sampling

In 2004, we surveyed 1,171 farms comprising a total of 1,638 cocoa agroforests located at three geographical sites (Bokito, Zima and Ngomedzap). They were representative of the north–south gradient characterizing natural conditions in the cocoa growing region of central Cameroon (Fig. 1). The sample distribution was as follows: 429 farms in Bokito (526 cocoa plantations), 421 farms in Zima (687 cocoa plantations) and 321 farms in Ngomedzap (427 cocoa plantations). Cocoa tree density, yield and age were monitored in a sub-sample of 402 cocoa plantations whose area had remained constant since their creation (Bokito: 86; Zima: 219; Ngomedzap: 97). Tree species associated with cocoa trees were inventoried in 45 of those cocoa plantations (15 per site).

Central Cameroon is located between 2.1° and 5.8°N and 10.5° and 16.2°E, at 600–800 m elevation. The climate is hot and humid, with an average annual temperature of 25°C (Santoir and Bopda 1995). It is divided into two distinct wet and dry seasons that vary in duration from north to south (bimodal rainfall regime). The main dry season lasts 5 months in Bokito (mid-November–mid-April) and 3 months in Ngomedzap (mid-November–mid-February). The average total annual rainfall is around 1,400 mm in Bokito, 1,600 mm in Zima, and 1,800 mm in Ngomedzap. Bokito is located in a forest–savannah transition zone with low land pressure, characterized by a patchwork of forest galleries and herbaceous and sedge savannahs on

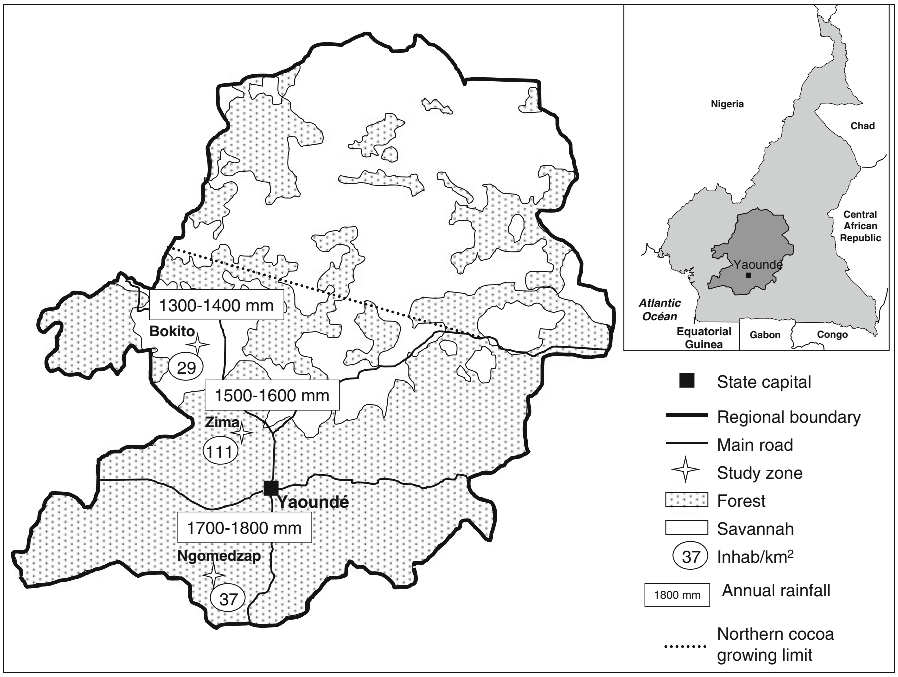

Fig. 1 Location and characteristics of the three study sites in central Cameroon

rejuvenated slightly desaturated soils. Zima is in a forest zone with substantial human activity, where the vegetation is influenced by forest clearing and tree cropping on moderately desaturated ferralitic soils. Ngomedzap is in a forest zone with low land pressure, where the prevailing vegetation is dense evergreen forest on highly desaturated ferralitic soils (Santoir and Bopda 1995).

Methodological approach

The monitoring was done on three scales: (i) plot, i.e. a 'cocoa plantation' or 'cocoa agroforest', defined as being a portion of an area where cocoa tree stands have a uniform age and structure; (ii) cocoa area, i.e. all adjacent (or not) cocoa plantations on a farm; and (iii) farm, considered as a territory with common resources managed by a family group under the authority of a head of family.

Plantation age, cocoa density and yield and regeneration practices were considered to be the main relevant variables to address and test the long-term dynamics of cocoa agroforests.

Our assessment of cocoa agroforests took their long-term dynamics into account. For cocoa tree stands, age, density and yield variables and farmers' regeneration practices were analysed according to seven cocoa plantation age (since creation) categories, which were defined in decades so as to be in line with the cocoa tree biological cycle: immature cocoa plantations under 10 years old; mature cocoa plantations: 11–20, 21–30, 31–40 years; senescent cocoa plantations: 41–50, 51–60, 61 years and over. Due to the small sub-sample size, the degree of agrobiodiversity in the cocoa plantations and the density of tree species associated with the cocoa trees were analysed according to the three main phases of cocoa cropping systems (<10 years: immature cocoa plantations; 10–40 years: mature cocoa plantations; >40 years: senescent cocoa plantations).

Data collection and observed variables

On a farm scale, the variables focused on in interviews with the 1,171 farmers were: (i) the cultivated land per crop and the available land; (ii) farmers' annual income calculated for 2003, including income from agricultural production on the farm, and non-agricultural income (hunting, fishing, salary, retirement pension, etc.); and (iii) the age, origin and ethnic group of the farmers.

On a plot scale, all interviewed farmers provided information on the following variables for each of their cocoa plantations (total sample: 1,638 cocoa plantations): (i) the year of creation (cocoa plantation age); (ii) variations in the area over time; (iii) annual number of cultivation operations carried out in the cocoa tree stands (pruning, mineral fertilization, weeding, insecticide and fungicide treatments); (iv) regeneration, i.e. replacing dead cocoa trees with seedlings (yes/no), rejuvenation of old cocoa trees by cutting back (yes/no), or both at once in the same plot; (v) average fermented dried cocoa yield according to the area, and production data declared by farmers in the sub-sample of 402 cocoa plantations for the three harvest seasons preceding the survey (2001–2003).

In the sub-sample of 402 cocoa plantations, data on the cocoa tree density (obtained by counting plants in a randomly bounded 100 m^2 quadrat) and the age of the counted cocoa trees (estimated on site with the farmers) were collected. In 45 cocoa plantations of the sub-sample, associated species were inventoried throughout each cocoa plantation, while only counting species over 1 m in height. The findings were used to calculate the associated tree density, the species richness and to estimate the degree of agrobiodiversity in the cocoa plantations by calculating the Shannon index (Krebs 1985). We also questioned farmers about the way they managed associated trees over time.

Statistical analyses

Data concerning densities, cocoa yield, Shannon index, number of associated tree species, areas and incomes were assessed by an analysis of variance (ANOVA) using a general linear model. Tests of significance between age categories of cocoa agroforests and sites were performed using the Fisher test. When significant differences were observed, the Newman–Keuls test was used to compare means between treatments. Correlations between variables were verified. When variables proved to be significantly correlated at the 5% limit, an analysis of simple and multiple regression was carried out (Pearson test at the 1% limit).

Results

Age of cocoa agroforests

At a regional level, 68% of the cocoa plantations had been planted more than 40 years previously (Fig. 2).

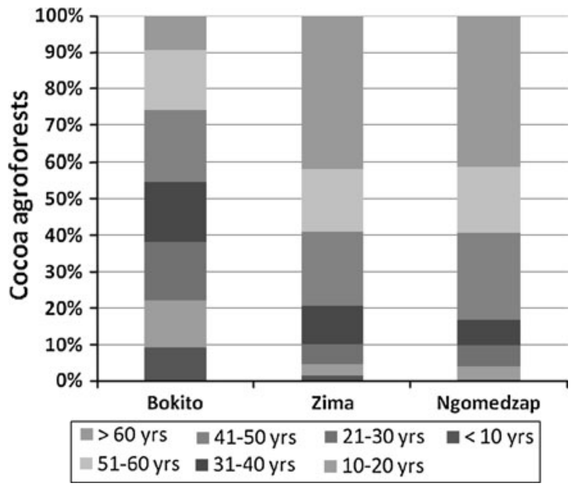

Fig. 2 Distribution of cocoa plantations by age category (data gathered from farmers' interviews, 1,638 cocoa agroforests, central Cameroon)

That proportion was 83% in Ngomedzap and 79% in Zima. In these two zones, most of the cocoa plantations had been planted before WWII. In Bokito, 45% of the cocoa plantations were over 40 years old and cocoa growing had mainly begun developing in the 1950 s. It was also found that plantations under 20 years old accounted for 11% of the dataset on average. These young cocoa plantations were more numerous in Bokito (22%) than in Zima (5%) and Ngomedzap (4%).

Agro-biodiversity and associated tree management

The average Shannon index for the cocoa plantations was 2.64 (Table 1). On average, 25 tree species, including 20 native species, were associated with cocoa trees, with an average density of 120 trees ha^{-1}. The Shannon index increased significantly from 2.35 in young cocoa plantations to 2.90 in cocoa plantations over 40 years old. No significant difference was found between the three sites, although an upward trend was noted with respect to the north–south pedoclimatic gradient in the central Cameroon region. The number of species per cocoa plantation increased significantly from 17 in young cocoa plantations to 30 in cocoa plantations over 40 years old, and from 18 in Bokito to 30 in Ngomedzap. The density of trees associated with cocoa trees decreased significantly from 155 ha^{-1} in young cocoa plantations to 92 ha^{-1} in cocoa

Table 1 Agro-biodiversity, average species richness per cocoa plantation and associated tree density ha^{-1} (±SD of the mean) depending on the cocoa plantation age and site (data measured in 45 plots, central Cameroon)

	Shannon index	Species richness	Associated tree density ha^{-1}
Cocoa plantation age			
<10 years	2.35 (±0.09) b	17 (±2.12) b	155 (±24.98) a
10–40 years	2.72 (±0.12) b	29 (±4.38) a	107 (±14.89) b
>40 years	2.90 (±0.15) a	30 (±4.86) a	92 (±9.99) b
Sites			
Bokito	2.48 (±0.09) a	18 (±2.18) b	96 (±16.18) b
Zima	2.66 (±0.15) a	27 (±5.73) b	94 (±12.39) b
Ngomedzap	2.77 (±0.15) a	30 (±4.28) a	158 (±20.76) a
Mean	2.64 (±0.08)	25 (±2.38)	120 (±11.52)
CV	0.19	0.58	0.59

Values within a column followed by the same letter are not significantly different ($P < 0.01$, Newman–Keuls test)

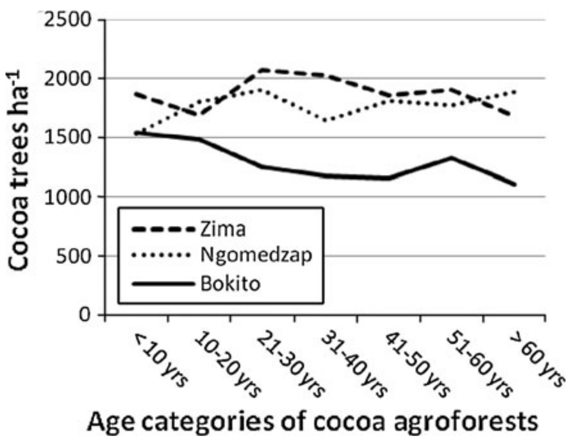

Fig. 3 Variation in cocoa tree density over time (data measured in 402 cocoa agroforests, central Cameroon)

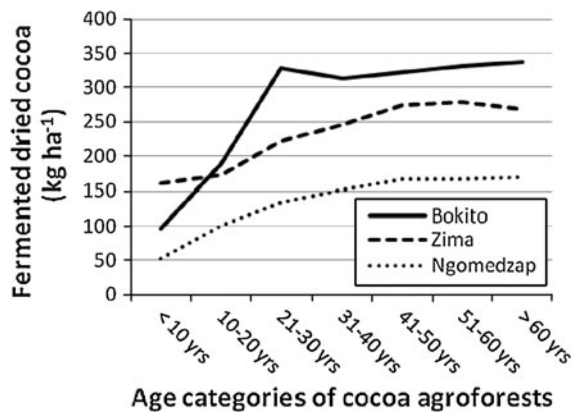

Fig. 4 Variation in fermented dried cocoa yields over time (data gathered from farmers' interviews, 402 cocoa agroforests, central Cameroon)

plantations over 40 years old, while it increased significantly from 96 ha^{-1} in Bokito to 158 ha^{-1} in Ngomedzap. Farmers explained that, in young cocoa plantations, associated trees were planted in high density stands to hamper rapid weed invasion in the plots and to obtain suitable shading conditions for the cocoa trees. The farmers then ensured that the shading conditions remained suitable for cocoa tree growth by thinning down the associated trees.

Density and yield of cocoa tree stands

The average cocoa tree density was 1,640 plants ha^{-1} and the average fermented dry cocoa yield was 255 kg ha^{-1}. The cocoa tree density was stable over time, without any significant difference between cocoa plantation age categories (Fig. 3). After 20 years, the fermented dry cocoa yield was stable over time, without any significant difference between cocoa plantation age categories (Fig. 4). No correlation between these two variables and the cocoa plantation age was found, irrespective of the site. However, significant differences were found between sites. In Zima and Ngomedzap, cocoa tree densities were significantly higher than in Bokito (1,707, 1,647, and 1,280 plants ha^{-1}, respectively). The fermented dried cocoa yield, on the contrary, was significantly lower in Zima and Ngomedzap than in Bokito (277, 144, and 326 kg ha^{-1}, respectively).

Agricultural management of cocoa tree stands

All farmers confirmed that they had not applied mineral fertilizers or herbicides. Cocoa tree pruning was conducted everywhere once a year. In Bokito, 91% of cocoa plantations were weeded 2–3 times a

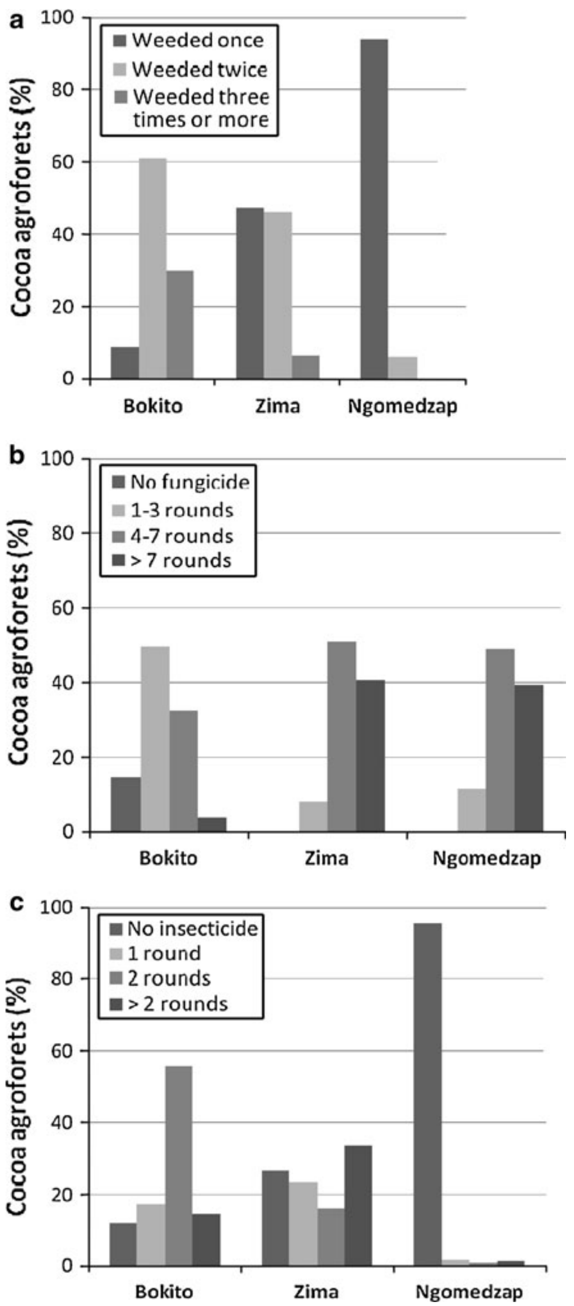

Fig. 5 Survey of farmers: agricultural practices in cocoa agroforests: number of plots (%) depending on the number of operations (1,638 cocoa agroforests, central Cameroon). **a** Manual weeding, **b** fungicide treatments against black pod rot and **c** insecticide treatments against mirids

year, whereas 47% were only weeded once a year in Zima and 94% in Ngomedzap (Fig. 5a). 64% of cocoa plantations were treated 0–3 times a year against black pod rot in Bokito, whereas 92% and 88% of cocoa plantations were treated four times a year or more in Zima and Ngomedzap, respectively (Fig. 5b). 71% of cocoa plantations in Bokito were treated twice a year or more against mirids, whereas 50% of cocoa plantations in Zima and 95% in Ngomedzap were not treated against mirids (Fig. 5c).

Regeneration of cocoa tree stands

A majority of farmers (94%) mentioned that they replaced dead cocoa trees with seedlings and an average of 53% of farmers said that they rejuvenated their cocoa trees by selectively cutting back senescent or unproductive cocoa trees (Table 2). In Ngomedzap, however, a higher number of farmers cut back their cocoa trees. On average, 50% of the farmers of the sample applied both techniques simultaneously in the same cocoa stand, and this proportion was higher in Ngomedzap than in Zima and Bokito. A majority of farmers regenerated their cocoa stands irrespective of the plantation age (Fig. 6): the absence of any correlation between the proportion of farmers who replaced dead cocoa trees and the age of the cocoa plantations confirmed that the process was ongoing. Cocoa tree rejuvenation, however, was mostly carried out in the oldest cocoa stands and the proportion of farmers who cut back their cocoa trees also increased significantly with the age of the plantations involved (Pearson's $r = 0.271$; $P < 0.001$).

Age of cocoa tree stands versus age of cocoa agroforests

Continuous cocoa tree replacement was reflected by the coexistence of cocoa trees of different ages in the

Table 2 Farmers regenerating their cocoa plantations, as a % of interviewed farmers, in three ways: replacement of dead cocoa trees with seedlings (yes/no), rejuvenation of old cocoa trees by cutting back (yes/no), simultaneous replacement + rejuvenation in the same plot (data gathered from 1,171 farmers, central Cameroon)

Site	Replacement	Rejuvenation	Replacement + rejuvenation
Bokito	96	48	48
Zima	94	46	44
Ngomedzap	89	70	63
Mean	94	53	50

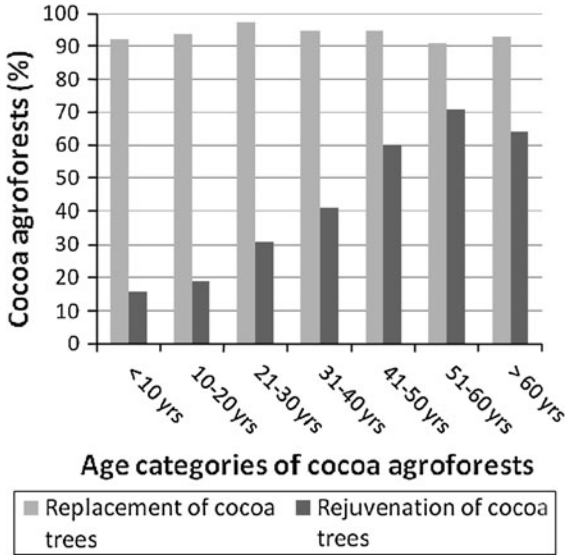

Fig. 6 Regeneration of cocoa plantations in central Cameroon per plantation creation age category (data gathered from farmers' interviews, 1,638 cocoa agroforests, central Cameroon)

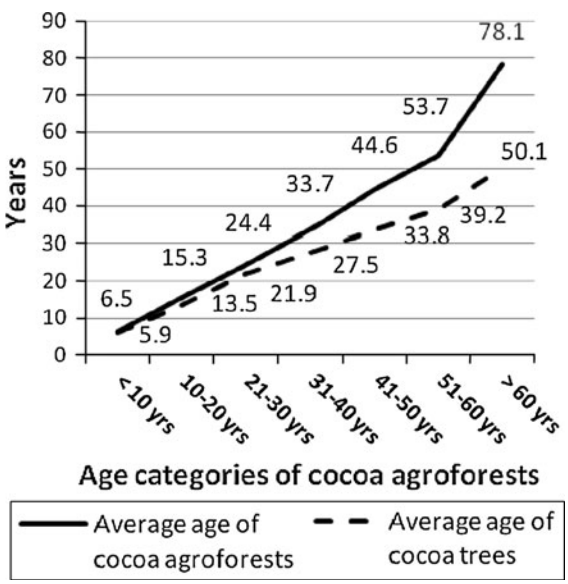

Fig. 7 Comparison of cocoa tree ages and cocoa plantation ages (cocoa tree ages measured in 402 cocoa agroforests, cocoa plantation ages obtained from the farmers of those plots, central Cameroon)

same stand. The main consequence of this was that it lowered the age of the cocoa trees compared to the plantation age (Fig. 7). At a regional level, whilst the average age of the cocoa plantations was 54 years, the average age of the cocoa trees was 40 years—this age gap increased with increasing age of the cocoa plantations.

Importance of cocoa agroforests for farmers

Globally, the farmers declared that they cultivated 5.3 ha on average, including 3.2 ha of cocoa agroforests, i.e. 60% of the total cultivated area (Table 3). Significant differences were found between the three sites, with the cocoa crop area gradually increasing from Bokito to Zima and then to Ngomedzap. At a regional level, and for each site, the area cultivated per farm increased significantly in line with the cocoa crop area (Pearson's $r = 0.82$; $P < 0.001$).

The importance of the role of cocoa growing in the farms of central Cameroon was supported by the amount of annual income derived from sales of fermented dried cocoa, i.e. 619,104 CFA F on average (n.b. 656 CFA F = 1 €), or 75% of the farmers' total income (Table 3). Significant differences in income were noted between the three sites, with the highest income from cocoa found in Zima, followed by Ngomedzap and then Bokito (778,419 CFA F for 76% of the total income, 572,289 CFA F for 77%, 495,445 CFA F for 73%, respectively). At a regional level, and for each site, the total income per farm increased significantly in line with the income from sales of fermented dried cocoa (Pearson's $r = 0.71$; $P < 0.001$).

Age of cocoa farmers

Young farmers (<40 years old) accounted for 30% on average of the farmers interviewed (1,171 farmers) (Fig. 8). There were significantly more of them in Ngomedzap and Bokito (31 and 39%, respectively) than in Zima (19%). Everywhere, the young farmers were from local communities, belonging to the Yambassa ethnic group in Bokito, Eton group in Zima and Ewondo group in Ngomedzap. There was no correlation between the age of the farmers and that of the cocoa plantations in Zima and Ngomedzap, whereas that correlation was significantly positive in Bokito (Pearson's $r = 0.23$; $P < 0.001$).

Increase in the cocoa agroforestry area

At a regional level, 66% of the cocoa plantations, 79% of which were over 40 years old, had increased

Table 3 Importance of cocoa agroforests on the farms in terms of area and income (±SD of the mean) (data gathered from 1,171 farmers, central Cameroon)

Sites	Farm area (ha)			Annual income (CFA F)[a]	
	Total	Cultivated		Total	Fermented dried cocoa
		Total	Cocoa area		
Bokito	7.3 (±0.46) c	3.5 (±0.10) c	2.1 (±0.06) c	678,233 (±25,091) b	495,445 (±21,335) c
Zima	11.9 (±0.69) b	6.1 (±0.18) b	3.8 (±0.12) b	1,019,936 (±37,143) a	778,419 (±26,432) a
Ngomedzap	57.3 (±17.72) a	6.8 (±0.22) a	4.1 (±0.14) a	742,149 (±47,164) b	572,289 (±24,177) b
Mean	22.2 (±4.90)	5.3 (±0.10)	3.2 (±0.07)	818,866 (±21,168)	619,104 (±14,451)
CV	0.76	0.67	0.74	0.88	0.80

Values within a column followed by the same letter are not significantly different ($P < 0.01$, Newman–Keuls test)

[a] 656 CFA F = 1 €

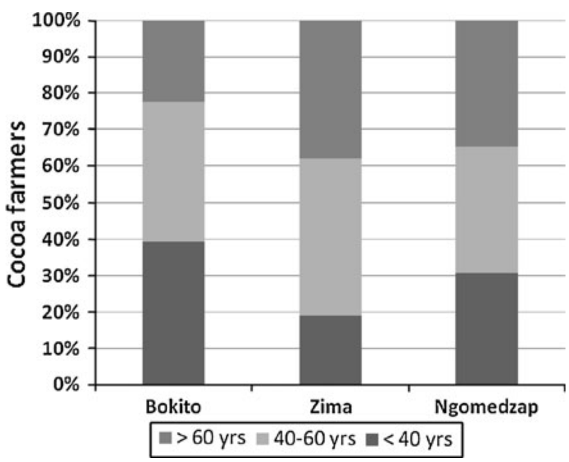

Fig. 8 Farmer ages (data gathered from 1,171 farmers' interviews, central Cameroon)

by 1.18 ha in size since their creation, i.e. an 85% increase (Table 4). However, in Zima, the increase in area concerned less cocoa plantations (48% of the sample) than in Ngomedzap (70%) and Bokito (80%). The increase in area was also significantly lower (+27%) than in Ngomedzap (+134%) and Bokito (+198%).

Discussion

The cocoa growing model in central Cameroon appears to be very different from the one prevailing in many cocoa producing countries, such as Côte d'Ivoire or Indonesia. In these countries, the dominant system is labour- and input-intensive and often favours uniform shade with little diversification (Ruf 1995; Hanak Freud et al. 2000). The management strategy applied in these cocoa plantations generates high cocoa yields in the early years (around 2–3 t ha^{-1} year^{-1}), but after a few years it slumps to 200–300 kg ha^{-1} year^{-1} (Petithuguenin 1995; Lachenaud 2005), leading to their abandonment after 30–40 years (Ruf 1995). On the contrary, in central Cameroon, we found that most cocoa stands had been planted more than 40 years earlier, corresponding to the age beyond which regeneration is generally necessary due to cocoa tree senescence. The cocoa stand structure in central Cameroon is therefore very different from that in other countries, such as Côte d'Ivoire, where cocoa plantations over 40 years old account for less than 5% of cocoa stands (Hanak Freud et al. 2000). At the same time, yields from old cocoa agroforests in central Cameroon had levelled off in the long-term at around 200–300 kg ha^{-1} year^{-1}, which is similar to yields observed by Duguna et al. (2001) in forest areas in central and southern Cameroon, i.e. a 264–500 kg ha^{-1} depending on the intensification level. The cocoa tree density also remained steady in the long-term at around 1,000–2,000 plants ha^{-1}, which invalidated the commonly acknowledged decrease in cocoa tree density with age, with mortality rates of around 50% at 40 years and more than 75% at 50 years (Laryea 1971).

The long-term dynamics of cocoa tree stands in central Cameroon suggests that the cocoa growing model adopted by farmers, where cocoa tree stands are the main component of complex agroforests, is more sustainable than the cocoa growing model prevailing in many cocoa producing countries and which is often recommended by agricultural research.

Table 4 Increase in cocoa plantation area (±SD of the mean) (data gathered from farmers' interviews, 1,638 cocoa agroforests, central Cameroon)

Site	Percentage of cocoa plantations	Area (ha)		Increase in area (%) (CA − IA/IA*100)
		Initial (year of creation) (IA)	Current (2004) (CA)	
Bokito	80	0.62 (±0.04) c	1.85 (±0.07) c	198 (±0.068) a
Zima	48	2.12 (±0.06) a	2.69 (±0.09) b	27 (±0.087) c
Ngomedzap	70	1.43 (±0.26) b	3.35 (±0.12) a	134 (±0.119) b
Mean	66	1.38 (±0.08)	2.56 (±0.05)	85 (±0.096)
CV		1.98	0.72	1.48

Values within a column followed by the same letter are not significantly different ($P < 0.01$, Newman–Keuls test)

The amazing longevity of the cocoa plantations in central Cameroon, even though farmers did not use any mineral fertilization, could be explained by the different farmers' practices. The high number of tree species associated with cocoa trees, which were similar to the numbers reported by Sonwa et al. (2007), i.e. 15–26 species per cocoa agroforest, and the high Shannon indices revealed the high degree of agrobiodiversity in these cocoa agroforests. However, the Shannon indices we obtained were lower than those obtained in central Cameroon by Sonwa et al. (2007), i.e. 3.1–3.9, and by Zapfack et al. (2002), i.e. 4.39, whereas they were similar to those obtained by Oke and Odebiyi (2007) in cocoa agroforests in Nigeria (2.7), by Asare and Tetteh (2010) in cocoa agroforests in Ghana (2.6) and by Salgado-Mora et al. (2007) in cocoa agroforests in Mexico (2.7–2.9).

Many studies have revealed the advantages of AFS for improving and maintaining the mineral richness of soils (Beer et al. 1998; Barrios and Cobo 2004; Isaac et al. 2005; Tapia Coral et al. 2005). The soil organic matter values mentioned by Duguna et al. (2001) in mature cocoa plantations set up in forest areas in central and southern Cameroon are around 4.1–4.7%. In these areas, Snoeck et al. (2009) also showed that the soil organic carbon level was 1.78 in cocoa plantations over 25 years old, but this value was lower in young cocoa plantations due to forest clearing, and then it increased back to a level similar to that of forest soils prior to cocoa planting. In the forest–savannah transition zone around Bokito, Glatard et al. (2007) showed that the soil organic matter under cocoa plantations set up on savannah was around 3% in 10 year-old cocoa plantations and higher than in savannah before cocoa planting. These values confirm that the soil fertility in cocoa agroforests in central Cameroon is in line with the cocoa tree requirements, i.e. approximately 3% organic matter in top soil (Braudeau 1969).

The significant variations in diversity and number of trees associated with cocoa trees with the cocoa plantation ages and sites highlights the farmers' observational capacity and experience acquired in managing these species according to the constraints they face. Our results showed that environmental conditions influenced the way farmers managed their cocoa tree stands. In the forest–savannah transition zone of Bokito, the lower densities of tree species associated with cocoa trees fostered mirid outbreaks (Babin et al. 2010) and *Imperata cylindrica* infestation. This led most farmers to spray their cocoa tree stands with insecticides and weed them more often than in the Zima and Ngomedzap forest zones. In these areas, the denser shade provided by the great number of trees associated with cocoa trees limited mirid attacks and weed growth, but was favourable to black pod rot caused by *Phytophthora megakarya*, thus prompting farmers to treat their cocoa tree stands with fungicides more frequently than in the forest–savannah transition zone. Finally, pest and disease protection in cocoa tree stands in central Cameroon was less than that recommended by agricultural research, i.e. at least two insecticide rounds per year against mirids and four fungicide rounds against black pod rot (Varlet and Berry 1997). In this field, our results confirmed the findings of Sonwa et al. (2008), who showed that pest and disease control treatments in central Cameroon were lower than recommended.

Cocoa tree regeneration practices implemented by farmers also appeared to be another decisive factor in the long-term dynamics of cocoa tree stands in central Cameroon. Our results invalidated the common claim that cocoa tree stands become senescent due to the lack of regeneration of old cocoa trees (Champaud 1966; Losch et al. 1991). The two continuous cocoa tree regeneration methods are further evidence that the farmers use their observational capacity and experience to lower the age of their cocoa tree stands and rejuvenate them by taking advantage of the morphological and physiological characteristics of the cocoa trees. By replacing dead cocoa trees, farmers take advantage of the capacity of this species to develop in a shaded environment (Burle 1961). By cutting back senescent cocoa trees and then opting for their multiple-stem management before eliminating old trunks, they make optimum use of this tree's ability to produce orthotropic suckers (Braudeau 1969).

Otherwise, our results showed that the long-term dynamics of cocoa agroforests could be also explained by several socio-economic factors. The importance of cocoa agroforest on farms in the area confirmed the values mentioned by Santoir (1992) in central Cameroon, i.e. 61–63% according to the sites. Our results concerning the importance of these cocoa agroforests with respect to household income also confirmed the values reported by Leplaideur (1985). In the same areas, this author mentioned that cocoa accounted for between 50 and 75% of the income of more than 90% of cocoa farmers. Farmers' interest in the cocoa agroforestry model was demonstrated by the fact that a many of them, including almost a third of farmers under 40 years old, increased the area of their old cocoa plantations and managed them according to the same model rather than setting up new plantations. This pattern, which was reflected in the field by the grouping of several adjacent cocoa plantations in one spot, even though they differed agronomically in age and structure, invalidated the common claim that there is a lack of new cocoa plantations in central Cameroon (Champaud 1966; Losch et al. 1991). In Zima and Ngomedzap, where cocoa growing has a longer history, the low ages of farmers shows that old cocoa plantations are no longer managed by the farmers who set them up. This indicates that old cocoa plantations are passed on from generation to generation, favouring their longevity whilst enabling young farmers to maintain their land rights, to start out and increase the cocoa growing areas they have inherited.

Concerning the methods adopted for this study, using survey variables declared by farmers and variables measured in the field generated consistent indicators for clear assessment of the long-term dynamics of cocoa agroforests in central Cameroon. Further investigations are needed, however, to study the biological interactions existing between the different tree species components that constitute these complex AFS. The initial systems were also unknown, and they may have undergone a range of variations over time, depending on local environmental conditions and farmers' strategies. It would be possible to identify patterns of change in the technical management of plots and the key socio-economic factors determining such changes by implementing an approach focused on the main crop stand (cocoa trees), and taking those changes into consideration over time.

Conclusion

As the sustainability of cocoa growing systems in the humid tropics is debatable, our study confirmed the long-term dynamics of cocoa agroforests in central Cameroon. It described long-standing but ongoing systems characterized by a high degree of agrobiodiversity with remarkably stable cocoa yields in the absence of mineral fertilization. The agroforestry practices adopted by farmers who continuously regenerated their cocoa plantations appeared to be key factors in the long-term evolution of these cocoa plantations. The substantial proportion of young farmers, and the importance of cocoa agroforests on the farms and in the income of agricultural households, also appeared to be the main social factors ensuring their longevity after 40 years, even in theoretically less suitable zones for cocoa growing such as the forest–savannah transition zone.

Finally, cocoa agroforests in central Cameroon are a model of very long-term stabilized and viable cocoa growing that differs from the intensive production models usually recommended. These AFS appear to be a possible answer to the technical and economic constraints faced in the regeneration of old cocoa plantations, while addressing the challenges raised by the disappearance of forests which had previously allowed the settlement of new cocoa production zones.

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References

Asare A, Tetteh DA (2010) The role of complex agroforestry systems in the conservation of forest tree diversity and structure in southeastern Ghana. Agrofor Syst 79:355–368

Assoumou J (1977) L'économie du cacao. Agriculture d'exportation et bataille du développement. Editions universitaires Jean-Pierre Delarge, Paris

Babin R, Ten Hoopen GM, Cilas C, Enjalric F, Yédé M, Gendre P, Lumaret JP (2010) Impact of shade on the spatial distribution of *Sahlbergella singularis* in traditional cocoa agroforests. Agric For Entomol 1:69–79

Barrios E, Cobo JG (2004) Plant growth, biomass production and nutrient accumulation by slash/mulch agroforestry systems in tropical hillsides of Colombia. Agrofor Syst 60:255–265

Beer J, Muschler RG, Kass D, Somarriba E (1998) Shade management in coffee and cacao plantations. Agrofor Syst 38:139–164

Braudeau J (1969) Le cacaoyer. Collection Techniques agricoles et productions tropicales. Editions Maisonneuve et Larose, Paris

Burle L (1961) Le cacaoyer. Tome premier. Editions Larose, Paris

Champaud J (1966) L'économie cacaoyère du Cameroun. Cah Orstom Sér Sci Hum 3:105–124

Degrande A, Schreckenberg K, Mbosso C, Anegbeh P, Okafor V, Kanmegne J (2006) Farmers' fruit tree-growing strategies in the humid forest zone of Cameroon and Nigeria. Agrofor Syst 67:159–175

Duguna B, Gockowski J, Bakala J (2001) Smallholder Cacao (*Theobroma cacao*) cultivation in agroforestry systems of West and Central Africa: challenges and opportunities. Agrofor Syst 51:177–188

Enriquez GA (1985) Curso sobre el cultivo del cacao. CATIE, Turrialba, Serie Materiales de Enseñanza 22

Francis CA, Butler FC, King LD (1990) Sustainable agriculture in temperate zones. Wiley, New York, Chichester

Glatard F, Enjalric F, Jagoret P (2007) Characterization and assessment of Cocoa based agroforestry cropping systems in Cameroon according to site conditions and fertility management. In: Second international symposium on Multi-strata agroforestry systems with perennial crops: making ecosystem services count for farmers, consumers and the environment, 17–21 September 2007, Turrialba, Costa-Rica. CATIE Turrialba

Hanak Freud E, Petithuguenin P, Richard J (2000) Les champs du cacao. Un défi de compétitivité Afrique-Asie, Karthala, Paris

Harwich N (1992) Histoire du chocolat. Editions Desjonquères, Paris

Herzog F (1994) Multipurpose shade trees in coffee and cocoa plantations in Côte d'Ivoire. Agrofor Syst 27:259–267

Isaac ME, Gordon AM, Thevathasan N, Oppong SK, Quashie-Sam J (2005) Temporal changes in soil carbon and nitrogen in West African multistrata agroforestry systems: a chronosequence of pools and fluxes. Agrofor Syst 65:23–31

Jagoret P, Malézieux M (2007) Complex cocoa agroforests can be successfully established on savannahs: a local innovation in the central region of Cameroon. In: Second international symposium on Multi-Strata agroforestry systems with perennial crops: making ecosystem services count for farmers, consumers and the environment, 17–21 September 2007, Turrialba, Costa-Rica. CATIE, Turrialba

Jolly AL (1955) The effect of age of tree on cocoa yields. In: Cocoa, Chocolate and Confectionery Alliance Ltd. A report of Cocoa conference, 13–15 October 1955, London. International Cocoa Organisation, London, pp 54–57

Knapp AW (1920) Cocoa and chocolate. Their history from plantation to consumer. Chapman et Hall, Londres

Krebs CJ (1985) Species diversity. In: Krebs CJ (ed) Ecology: the experimental analysis of distribution and abundance. Harper and Row, New York, pp 507–534

Lachenaud P (2005) Densité évolutive en cacaoculture : la nécessité des éclaircies. In: 14th International Cocoa research conference proceedings: towards a sustainable cocoa economy. What strategies to this end? 13–18/10/2003, Accra. Cocoa Producers' Alliance, Lagos, Ghana, pp 309–315

Lanfranchi J (1971) Régénération cacaoyère. In: 3rd International cocoa research conference proceedings, 23–29 November 1969, Accra. Cocoa Producers' Alliance, Lagos, Ghana, pp 49–55

Laryea AA (1971) Cocoa rehabilitation in Ghana. In: 3rd International cocoa research conference proceedings, 23–29 November 1969, Accra. Cocoa Producers' Alliance, Lagos, Ghana, pp 37–48

Leplaideur A (1985) Les systèmes agricoles en zone forestière: les paysans du Centre et du Sud du Cameroun. Cirad-Irat, Paris

Losch B, Fusillier JL, Dupraz P (1991) Stratégies des producteurs en zone caféière et cacaoyère du Cameroun. Quelles adaptations à la crise? Montpellier, France, Cirad-Dsa, Collection « Documents Systèmes Agraires » (12)

Montgomery PJ (1981) Some thoughts on the life span of cocoa. Planter 57:604–609

Oke DO, Odebiyi KA (2007) Traditional cocoa-based agroforestry ants forest species conservation in Ondo State, Nigeria. Agric Ecosyst Environ 122:305–311

Petithuguenin P (1995) Regeneration of cocoa cropping systems: the Ivorian and Togolese experience. In: Ruf F, Siswoputranto PS (eds) Cocoa cycles: the economics of cocoa supply. Woodhead Publishing, Londres, pp 89–107

Rodrigues GS, de Barros I, Ehabe EE, Sama Lang P, Enjalric F (2009) Integrated indicators for performance assessment of traditional agroforestry systems in South West Cameroon. Agrofor Syst 77:9–22

Ruf F (1987) Eléments pour une théorie des agricultures tropicales humides. De la forêt, rente différentielle, au cacaoyer, capital travail. L'agron Trop 42(3):218–233
Ruf F (1995) Booms et crises du cacao. Les vertiges de l'or brun, Karthala, Paris
Ruf F, Schroth G (1995) Chocolate forests and monocultures: a historical review of cocoa growing and its conflicting role in tropical deforestation and forest conservation. In: Schroth G, Da Fonseca GAB, Harvey CA, Gascon C, Vasconcelos HL, Izac AMN (eds) Agroforestry and biodiversity conservation in tropical landscapes. Island Press, Washington, DC, pp 107–133
Ruf F, Forget M, Gasparetto A (1994) Production de cacao et replantation à Bahia (Brésil). CIRAD, Montpellier, 186 pp
Salgado-Mora MG, Ibarra-Núñez G, Macías-Sámano JE, López-Báez O (2007) Diversidad arbórea en cacaotales des Soconusco, Chiapas, México. Interciencia 32(11):763–768
Santoir C (1992) Sous l'empire du cacao. Etude diachronique de deux terroirs camerounais. Editions Orstom, Paris
Santoir C, Bopda A (1995) Atlas régional Sud-Cameroun. Editions Orstom, Paris
Snoeck D, Abolo D, Jagoret P (2009) Temporal changes in VAM fungi in the cocoa agroforestry systems of central Cameroon. Agrofor Syst 78:323–328
Sonwa DJ, Nkongmeneck AB, Weise SF, Tchatat M, Adesina AA, Janssens MJ (2007) Diversity of plants in cocoa agroforests in the humid forest zone of Southern Cameroon. Biodivers Conserv 16:2385–2400
Sonwa DJ, Coulibaly O, Weise SF, Tchatat M, Adesina AA, Janssens MJ (2008) Management of cocoa: constraints during acquisition and application of pesticides in the humid forest zones of Southern Cameroon. Crop Prot 27:1150–1164
Tapia Coral SC, Luizão FJ, Wandelli E, Fernandes ECM (2005) Carbon and nutrient stocks in the litter layer of agroforestry systems in central Amazonia, Brazil. Agrofor Syst 65:33–42
Trivedi RK (1992) A case study of cocoa replanting and new planting in Bahia, Brazil. J Dev Econ 39:279–299
Varlet F, Berry D (1997) Réhabilitation de la protection phytosanitaire des cacaoyers et caféiers du Cameroun. Tome I. Conseil interprofessionnel du cacao et du café, Douala
Willson KC (1999) Coffee, cocoa and tea. CABI, Wallingford
Zapfack L, Engwald S, Sonke B, Achoundong G, Birang AM (2002) The impact of land conversion on plant biodiversity in the forest zone of Cameroon. Biodivers Conserv 2:2047–2061