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Structure of cocoa farming systems in West and Central Africa: a review

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Abstract Cocoa agroforests are growing in importance with a view to meeting farmers' livelihood goals as well as ecological services. Following the recognition of cocoa agroforests as being useful for biodiversity conservation and farmers' livelihoods, there is a growing discourse on the fact that they may also be useful in climate change mitigation and biodiversity conservation. Several companies have expressed their willingness to be "deforestation" certified within the next two decades. In West and Central Africa, cocoa is part of the endeavour to contribute to the REDD+ mechanism. Besides producing cocoa beans, the additional expectations from cocoa agroforests (timber, NWFP, biodiversity conservation, carbon storage, etc…) depend on the trees associated with the cocoa plants. The manner in which associated trees are mixed in the system impacts on the cocoa plants and plants associated with cocoa trees within the agroforestry system thus impact on the products and services produced by these farming systems. Studies

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are being undertaken to identify the exact composition of these associated trees but very few deal with the manner in which these trees are structurally distributed—vertically and horizontally—within the cocoa agroforest. Understanding the way in which cocoa and non-cocoa trees are distributed within the system would be useful with a view to improving the farm system, thus meeting the needs of several stakeholders. The present study reviews the structure of cocoa orchards and agroforests in West and Central Africa (Cameroon, Nigeria, Ghana and Cote d'Ivoire) with a view to improving the products and services of cocoa landscapes. This review is centred around: (i) density of cocoa, (ii) density of associated plants, (iii) basal area or associated plants, (iv) stratification and space between components, and (v) the life cycle of cocoa plantation components.

Densities of cocoa and associated plants in the field are not always those advised by extension services. The cocoa varieties play an important role in type and intensity of shade of the cocoa farms. In the context of multiple expectations placed on cocoa plantations, the unproductive cocoa trees in the farmer fields can be substituted by more vigorous ones or replaced by useful associated plants (Timber and NWFP). With the growing desire to reproduce some key attributes of local forests while responding to other economic and social needs associated with cocoa farms, the neighbouring/previous forest climax and its related basal area can be considered as a reasonable aim, when managing the cocoa agroforest. The life cycle of each of the plant components needs to be optimized in these spatial–temporal intensification considerations. In the prospect of vertical intensification, there is a need to give more attention to understorey management and the number of strata of the agroforest. In the context of sustainable management, a well-structured cocoa agroforest system needs to take landscape, local, national and global socio-economic and political issues into consideration.

Keywords Structure of cocoa agroforest · Forest biodiversity · Cocoa landscape · Non-cocoa associated plants · Ecological services

Introduction

Cocoa farming systems in Africa are at the forefront of several development and conservation considerations that require attention with regard to management, both horizontally and vertically (Sonwa et al. 2017). Since the introduction of cocoa beans into the African continent, several types of management options had been applied to cocoa fields, leading to different densities. With the initial growth under forest, cocoa has gradually moved, with some clones/varieties, to orchards in certain parts of the continent, while in other areas, depending on the cocoa varieties available, the agroforestry system had been the main system for the production of cocoa beans (Sonwa et al. 2003a, b, c, d, 2007, 2010; Duguma et al. 2001). Such considerations (orchard or agroforestry systems) were of relevance within the only production system of cocoa beans available to fulfil the need of private companies via income provided to the rural and national economies of the cocoa producing countries.

During the past two or three decades, ecological considerations have emerged on the cocoa agenda (Schroth et al. 2004; Jiménez and Beer 1999; Neisten et al. 2004; Rice and Greenberg 2000; Shapiro and Rosenquist 2004; Harvey et al. 2006; Sonwa et al. 2014; Armengot et al. 2016; Blaser et al. 2018; Lojka et al. 2017; Mortimer et al. 2017). Environmental considerations emerged in particular, due to the fact that cocoa fields are being set up on land that was previously forest (Mossu 1990; Champaud 1966) and also because these farming systems are sometimes part of the forest landscapes or part of a matrix in which forest is mixed with farming systems (Leplaideur 1985; ASB 2000; Gockowski and Weise 1999). With this dynamic present on the cocoa agenda, plants associated with cocoa appear to be one of the main preoccupations of many stakeholders. These trees are intended to provide shade to cocoa trees, provide products (timber and non-timber) to farmers and national economies, and also provide ecological services such as biodiversity conservation and climate change mitigation (Sonwa et al. 2001, 2010; FAO 2002; Lojka et al. 2017).

A recent review by Andres et al. (2016) reveals that benefits provided by the cocoa agroforestry system could include: improvement of pollination; long term cocoa yield; longer life span of cocoa plantations; control of pests and diseases, erosion control;

biodiversification conservation enhancement; climate change mitigation through carbon sequestration; nutrient cycling; soil fertility maintenance or enhancement; watershed protection; and a reduction in deforestation. Some studies on station and farmers' fields show how cocoa production may be influenced by associated plant densities [Osei-Bonsu et al. (2002), Graefe et al. (2017) and Blaser et al. (2018) in Ghana; Sonwa (2004) and Saj et al. (2017) in Cameroon; Koko et al. (2013) in Cote d'Ivoire]. Ruf (2011) also highlights the fact that the density of associated plants depends on the cocoa varieties concerned. In fact, each cocoa variety presents its own ecophysiology characteristic needs which are achieved through specific cocoa pruning and management of associated plants (including their density and canopy management). For the specific conditions in Ghana see Blaser et al. (2018). In searching for suitable trade-offs, between agricultural yield and the provisioning of other ecosystem services, and following the recent study on Ghana, Blaser et al. (2018) concluded that low-to-intermediate shade agroforests providing approximately 30% cover constituted the ideal balance.

Some certification bodies are citing tree associated plants as being one of the main indicators of sustainability in their framework. Some private companies have even started putting zero-deforestation as pledges under different international initiatives, such as REDD+ (Reduced Emissions from Deforestation and Forest Degradation and conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries), the New York Declaration for Forests. With a view to ascertaining field realities, and helping to contribute to the management of associated plants, several studies had been conducted on the diversity of plants inside cocoa farming (Osei-Bonsu and Anim-Kwapong 1997; Asare 2005; Sonwa et al. 2007), as well as their economic importance (Gockowski and Dury 1999; Gockowski et al. 2004) in West and Central Africa. These studies do not necessarily investigate the way in which plants are distributed vertically and horizontally within the cocoa farming system, and when they evaluate the densities, they do not necessarily calculate the space between the plants, etc.

Cocoa is usually established on forest land so when we speak about the structure of such systems, we refer initially to that of the forest *'man made modified'* architecture (Sonwa et al. 2017). Authors such as McElhinny et al. (2005) and Zenner (2000) had defined forest structure as having stand structural attributes and stand structural complexities. Stand structural attributes include measures such as (i) abundance (e.g. density), (ii) relative abundance (Dbh, diversity, basal area), (iii) richness, (iv) size variation (e.g. standard deviation of Dbh), and (v) spatial variation (e.g. coefficient of variation of distance from the nearest neighbour). Such parameters can help to quantitatively describe the complex realties of the biotic and abiotic components of the system. With regard to the cocoa farming system, this is generally established by reducing/removing forest trees and replacing them with cocoa trees. Such modifications create new biotic and abiotic conditions that will help in the production of cocoa beans. From a management viewpoint, knowing the structure can be of considerable help in correctly orienting interventions within the farming system. For example, it is known that more shade will lead to black pod disease whereas less shade will lead to more miridae development.

Recent studies in Ghana show that cocoa agroforestry systems can mitigate the severity of cocoa swollen shoot virus disease (Andres et al. 2018). By modifying the structure through the elimination of some biotic elements (mainly associated plants), farmers can find a good balance for the pest and disease management of their system. In Latin America, a positive correlation had been established between the bird family and vegetation variables describing the height, density and cover of the herbal layer, midstorey density, canopy cover, and the structural complexity of vegetation cabruca and forest (Schroth et al. 2004). The cocoa structure also has a role to play in biodiversity conservation at the landscape level (Tscharntke et al. 2011). The structure of the cocoa system is thus useful in managing the plantation for the provision of services both within and outside cocoa farming. In the context of the multiple expectations directed towards the cocoa system (both products and services), few studies have been carried out on the actual structure of the cocoa plantation [see the work of Deheuvels et al. (2012) in cocoa Talamanca in Costa-Rica]. A recent study by Sonwa et al. (2017) undertook an analysis of the structure of the cocoa farming system in Cameroon. This study reveals the diversity of structural situations, indicating different forms of microclimatic conditions. The study suggests different intervention options that could be applied once the structure is well established; it also endeavours to review some information now available in West and Central Africa with a view to providing the way forward in terms of structuring the cocoa farming system. Some authors, such as Sonwa et al. (2002) and Leakey and Tchoundjeu (2001), are recommending the domestication of trees in perennial crop fields. However, such recommendation does not provide any technical characteristics as to the cropping system structure of these perennials. Information on structure would be useful in planning domestication and intensification, and in directing same towards the products and services that are expected to emerge from perennial cropping systems.

The information provided herewith is based on a literature review and divided up as follows: (i) density of cocoa, (ii) density of associated plants, (iii) basal area of associated plants, (iv) stratification and space between components, and (v) life cycle of components.

Theoretical background and methodological approach

Cocoa farming systems are usually man-made plantations established under forest modified stands. The structure study of these farming systems thus builds on experience in forest structure research and implications that can have an agronomy component mainstream in these vegetation stands. Sonwa et al. (2017) provides some basic information on vegetation structure. Forest stand structure is generally defined by its attributes and complexity (McElhinny et al. 2005; Zenner 2000). Conceptually, Bauhus et al. (2009), summarised the structural attributes commonly associated with different old-growth forest (subset of primary forests that develop only under a limited set of circumstances, mainly associated with long periods without major natural disturbances) as follows: high number/basal area of large trees; high stand volume or biomass; large number/basal area of dead/dying standing trees; large amount/mass of downed CWD (Coarse woody debris); wide decay class distribution of logs and/or snags; several canopy layers/vertical variability; high number/cover of late successional/shade-tolerant species; high variation in tree sizes, presence of several cohorts; high spatial heterogeneity of tree distribution/irregular size and distribution of gaps; thick forest floor; special attributes (pit and mound relief, presence of epiphytes, presence of cavity-trees, tree hollows); high variation in branch systems and crown structure/development of secondary crowns; and the presence of advance regeneration. Stand structural attributes summarized in a very simple way by McElhinny et al. (2005) and Zenner (2000) include: (i) abundance (e.g. density), (ii) relative abundance (Dbh, diversity, basal area), (iii) richness, (iv) size variation (e.g. standard deviation of Dbh), and (v) spatial variation (e.g. coefficient of variation of distance to the nearest neighbour). Such metric can be used to express, quantitatively speaking, the environment created by the combination of different biotic components which, when put together, create an abiotic habitat. Thus, a vegetation stand can be managed by modifying one or more attributes, to favour a particular structure aimed at a specific function.

Whereas in agriculture, generally, one or more biotic components (usually crop and/or animal) are managed in a very simple structure for a short period, in a silviculture plant component (usually forest) the product may last for a longer period. When one particular product (usually timber) constitutes the main aim of the vegetation stand, one or more species will be at the central point of the plant management. When services such as biodiversity conservation are the aim of the vegetation stand management, the tendency is that of a gradual retention of forest (Guftafsson et al. 2012) or management, with a view to maintaining Old-Growth attributes (Bauhus et al. 2009).This tendency of maintaining the function of the natural forest is gradually attracting the attention of the cocoa agroforest management, with a progressive effort being made to see that these farming systems play a role in the function of the neighbouring forest stand or those that had existed earlier.

Cocoa farming in West and Central Africa is usually established by modifying the existing vegetation in humid forest landscapes. Previous expectations to have cocoa beans are now associated with the production of NWFP (Now Wood Forest Products), timber and, more recently, forest biodiversity conservation and carbon storage. The ecological services (biodiversity conservation and carbon stock storage) expected to be provided are generally the same as those provided by the forest stand that preceded the cocoa farming. Characterisation of the cocoa farming system, so as to better provide the multiple products and services required, has already begun to include associated plant components as well as monitoring the way in which such components are distributed within the farm. Sonwa et al. (2017) provided one of the papers that explicitly addresses the issue of forest structure in cocoa agroforest. The author describes the cocoa agroforest by considering horizontal structure, vertical structure, complexity, eco-volume and typology of the farming system [see Sonwa et al. (2017) for details]. In the present study, the following issues were addressed: (i) density of cocoa, (ii) density of associated plant(s), (iii) basal area of associated plants, (iv) stratification and space between components, and (v) life cycle of the different components in the farming system. Whereas the first three (density and basal area) constitute characteristics of the horizontal structure, the fourth (stratification) refers to vertical structure. The space between components can normally be covered within a horizontal structure, but here it is associated with the vertical distribution of plant components. Since the work is undertaken in a management perspective, the life cycle of plant components is also included as a discussion element. The result is thus a spatio-temporal framework consideration, related to the management of cocoa farming in the context of West and Central Africa.

The methodological approach adopted here is based on the literature review search for publications covering the spatio-temporal framework (density, basal area, stratification, space between plants and life cycle) indicated above. The study was carried out in the same way as the previous review, related to the way in which the household and market demands influence the diversity in cocoa farms (Sonwa et al. 2014). As was the case then, the focus of this paper has been on Cameroon, Nigeria, Ghana and Cote d'Ivoire.

With a view to giving greater importance to non-cocoa trees, we are opening an early discussion on the appropriate way in which to change/remove the unproductive cocoa trees and/or change the plants. Since structures take into consideration both the vertical and the horizontal distribution of trees simultaneously, we are endeavouring to provide some additional information, such as density of plants per strata, and also the space between plants. With regard to horizontal distribution, since few studies had been carried out on this, we have focused on plant density. Based on the density provided in the literature, we have calculated the equivalent space between plants. The study ends by reflecting on some of the driving factors that may help in structuring the cocoa agroforest and landscape implications.

Density of cocoa

Recommendations versus field realities

In West and Central Africa, the advice usually given is to plant cocoa with a density of more than 1000 trees per hectare, with the possibility of reaching 2000 cocoa/ha. The cocoa density recommendation is 1333 cocoa/ha in Côte d'Ivoire (Akeyssey 1992); and 1600 cocoa/ha in Cameroon, with a possibility of reaching 2000 or 2500 cocoa/ha for non-shade systems. (Nya-Ngatchou 1984). Increasing the density of cocoa when shade is removed generally allows for the closing of canopy and reduces the development of weeds (Lachenaud 2001). The above density advice provided to farmers is based mainly on situations in which cocoa is the main or only crop. However, farmers do not always follow the advice given. Between 1028 and 1212 cocoa trees/ha are under shade around Baoule (Zougoussi and Bingakro), and approximately 2400 cocoa trees/ha are un-shaded in Côte d'Ivoire (N'Goran 2003). The density of cocoa trees in Ghana ranges from 1000 to 2500 trees/ha, despite the fact that the extension services advise 1730 cocoa plants per ha (Wood and Lass 1987). A recent survey found that the average density of cocoa in Southern Cameroon is 1168 tree/ha (Sonwa 2004), while the density of cocoa in Nigeria is 1000–1750/ha (Wessel 1971). Here, cocoa is grown with little or no permanent shade (Wessel 1971).

Cocoa is usually planted homogeneously on the farm in West Africa. An "Avenue planting" system has been tested in Côte d'Ivoire and Togo (Lachenaud 2001) with density sometimes lower than 1000 cocoa/ha. The aim here is to provide space for food crops at the early stage of the orchard. According to Wessel and Quist-Wessel (2015), cocoa yields have been between 500 and 600 kg/ha for the last 20 years in Cote d'Ivoire; around 400 kg/ha in Ghana (mainly with the High Yield Amazon Hybrids); around 400 kg/ha in Nigeria; and 300–400 kg/ha in Cameroon. The thinning of 50% of the 1333 to 1666 cocoa/ha could favourably influence the yield of cocoa beans.

Advice regarding density is generally geared towards controlling weeds. In farmers' fields, a reduction of density does not necessarily slow down cocoa production. Production can even increase in a situation where pesticides were not well applied. This has been explained in the previous studies, showing that in some cases losses due to black pod disease (Phytophtora) are less in the lower density (Moses and Enriquez 1979). A recent study by Sonwa (2004) indicates however that where pesticides are not applied, the high density of cocoa does not produce more cocoa beans.

Overproduction of cocoa is generally cited as being the reason for the low price of cocoa on the international market. Some believe that cocoa farmers need to reduce their production in order to influence the market system (Koning and Jongeneel 2006). This action does not necessarily mean that the cocoa area needs to be reduced. Reduction of cocoa production can be achieved through the conversion of some cocoa trees or space into associated plants. Such replacement can help in reducing the density of cocoa while increasing the importance of associated plants. The situation of Tsan villages in southern Cameroon can be illustrative of this type of orientation.

Not all trees in the cocoa field produce sufficient cocoa pods. In a recent study in southern Cameroon, Sonwa (2004) stated that without fungicide application, 21% of cocoa trees are unable to produce healthy pods. Even with an intensive application of fungicide, 6% of cocoa trees were still unable to produce any healthy pods after 2 years of experimentation in farmer fields. Farmers 'investment (mainly pesticide applications) on these unproductive trees is considered to be a wasted effort that negatively affects the management of the cocoa system.

The need to revisit the current cocoa densities

From the above (Sect. "Recommendations versus field realities" under "Density of cocoa"), at least two reasons can be seen to justify the need to reduce cocoa density: (i) proper diversification of farmers' investment means that some cocoa trees need to be substituted by other trees or plant species, (ii) reducing the density of cocoa trees can help in slowing the spread of *Phytophtora* spp. (putting some trees will constitute a barrier to the movement of the *Phytophthora*), (iii) Not all cocoa trees in the field produce healthy cocoa pods at an acceptable level, justifying their maintenance, and (iv) halving the density does not necessarily reduce the yield of cocoa production. In fact, it can sometimes actually increase the yield.

Previous findings easily lead to the need to reduce the density of cocoa and increase the importance of other plants. Few studies exist on the way in which plants need to be settled on the farm. Targeting a 600 cocoa/ha (approximately half of the current cocoa density) can be a good starting point. Participatory discussions with farmers can help in designing appropriate models. Of course, at least in the case of cocoa, densities will be justified by the yields and by pest and disease incidence, as well as by what other products and services are expected to emerge from the cocoa plantation.

In the Ntsan village (Cameroon), efforts to introduce citrus were made by missionaries, with the aim of diversifying the food allowance in the early 1970s through giving seedlings to farmers to help in the growth of this plant in cocoa agroforests. More than three decades later, a study undertaken by an ITTA-CIRAD (Aulong et al. 2000) program ascertained that 80% of citrus is grown in cocoa plantations. In this small village where cocoa 'orchards' have a density of 900 cocoa/ha (and even more than 2000, for some fields), cocoa agroforests enriched with citrus have a cocoa density divided by two (i.e. approximately 500 trees/ha). Initially grown for consumption purposes, citrus is now being sold as a consequence of the development of the urban and peri urban markets of Obala and Yaoundé. Despite its importance, however, farmers still prefer cocoa because the production of citrus has been close to zero in some years (e.g. 1997–1998). This is one of the constraints faced by farmers growing citrus in Ntsan village.

We realised from this experience that, (i) income sources other than cocoa can be easily intercropped in cocoa agroforests; (ii) incentives such as those provided by religious bodies in the Ntsan are necessary in order to support the management of other products in the system; (iii) a good technical package is required in order to support the introduction of such components in rural areas. NWFP could have been promoted in the same way as citrus. Of importance here are the dynamics surrounding cocoa agroforests (not the issue of intensification with exotic plants).

Density of associated plants

Recommendations versus field realities

Few studies have adequately focused on the design and density of associated plants in cocoa agroforests. Previous efforts to settle cocoa orchards and agroforests placed greater importance on the presence of shade. For associated plants, the advice given is to settle them in such a way that they allow 50–75% of light to reach the cocoa plants (Van Himme and Snoeck 2001).

In Cameroon, advice from the "projet-semencier" Cacao-Café-ONADEF services (a project which was created to support the development of cocoa in Cameroon around 1990) generally favours a 'space' of 12 m × 10 m for the following *Terminalia superba, Spathodea campanulata, Alstonia congensis, Antrocaryon klaineanum, Ficus mucuso, Pycnanthus angolensis and Canarium schweinfurthii*. This gives an average of 83.3 trees/ha. Although the recognized *Milicia excelsa, Entandophragma, Albiziaferruginea* and *Albiziaglaberima* are good shade-providing trees for cocoa, they do not provide any density for the association of these trees with cocoa. Density is not far off 85 t/ha—as was advised for species such as *Terminaliaspp* at 17 years for the mono-specific stand (Memento de l'Agronome: CIRAD, et al. 2004). In this monospecific stand of *Terminalia* (Table 1), expectations are to have 70 plants/ha at the harvest period (35–45 years after establishment), with a basal area of approximately 20 m^2/ha (Memento de l'Agronome: CIRAD et al. 2004). In Ghana, the recommendation (Table 2) is 10–15 trees/ha (Padi and Owusu 2003). The main species targeted by researchers in Ghana are *Terminalia ivorensis, Ricinodendron heudelotii, Spathodea campanulata, Albizia* spp. and coconut, as these are plants that can be associated with cocoa (Osei-Bonsu et al. 2002; Anin-Kwapong 2003; Padi and Owusu 2003). Ruf (2011) clearly explains how the introduction of hybrid cocoa in a rural milieu is modifying farmers' perception of associated tree density. Studies on the intercropping of kola and citrus with cocoa show that the stem girth and canopy scores of cocoa, kola and citrus in cocoa-kola-citrus were better in larger spacing and lower plant population densities of 17 plants/ha each of kola and citrus than smaller spacing and a higher plant population of 69 plants/ha, although the difference was not significant ($p = 0.05$) (Fanaye et al. 2003). There were no allelopathic effects on any of the component crops. Recently, Van Himme and Snoeck (2001) suggested a spacing of 9–18 m between plants associated with cocoa. This gives a density of 31–278 plants per hectare. After observing palm oil growing in Côte d'Ivoire, Tchoume (1982) concluded that cocoa could be grown with palm oil in avenue planting.

Studying a combination of cocoa, mango and avocado, Koko et al. (2013) found that associated plant species density and organisation/distribution within the system were impacting on the cocoa production. In the past, Grimaldi (1979) suggested planting *Cassia spectabilis* (now known as *Senna spectabilis*) at 5 m × 5 m for adequate shading of cocoa after 4–5 years in Southern Cameroon (Wood and Lass 1987). In Southern Cameroon, 321 associated plants (with diameter ≥ 2.5 cm) per ha (i.e. average space of 5.38 × 5.38) were found inside cocoa agroforests (Sonwa 2004). This figure is very high, compared to the 12 m × 10 m advice for the

Table 1 Density, in pure stand, of some species potentially associable with cocoa in West and Central Africa *Source*: Mémento de l'Agronome, Agriculture en Région tropicale; Kengue and Degrande (2003)

Species	Density (trees/ha)	Space between tree	Comment and country
Terminalia spp	70–85	11.95 m × 11.95 m to 10.8 m × 10.8 m	Tropic, expected basal area 20 m^2/ha
Mango	100	10 m × 10 m	Tropic
Mandarin	110	9 m × 10 m	Tropic
Clementinier	238	6 m × 7 m	Tropic
Orange	125–200	8.9 m × 8.9 m to 7 m × 7 m	Tropic
Cola spp	156	8 m × 8 m	Côte d'Ivoire
Dacryodes edulis	125	10 m × 8 m	Cameroon (Center, South and East province)

Table 2 Advice on the density of some plants associated with cocoa. Build from: Osei-Bonsu et al. (2002); Anin-Kwapong (2003); Padi and Owusu (2003); Fanaye et al. (2003); Grimaldi (1979); Van Himme and Snoeck (2001)

Species	Density (trees/ha)	Average space	Country/Source
Terminalia superba	83.3	12 m × 10 m	Cameroon. Cacao-café-ONADEF Project
Spathodea campanulata			
Alstonia congensis			
Antrocaryonklaineanum			
Ficus mucuso			
Pycnanthus angolensis			
Canarium schweinfurthii			
Kola	17	24.25 m × 24.25 m	Nigeria
Citrus			
Terminalia ivorensis	10–15	(31.62 m × 31.62 m) to (25.8 × 25.8)	Ghana
Ricinodendron heudelotii			
Spathodea campanulata			
Albizia spp.			
Coconut			
Cassia spectabilis		5 m × 5 m	Grimaldi (1979)
Gliricida sp.	277.7–30.8	9 m × 9 m to 18 m × 18 m	Van Himme and Snoeck (2001)
Leucaena s.			
Albizia sp.			
Erythrina sp.			
Calliandra sp.			
Any forest species			
Terminalia superba			
Alstonia sp.			
Ficus sp.			
Fagara sp.			
Phyllanthus discoideus			
Croton haumanianus			
Macaranga sp.			

timber species of the "Projet semencier Cacao-café" in Cameroon. The system resisted because of the mixture of species belonging to several strata. In Ghana, it was recently observed that the density of shade trees varies from 9.33 ± 1.22 to 22.8 ± 1.71 stem/ha with an average of 15.6 ± 1.34 stem/ha (Dawoe et al. 2016).

In the pure plantation (Table 1), the advice provided regarding the space/density of fruit trees is as follows: 10 m × 10 m for mango; 6 m × 6 m or 6 m × 13 m, followed by proper thinning for avocado; 9 m × 10 m (i.e. 110 plat/ha) for mandarin; 6 m × 7 m (i.e. 238 plant/ha) for clementinier (Memento: CIRAD et al. 2004); and 125–200 plants/ha for orange. In the pure *Cola spp* plantation in Côte d'Ivoire, advice regarding density was 156 trees/ha (8 m × 8 m) (Table 1). Few studies exist on the proper density of associated plants in cocoa agroforests (Table 2). Where data does exist, the information is not based on a proper combination of main species. The density of associated plants needs to be managed with the objective of achieving a certain basal area. Recent studies by Asare and Ræbild (2016) have begun to highlight the inadequacy of using density as the sole parameter of associated plant management in cocoa farming.

From the above observation it would appear that little research has been focused on the density of plants associated with cocoa and none focused on the valorisation of understorey plant species (See Sect. "Neglected under-storey plant species"). With regard to plants potentially associable with cocoa, density for pure plantation exists for timber and edible exotic fruits, but not for NWFP. Scientists' advice on the density of plants to be associated with cocoa does not always consider the association of several species with different types and strata. In southern Cameroon, the density adopted by farmers, who generally view agroforest as a system with multi-purpose outputs, is higher than that advised by the scientists.

Neglected under-storey plant species

Slashing under-storey components is one of the main management tasks related to cocoa agroforests or orchards. Under cocoa based agroforest, 1.21 t/ha of weed can thus be returned to the soil, 3 t/ha when shade is not present (Sonwa 2004). The management option of removing this understorey is driven by the need to avoid competition with cocoa. This continuous removal of plants from year to year helps slow down the seed bank and reduces the diversity of understorey plant species. Within 9 subplots of 1 m × 1 m in cocoa or coffee agroforestry systems in the Korup area in Cameroon, 137 understorey plants were found, as against 364 and 200 respectively, in secondary forests and near-primary forests (Bobo et al. 2006).

Little effort has been made to see if those understorey plant species could be valorised inside the cocoa agroforest in one way or another. It is known that forest understorey plays a role in traditional medicine and as food in rural areas but it can also provide some additional services. When well managed, understorey can help in avoiding land degradation; providing a habitat for predators (e.g. beneficial insects or spiders) that can help maintain an ecological balance between 'pests' and other species; providing a habitat for a variety of animals; reducing the impact of rain and runoff; contributing to taking nutrient from the soil and depositing it as litter on the surface; and providing edible plants and medicines. If cocoa density is reduced, this would improve the quantity per unit of land and reach an acceptable economic level.

When well managed, understorey can play a key role in meeting ecological services and household needs. Consequently, it requires careful attention so as to achieve a proper multistrata and multispecies cocoa based agroforest.

Basal area of associated plants

The basal area is the cross sectional area of the stem or stems of a plant or of all plants in a stand, generally expressed in square units, per unit area. In plantation forestry, a fairly good correlation exists within species between the basal area of a tree and the cross-sectional area of its crown, and the sum of all basal areas in a stand (stand basal area) has conventionally served as a basis for the scheduling of thinning to reduce inter-tree competition [Smith et al. (1997) cited by Nissen and Midmore (2002)]. The basal area is also seen to be of use for the monitoring of agroforestry systems, where both crops and trees are mixed (Nissen and Midmore 2002). Another parameter which can go with the basal area is eco-volume (the space created by the presence of associated plants, providing proper ecological conditions for other plants and animals). Recent studies by Sonwa (2004), taking into consideration cocoa and associated plants, indicated an average basal area of 36 m^2/ha, 85% of which is taken up by those plants associated with cocoa. This study, conducted in different ecological zones and different types of cocoa plantations, gave an average of 30 m^2/ha for plants associated with cocoa. There was no statistical difference between the ecological region and type of cocoa (Sonwa 2004) for the achievement of a better multistrata system.

If we consider the advice of 12 m × 10 m *Terminalia superba* per hectare, this can easily lead to a density of 85 trees/ha (with probably 70 trees/ha and a basal area of 20 m^2/ha at harvest time, 35–45 years after establishment (CTFT, 1989). The expected basal area of 20 m^2/ha is less than the average 30 m^2/ha (Sonwa 2004) found in the farmers' cocoa fields (Table 3), but not far from that obtained by ASB (2000) in the study in two cocoa fields in Cameroon (17 m^2/ha and 20 m^2/ha for associated plant and cocoa). This expected basal area is greater than the average 13 m^2/ha of the upper strata (> 20 m) of the Humid Forest Zone of Cameroon (HFZ). The advice provided suggests 17 trees/ha in kola fields in Ghana (i.e. 13.34 m2/ha if all the trees have a diameter of 1 m); this would appear to be low but would seem more compatible with the possibility of managing

Table 3 Density, basal area and average space between plants in the cocoa agroforest of Southern Cameroon *Source*: Sonwa et al. (2017), Build by analysing and combining Tables 2 and 6 of Sonwa et al. (2017)

		Strata				
		0–5 m	5–10 m	10–20	> 20 m	Tot
Yaoundé	Basal area m^2/ha	1.1	2.5	15.8	10.3	29.7
	Density/ha	142	64	89	13	308
	Average space between plants (m)	8.39 m × 8.39 m	12.5 m × 12.5 m	10.59 m × 10.59 m	27.33 m × 27.33 m	5.69 m × 5.69 m
Mbalmayo	Basal area m^2/ha	0.4	3.1	14.3	12.8	30.7
	Density/ha	60	108	161	28	358
	Average space between plants (m)	12.90 m × 12.90 m	9.62 m × 9.62 m	7.88 m × 7.88 m	18.89 m × 18.89 m	5.26 m × 5.26 m
Ebolowa	Basal area m^2/ha	0.9	1.5	11.9	17.0	31.2
	Density/ha	67	59	138	34	298
	Average space between plants (m)	12.21 m × 12.21 m	13.01 m × 13.01 m	8.51 m × 8.51 m	17.14 m × 17.14 m	5.79 m × 5.79 m
HFZ	Basal area m^2/ha	0.8	2.4	14.0	13.4	30.5
	Density/ha	90	77	129	25	321
	Average space between plants (m)	10.5 m × 10.5 m	11.39 m × 11.39 m	8.8 m × 8.8 m	20 m × 20 m	5.38 m × 5.38 m

other trees under the upper strata. However, the Ghana potential upper strata is that of the average basal area of the upper strata (13 m^2/ha for plants above 20 m) in Cameroon.

Few studies have aimed at evaluating the basal area of cocoa multistrata and multi-specie systems in cocoa agroforests in West and Central Africa. The eco-volume (space created by the agroforest for life cycle) has not been properly exploited. The current advice of scientists to grow cocoa with just one species has resulted in creating unexploited basal areas. The indigenous cocoa farming system of Southern Cameroon has 30 m^2/ha (Sonwa 2004), which is more than what can be expected, according to the scientists' advice. Such advice does not always allow for the proper distribution of basal area across strata.

Stratification and space between components

Field realities

Cocoa agroforests that have a structure similar to the forest are of particular interest for the environmental services they can provide. Ruf and Zadi (2003) noted that cocoa established in forest shade trees could form a stratum of up to 40 m above the cocoa grove. ASB (2000) observed a mean canopy height of 12 and 18 m in maintained (> 45 years) and un-maintained (< 30 years) cocoa agroforest respectively, in Cameroon. One of the main challenges is to keep the stratum of associated plants at a level that does not hamper the development of cocoa. Few studies exist on stratification within cocoa agroforests. The cocoa agroforest in Southern Cameroon has the basal area distributed across several strata, as a result of varying density in the strata (Table 3).

From the above table we can gain some basic information on the cocoa agroforest. Using the Cameroon model, the basal area of associated plants in cocoa agroforests at the climax (Janssens et al. 2004), will be around 30 m^2/ha (Sonwa 2004). However, the system would be more aerated if the density of plants within the strata of 5–10 m could be reduced. On average, without taking into consideration the patchiness that sometimes appears in the agroforestry system, plants of the upper strata (> 20 m) present a distance of 20 m × 20 m between trees. By proposing a density of associated plants of 15–18 trees/ha in

Table 4 Potential life cycle of several components of the cocoa agroforest of West and Central Africa

Plant components	0–20 years	20–40 years	40–60 years	60–80 years
Timber	←———	———	———	———→
Fruits (NWFP and exotic)	←———	———→		
Cocoa	←———	———→	←———	———→
Crop	←———→			

Legend: the ←——→ covered the maximum period expected from the crop components

Ghana (Asare 2005), CRIG is suggesting a space of 26 m × 26 m between plants. This is not very different from the situation in the upper strata of the Yaoundé block in Cameroon, where an average of 27 m × 27 m can be found. In the case of Cameroon, however, farmers tried to exploit the under canopy of this strata by managing other plant components [see Table 4 on main species per strata in Sonwa et al. (2017), for details] in the system. This leads to an increase in the basal area of associated plants per unit land.

The upper canopy is generally occupied by the timber species, while the lower canapy is filled with fruit trees, medicinal species or timber plants in the growing phase. In order to allow for the proper circulation of air, it would be advisable to share the basal area of associated plants between the two important strata 10–20 m and the upper strata (more than 20 m). Previous studies undertaken in Africa usually endeavoured to create a combination of cocoa with one or 2 species, with the target of only one strata different from the cocoa strata (Amoah et al. 1995; Koyo 1982; Fanaye et al. 2003; Petihuguenin 1995). Building a multistrata system serves to fill the gap between cocoa and the upper strata. It would be good to have a proper vertical distribution of the basal area (ex. 15.8 m^2/ha within the strata of 10–20 m and 10.3 m^2/ha for the strata > 20 m) or density of associate plants (89 plants/ha within the 10–20 m strata and 13 within the strata > 20 m). The management of different strata (see Sect. on "How many strata are useful in a cocoa agroforest?") needs to fit into a proper chronology, taking into account the life cycle of cocoa and that of associated plants.

How many strata are useful in a cocoa agroforest?

Providing shade for cocoa is the main task assigned to associated plants in cocoa agroforests. Previous advice stated that associated plants should be managed in such a way as to allow 60% of sun to reach the cocoa canopy. Although this was accepted as a rule (Braudeau 1969), some studies are endeavouring to test ways in which associated plants can be properly managed in an appropriate ecological manner, thus providing good economic outputs.

The cover within the cocoa agroforest can be expressed in terms of leaf area index. The basal area can also help in expressing the coverage of the upper canopy. One of the main questions that still need to be solved is the vertical distribution of the leaf area index or the basal area. Is it ecologically, agronomically and economically profitable to maintain the leaf area index of the system in just one strata or should it be shared on several vertical strata? One of the main challenges for scientists working on cocoa agroforest will be that of making an in-depth investigation into this issue.

Life cycle of the cocoa agroforest

Cocoa agroforest and local forest climax

A complex cocoa agroforest is a combination of plants with different life cycles. At the climax, the humid forest, with a structure similar to forests expected for cocoa agroforest, presents a combination of species and population that are dynamic but with components maintained over time. At the climax (Janssens et al. 2004), young individual plants are in sufficient quantities to replace the old ones. Depending on the goal to be achieved with the cocoa agroforest, the approach may be different. The cocoa agroforest will probably be related to the local forest climax.

The expectation when developing a cocoa agroforest is that of creating the same structure as that of the forest. Basically, the idea is to set up a system able to provide the same ecological services offered by forests. Such services are generally well functioning by the time the forest reaches its climax. This is the final stage in the forest's ecological succession, when it reaches equilibrium. At this stage, the greater part of the energy produced by the system is devoted to the life of the plants and animals therein. In the forest succession, this equilibrium stage is characterized by a certain biomass and basal area.

Agriculture and agroforest practices involve the deliberate prevention of the ecosystem from developing towards a climax. The agroforestry system needs to be in constant production, as cocoa beans and other plant products will be removed annually from the system. A study in southern Cameroon reveals that a primary and secondary forest can have a basal area of 44.9 and 39.2 m^2/ha respectively (Zapfack et al. 2002). Within the same site, cocoa agroforest has a basal area of 36 m^2/ha (Sonwa) or 30 m^2/ha (Zapfack et al. 2002). The above data would suggest that 5–10 m^2/ha difference can exist between the basal area of an agroforest and the local basal area of the primary forest. The difference between the agroforest basal area and the local climax basal area will then constitute the magnitude left for the production of cocoa beans and other products that can be harvested from the system.

Life cycle of cocoa agroforest components

Un-shaded cocoa usually lasts for approximately 25 years (Ruf and Zadi 2003). After this period the orchard returns to fallow before the cocoa plants get re-established. Under shade conditions in southern Cameroon, with the combination of added components, each one can be changed at the end of its life cycle without necessarily destroying the whole system. During the replacement of cocoa, the system is rich in organic matter and does not develop a lot of weeds which would compete for water with young cocoa plants.

The life cycle of the different components is variable. In general, for wood of 50–60 cm DBH (diameter at breast height), 25–40 years is required for fast growing trees such as *Terminalia ivorensis, T. superba, Cedrela odorata, Triplochiton scleroxylon and Gmelina arborea* (CFTC, 1989). For the same diameter and for plants in the middle growth rate, such as *Tectonia grandis, Aucoumea klaineana, Khaya* sp., 40–70 years would/may be needed. Fruit trees, such as avocado, citrus, and mango, can last for 20–40 years, on average. Cocoa can produce for approximately 25–40 years. A summary of the different components are represented in Table 4.

An agroforest can then be created with the aim of achieving the same duration as the life cycle for timber, which may be the one component of the system that will stand for too long a time. After this period, the renewal of cocoa can be undertaken within the same system. Alternatively, the system can be left in fallow. The option will depend on the farmers' strategy and goals. At the landscape level, the main driving force may lead to different models of cocoa agroforest. An integrated approach is needed to achieve a more sustainable system (see Sect. "Policy and socioeconomic research on cocoa agroforests").

From the above, it can be seen that a cocoa orchard has a life cycle shorter than a multistrata and multispecies agroforestry system. In a complex system with a combination of different components, replacement of each element can be undertaken without necessarily destroying the whole system. This is generally the case in the cocoa fields of Cameroon and other parts of West Africa that have old cocoa plantations. The multistrata and multispecific approach allows for the replacement of individual plants between and/or within species.

Policy and socioeconomic research on cocoa agroforests

At the landscape level, the main driving force may lead to different models of cocoa agroforest (Fig. 1). Socio-economic and policy research related to cocoa agroforest and orchards is useful in order to understand the rural context and achieve development goals in the cocoa belt. Mercier and Miller (1998) recommend that socio-economic research be focused on three principal areas: (i) understanding the agroforestry adoption decision-making process, (ii) empowering economic analysis of the agroforestry system, and (iii) analysing the impact of alternative

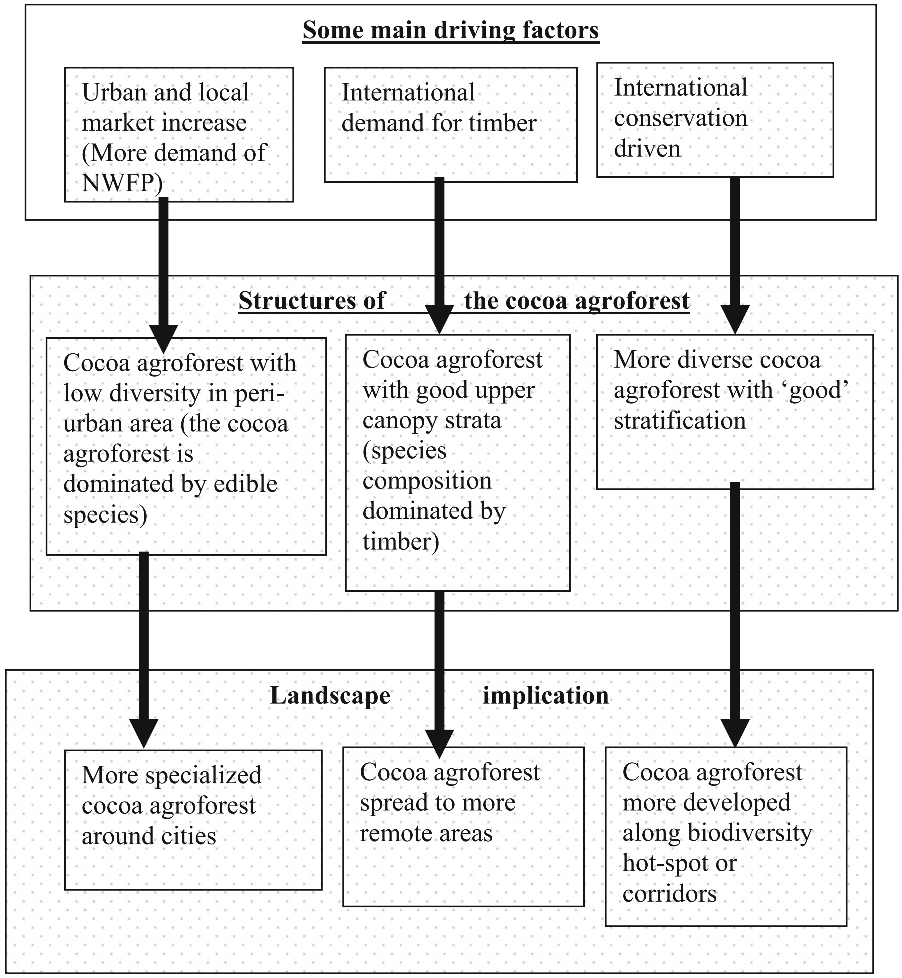

Fig. 1 Potential impact of different driving forces on the structure of cocoa agroforest and landscape implications in the humid forest zone of West and Central Africa

policies (at local, regional and national levels) on the potential of agroforestry-based rural development initiatives. Such recommendations can easily be applied to the cocoa agroforestry system. However, socio-economic research on cocoa agroforest has focused mainly on cocoa bean production. The studies concerned villages and the national economy of cocoa in several countries of West and Central Africa. The information provided by the data relates to the importance of cocoa for rural and national economies. Since cocoa land is now targeted for inter-cropping timber, non-timber production and ecological services, additional research would be of use.

It is no exaggeration to say that the findings of Russell and Franzel (2004) could also be applied to multipurpose trees growing in cocoa agroforests. Following a general review of agroforestry practices over 3 decades, the above-mentioned authors noticed that forest policy, physical and social barriers to smallholder participation in markets, an overall lack of information at all levels regarding markets for agroforestry products, and the challenges to out- growing schemes and contract farming all inhibit the growth of the smallholder tree products sector in Africa, outside of traditional products. Policy and scoio-economic research will be useful in order to address these issues and further the proper development of a diverse cocoa agroforestry system.

In the context of West and Central Africa, there is little data available regarding the demand for NWFP, timber and ecological services and the ways in which satisfying this demand can impact on cocoa farmers.

Conclusions

Based on agronomy research, some advice was provided on the density of cocoa trees in countries of West and Central Africa. Depending on the cocoa varieties and the economical perspectives of the various countries, orchards or agroforests were the main field for cocoa bean production there. Associated plants which, initially, were considered merely as shade providers, now have not only the additional function of timber and non-timber production but also that of ecological service providers. Despite this new-found importance, these plants have not yet received the same level of attention and recommendation as was the case with regard to cocoa.

Not all of the cocoa trees produce sufficient cocoa beans to justify their maintenance. In a context in which there are growing expectations for associated plants, we open up a discussion on the need to remove the unproductive cocoa trees and/or replace them with useful companion plants.

Few studies have been carried out on the basal area of cocoa farming. Because the cocoa agroforest tends to mimic the forest structurally, the neighbouring forest can already be considered a good example towards which the cocoa agroforest should be drawn. Intensification of the system will thus need to consider neighbouring/previous forest basal areas as representing a goal for which to strive. The basal area can thus become one of the main parameters for cocoa management.

Understorey components of cocoa farming have not yet received the same attention as the cocoa canopy plants mentioned earlier. They are important components of vertical intensification of the cocoa agroforest. More complex cocoa farming includes components with differing life cycles that need to be taken into consideration when managing cocoa farming. The intensification thus needs to consider these multitudes of life cycles and take them into account in the management of the farming system. Such structural spatial–temporal consideration is key in addressing the multiple functions expected of cocoa agroforests of West and Central Africa.

The structure of the cocoa farming system is not merely an issue of ecological/agronomic disciplines alone. Other disciplines, such as policy and socio economic issues, should also be taken into consideration.

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