New Forests
DOI 10.1007/s11056-015-9515-3

Tree diversity and canopy cover in cocoa systems in Ghana

Asare Richard[1,2] · **Anders Ræbild**[1]

Received: 19 May 2015 / Accepted: 8 October 2015

Abstract Cocoa (*Theobroma cacao* L.) growing systems in Ghana and West Africa consist of diverse tree species and densities. This study was conducted to determine factors that influence tree species configurations and how tree characteristics affect canopy cover in cocoa farms. Eighty-six farmers and corresponding farms were selected in a systematic approach in four districts across two agro-ecological zones in Ghana. Results show that men tend to have larger farm sizes, higher tree density and diversity than women. Tree density and canopy cover of shade trees were low on large farms, but diversity increased with increasing farm sizes. Even though there was a significant correlation between diameter at breast height and crown area for all species investigated, tree species differed considerably in their crown area and thus the amount of ground cover provided. Current recommendations for shade are usually expressed in number of trees per ha, and our results suggest that these should be refined to reflect the effects of species, the size of their diameter at breast height and the crown area.

Keywords Cocoa agroforest · Tree diversity · Structural diversity · Canopy cover

Introduction

Cocoa (*Theobroma cacao* L.) landscapes in West and Central Africa consist of a mosaic of smallholder cocoa farms that range in their structural diversity and species richness between highly diverse cocoa agroforests like those encountered in southern Cameroon (Nomo 2005; Sonwa et al. 2007) and cocoa monocultures, which exist in parts of Ghana

✉ Asare Richard
r.asare@cgiar.org; wjz479@alumni.ku.dk

[1] Department of Geosciences and Natural Resource Management, University of Copenhagen, Denmark Rolighedsvej 23, 1958 Frederiksberg C, Copenhagen, Denmark

[2] International Institute of Tropical Agriculture, Private Mail Bag L-56, Legon, Ghana

Published online: 15 October 2015

and Côte d'Ivoire (N'Goran 1998; Padi and Owusu 1998; Ruf and Schroth 2004; Asare 2005; Anglaaere et al. 2011). Tree diversity in cocoa farms offers farmers a range of agronomic, economic, cultural, and ecological benefits (Rice and Greenberg 2000; Duguma et al. 2001; Di Falco and Perrings 2003; Somarriba and Beer 2011). However, the composition and structure of shade tree stands in mixed systems have been reported to also cause excessive shade, which can lead to high humidity and create favourable conditions for black pod diseases in cocoa systems (Dakwa et al. 1976; Opoku et al. 2002) and also affect the mechanisms that drive fruit losses on cocoa trees (Bos et al. 2007). Monocultures of cocoa tend to have higher productivity under high-input conditions (fertilizer and pesticides) than cocoa in mixed systems (Gockowski et al. 2013) but also have shorter economic life span compared with low input, mixed systems, which sustain production over a relatively long period of time (Obiri et al. 2007). Hence, discussions on tree diversity, density and canopy cover in cocoa systems have been polarized between environmentalists looking for the long-term sustainability and those who seek to increase cocoa bean production in the short term (Asare and Asare 2008).

Environmentalists argue that cocoa farms with a diversity of forest tree species can connect fragmented forests and form corridors for animal passage, helping to conserve and improve the integrity of the ecosystem (Schroth and Harvey 2007; Asare et al. 2014). In upholding its environmental obligations, Rainforest Alliance through the Sustainable Agriculture Network has developed environmental criteria and indicators for cocoa production which advocate for 70 emergent non-cocoa tree species per hectare of cocoa of which 12 must be native species (SAN 2005). This is estimated to provide a canopy cover of approximately 40 % for cocoa trees underneath the upper canopy, although it is not clear at what stage in the life of the cocoa and tree plantation this would be (Asare and Asare 2008). This density is equivalent to shade tree spacing of 12 m × 12 m. In Ghana these criteria and indicators have been modified to meet requirements of the Ghana Cocoa Board (COCOBOD) through the Cocoa Research Institute of Ghana (CRIG), whose aim is primarily focused on optimal cocoa production. The recommendation is to plant up to 18 emergent trees (≥12 m height) per hectare (24 m × 24 m) also providing permanent canopy cover corresponding to approximately 30–40 % shade (Anim-Kwapong 2006).

The variations in the recommended number of trees with respect to the appropriate range of shade cover per ha can be attributed to the species and structural diversity of trees in the system i.e., tree species, density, tree characteristics like canopy architecture, diameter at breast height, trunk height as well as age. Such variations may exist as a result of farmers' management practices, which include the area cultivated and the tree species configurations in the cocoa systems. This is because in Ghana and the rest of West Africa shade tree recruitment is part of an anthropogenic process in which the eventual density and structure of trees is as a result of farmers' preferences (Asare 2010). However, this process makes it difficult for farmers to determine in advance and over the life span of the cocoa trees the amount of canopy cover available at any particular stage and age.

There is limited information on factors that influence tree species configuration and how this affects canopy cover in cocoa systems. These gaps in knowledge in part have led to the uncoordinated management of naturally regenerated desirable forest trees, rather than advance planning of their composition and arrangements in cocoa systems (Asare and Asare 2008). Over the last couple of decades, rapid expansion of extensive cocoa growing systems characterized by no-shade cocoa production has been cited as one of the major drivers of deforestation and forest degradation in West Africa (Asare 2006a). Paradoxically, shade grown cocoa holds the potential to reverse this trend. The first aim of this work was to understand the factors influencing variability in tree density and diversity and how this contributes to canopy cover by shade trees in cocoa farms. Secondly, we tried to identify a simple indicator for canopy cover for different tree species in cocoa systems in order to help farmers determine appropriate canopy levels.

Materials and methods

Study area

The study was conducted in four cocoa growing communities (Jeninso, Nerebehi, Nsuosua and Nkrankrom) in four districts in the Ashanti (Amansie West and Atwima Nwabiagya) and Western regions (Sefwi Wiawso and Wassa Amenfi West) of Ghana (Fig. 1), which fall under the Moist Semi-Deciduous (MSSE) and Moist Evergreen (ME) forest zones respectively. Both areas have two rainy seasons annually. The major rainy season occurs from April to the end of July and the minor occurs from September to the end of October with a short dry spell in August. The ME and MSSE forests correspond to the *Lophira*-*Triplochiton* and the *Celtis*-*Triplochiton* associations (Taylor 1960) respectively, which enable the establishment of high forest vegetation with the characteristic multi-tier vertical stratification.

The ME forest is characterized by a semi-equatorial climate with high rainfall (1500–1750 mm) and daily temperatures between 22 and 34 °C. Temperatures are high throughout the year, with the hottest month being March. The high rainfall and the

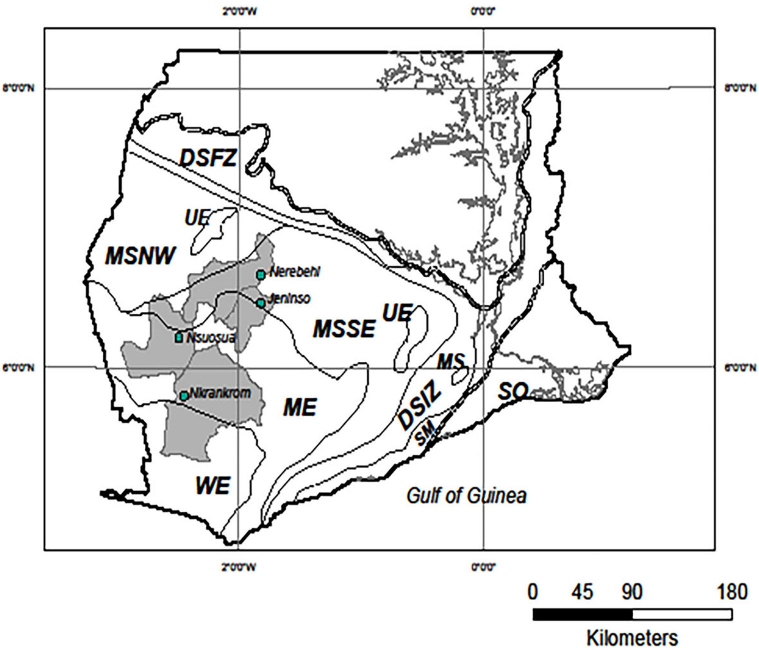

Fig. 1 Map of Southern Ghana showing *four shaded* districts consisting of the study sites (*blue dot*). Forest type boundaries are shown by *broken line*. Forest-type abbreviations: *WE* wet evergreen, *UE* upland evergreen, *ME* moist evergreen, *MSSE* moist semi-deciduous (*NW* Northwest subtype, *SE* Southeast subtype), *DS* dry semi-deciduous (*FZ* fire zone subtype, *IZ* inner zone subtype, *SM* Southern marginal). (Color figure online)

proximity to the Atlantic Ocean create moist atmospheric conditions that result in high relative air humidity, ranging between 70 and 90 % for the monthly means. The climatic conditions provide optimum conditions for biomass production, due to the high rainfall coupled with the fertile ochrosol soil (Hall and Swaine 1976). The MSSE is marked by moderate annual rainfall (1250–1500 mm) with uniformly high temperatures (mean monthly minimum and maximum of 27–31 °C) and high relative humidity.

Farmer selection criteria

Ashanti and Western regions were chosen as they represent old and new frontiers of cocoa cultivation in Ghana respectively, with the latter generating over 50 % of the country's annual total production. Western region is the last frontier for expansion of cocoa cultivation due to the presence of patches of forests, while the Ashanti region is noted to be denuded of natural forest. In total, 86 cocoa farm owners (25 females and 61 males) representing a similar number of farms were selected from the four districts. This was carried out through a systematic sampling process that involved focus group discussions on access to tree resources on farm and follow up interviews that targeted farmers who had shade trees on cocoa farms. Farms were selected such that they were at least 100 m apart in each community. These cocoa farms range between the ages of 8–28 years, which is noted to be the economically productive age of cocoa trees (Obiri et al. 2007). Farmers were asked questions on socio-cultural factors including land history (was farm made from forest, fallow or already cropped land), mode of land acquisition (purchased, inherited, share cropping or tenancy), educational background, training experience on agricultural practices and whether trees were planted or naturally regenerated. Thirty-five percent of the farmers have had a form of training in cocoa cultivation. About 30 % were women almost all of whom inherited their lands from their spouses or family for the creation of the farms. In total, 56 % of the farms were cultivated on old fallow lands, 23 % on former forestlands and 21 % on already cropped land. 60, 80 and 99 % of farmers use fertilizers, fungicides and insecticides, respectively.

Tree species and tree characteristics assessment

Cocoa farms for this research were selected and delineated by virtue of the fact that management decisions on each farm were taken by only one person in order to ensure consistent flow of information. The area of each farm was recorded with a Garmin Global Positioning System (GPS) by walking along the entire perimeter of the farm. All shade trees with canopy above the cocoa canopy and lying within the perimeter of the farm were identified, counted and measured. In total, 1042 shade trees were recorded on a total area of 127.7 ha. Almost all trees, 96 %, were a result of natural regeneration. Shade trees comprised 90 species from 30 families (see "Appendix"). Forty-nine species appeared in both agro-ecological zones. The most predominant species were *Terminalia superba, T. ivorensis, Newbouldia laevis, Milicia excelsa, Persea americana, Ficus exasperata, Antiaris toxicaria, Amphimas pterocarpoides, Albizia zygia and Morinda lucida*. Most trees were timber species, but some fruit trees such as *Persea americana*, *Cola nitida* and *Ricinodendron heudelotii* were also found.

The extent of tree diversity on farm was measured using the Simpson Reciprocal index (1/D), Simpson's measure of Evenness ($E_{1/D}$) and the Shannon index (H) (Magurran 2004). $1/D$, $E_{1/D}$ and H were calculated by using formula (1), (2) and (3), respectively:

$$1/D = \frac{1}{\sum_{i=1}^{R} (P_i)^2} \quad (1)$$

$$E_{1/D} = \frac{(1/D)}{R} \quad (2)$$

$$H = \sum_{i=1}^{R} -(P_i * \ln P_i) \quad (3)$$

where R is the number of species encountered, P_i is the proportion of the individuals of species i in the farm (Krebs 1985), and $\sum$ is the sum from species 1 to species R.

Diameter at breast height (DBH) and crown diameter (CD) of each tree were measured according to the National Forest Inventory Field Manual Template (FAO 2004). DBH was measured over the bark of the tree at 1.3 m breast height above the ground using a diameter tape. CD was assessed measuring the diameter of the crown in four different directions, following the cardinal points and figures averaged. The diameter measurements were taken across the crown spread from one tip to the other (Blozan 2006). This was to ensure that variations of the projected shape of the crown were captured. CD was then used to estimate the crown area (CA) by the following formula:

$$CA = \pi * \left(\frac{CD}{2}\right)^2 \quad (4)$$

The total crown cover (CC) for all the upper canopy trees was expressed as a percentage per ha to ensure easy comparison between farms using the following formula:

$$CC = \left(\frac{TCA}{farm\ size}\right)/10000 \quad (5)$$

where TCA is the sum of CA of all trees recorded per farm.

Data analysis

In order to analyze the effect of a range of farm and farmer related parameters on tree density, the diversity indices and canopy cover, the following general linear model was applied:

$$Y = district + gender + history + acquisition + fertilizer + fungicide + insecticide + propagation + farmsize + \varepsilon$$

where,

- Y is the response variable (Tree density, R, 1/D, $E_{1/D}$, H and canopy cover),
- District represents the four communities,
- Gender (female or male),
- Acquisition (inherited, purchased and sharecropping),
- History (forest, old fallow or cropped land),
- Fertilizer (yes or no),
- Fungicide (yes or no),
- Insecticide (yes or no),
- Propagation (planted or naturally regenerated),

- Farm size is a covariate denoting the size of the farm in ha, and
- ε is the residual, assumed to be independent and following a normal distribution with expectation zero.

In this model we used farm size as a covariate as we wished to account for the effects of increasing sample plots (farms) on the response variables. However, we also wished to study whether different social strata possessed different sizes of farms, and so in a second model farm size was analysed as a dependent variable. This model was as follows:

$$Y = district + gender + history + acquisition + \varepsilon$$

where Y represents farm size. The analyses were performed using the PROC GLM in the SAS 9.3 software (SAS Institute Inc, Cary, NC, USA).

Non-significant variables were removed sequentially by removing the variable with the highest *P value*, until all remaining variables were significant. Where the tests showed significant differences, pairwise comparisons were made using Tukey's studentized range test ($P < 0.05$). Model assumptions were tested by plots of residuals against predicted

Table 1 Analysis of variance showing differences in farm size, tree density and tree diversity as influenced by gender of farmers in cocoa growing systems in Ghana

Source	Degree of freedom	Sum of squares	Mean squares	F value	*p value*
1. Farm size (log transformation)					
Gender	1	7.67	7.67	12.69	<0.001
District	3	11.81	3.94	6.51	<0.001
Error	80	48.38	0.61		
Total	84				
2. Tree density					
Plot size (inverse transformation)	1	10081.86	10081.87	718.31	<0.001
Gender	2	538.74	268.39	19.12	<0.001
Error	83	1164.96	14.04		
Total	86				
3. Richness (R)					
Gender	2	2262.35	1131.18	235.60	<0.001
Plot size	1	131.27	131.27	27.34	<0.001
Error	81	388.90	4.80		
Total	84				
4. Simpsons index (D) (inverse Simpson)					
Gender	2	1759.89	879.95	182.76	<0.001
Plot size	1	58.53	58.53	12.16	<0.001
Error	82	394.82	4.82		
Total	85				
5. Crown cover (log transformation)					
Plot size	1	24.095	24.10	66.55	<0.001
Error	84	30.41	0.36		
Total	85				

effects and Shapiro–Wilks tests of normality (Crawley 2007) as implemented in the UNIVARIATE procedure. Where model assumptions were not fulfilled, appropriate transformations (natural logarithm, square root) were used.

The relationship between diameter and crown area was investigated for all tree species recorded at least 10 times across all the farms. The *lm*(), *cor*() and *summary*() functions in the statistical package R (Ekstrøm and Sørensen 2011) were used to fit the model, determine correlations between the various parameters and test and report the estimates respectively in the regression model:

$$CA = a + b(DBH) + \varepsilon$$

where CA is the crown area expressed in m^2, a is the intercept, b is the slope, DBH is the tree diameter in m and ε is the residual, assumed to be independent and following a normal distribution with expectation zero. Model assumptions were tested by using the residuals and quantile–quantile plots. When necessary, logarithmic transformations were performed on both CA and DBH in order to fulfil model assumptions.

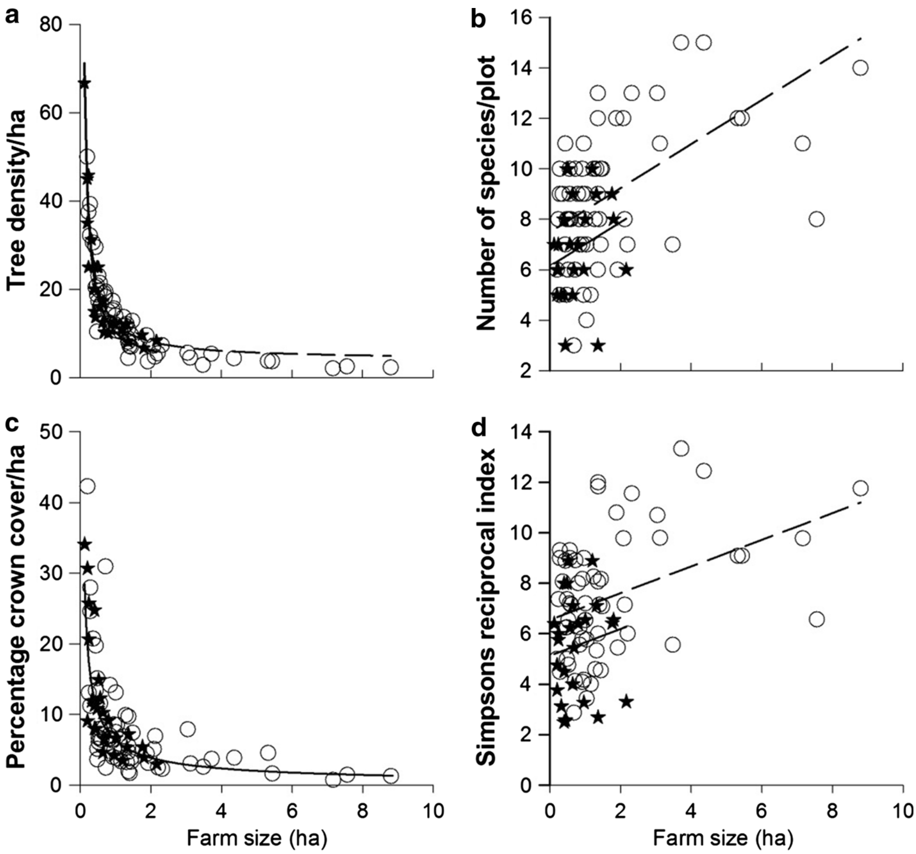

Fig. 2 Plots showing the relationship between tree density/ha, crown cover, species richness, and Simpsons reciprocal index between men (*open circles* and *broken line*) and women (*close stars* and *continuous line*)

Results

Cocoa farm sizes recorded under this study were small as they varied from 0.2 to 8.8 ha with men having significantly larger farm sizes compared to women (Table 1). Only one woman had a farm larger than 2 ha, and the average farm size was 0.75 ha for women and 1.67 ha for men. There were also differences in farm sizes between the communities and districts. Average farm sizes were 1.8 ha for farms in Nerebehi (Atwima Nwabiagya), 1.09 ha for Jeninso (Amansie West), 1.94 ha for Nkrankrom (Wassa Amenfi West) and 0.8 ha for Nsuosua (Sefwi Wiawso) respectively. However, history of farms, educational background of farmers, training of farmers and regeneration types of shade trees had no effects on the variables analysed and will not be referenced further.

The density of trees tended to be high (up to 76 ha^{-1}) on small farm sizes but decreased to low values (<5 ha^{-1}) on large farm sizes. The shape of the curve was hyperbolic, and differences between women and men were again significant, with women having fewer trees per ha than men (Fig. 2a). This was also indicated by the least square mean values which were 16.6 trees per ha for men compared to the females who had 14.7 trees per ha. Canopy cover ranged between 1 and 40 % as shown in Fig. 2c. There was an inverse relationship between farm size and canopy cover, as relatively large farms had smaller canopy cover from shade trees compared to smaller farms. All the measures of diversity showed that gender of the farmer had an influence on tree diversity, with female farmers having less diverse farms compared to men (Table 1; Fig. 2b, d). Large farms had more tree species compared to smaller farms. Simpsons and Shannon's indices increased with

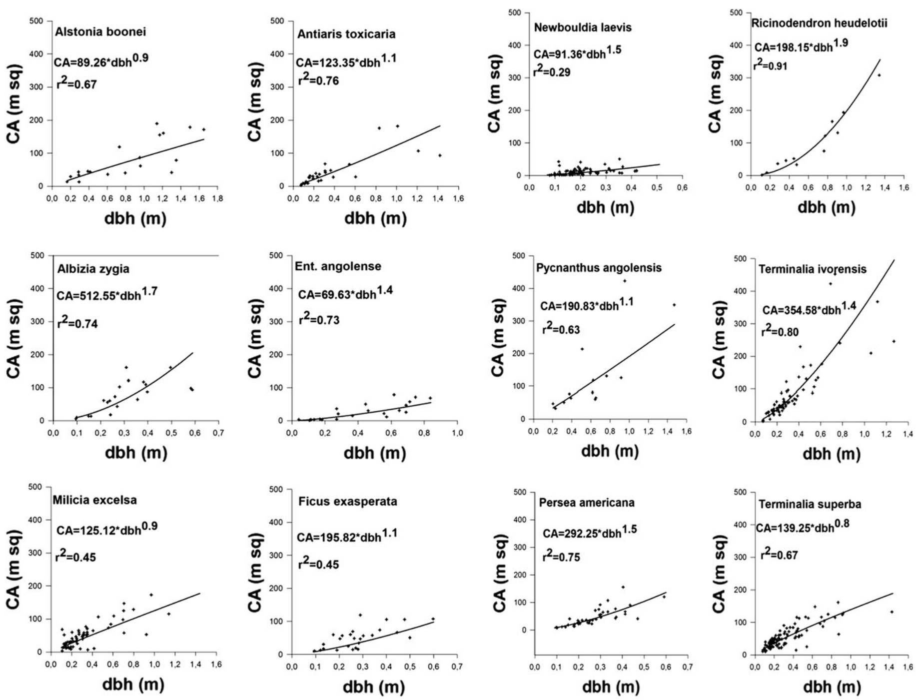

Fig. 3 Plots showing the relationship between CA and DBH of recommended *shade trees* in Ghana

increasing farm size. However, Simpsons measure of evenness was unaffected by farm size and any of the other farmer related parameters, and only varied significantly between districts. The overall evenness was high, being 0.80, 0.85, 0.79 and 0.86 for Nwabiagya, Amansie West, Wassa Amenfi West and Sefwi Wiawso districts, respectively.

The relationships between the DBH and the CA were investigated by regression analysis for individual species recorded at least 10 times across all farms in the districts. For these species, there was a positive regression ($p < 0.001$) of the DBH on the CA when both were log transformed (Fig. 3). Ninety shade tree species were recorded, but 48 % of the trees belonged to only 12 tree species previously identified as compatible with cocoa cultivation and recommended in cocoa systems (Manu and Tetteh 1987; Asare 2005). These 12 species are presented in Fig. 3, whereas the estimated equations for the remaining species are shown in Table 2. *Ricinodendron heudelotii* recorded the highest r^2 of 0.91 showing an almost direct relationship between the CA and DBH, while *Newbouldia laevis* had the lowest r^2 of 0.29.

Pycnanthus angolensis had the largest mean CA of a little over 132 m^2 while *Newbouldia laevis* recorded the least mean CA of about 13 m^2. Likewise, the slopes of the relationships varied between species. For example, *N. laevis* and *Entandophragma angolense* had narrow crowns meaning that CA increased only little with increasing DBH, whereas species like *Terminalia ivorensis* and *Ricinodendron heudelotii* had strongly increasing CA with increases in diameter.

Table 2 Relationship between CA and DBH of frequently used shade tree species in cocoa growing systems Ashanti and Western regions of Ghana

Species	#	Mean DBH	Mean CA	Equation	r^2
Albizia adianthifolia	11	0.34	95.77	$CA = 273.47 \times dbh^{1.02}$	0.42
Albizia ferruginea	11	0.43	74.57	$CA = 140.02 \times ^{\circ}dbh^{0.76}$	0.45
Amphimas pterocarpoides	24	0.34	48.09	$CA = 135.21 \times ^{\circ}dbh^{1.12}$	0.66
Anthocleista nobilis	10	0.39	29.45	$CA = 129.83 \times ^{\circ}dbh^{1.94}$	0.73
Bombax buonopozense	33	0.72	107.76	$CA = 137.03 \times ^{\circ}dbh^{1.13}$	0.43
Ceiba pentandra	19	0.95	151.82	$CA = 131.43 \times ^{\circ}dbh^{1.24}$	0.74
Cola nitida	26	0.35	48.11	$CA = 167.08 \times ^{\circ}dbh^{1.32}$	0.63
Ficus capensis	11	0.49	85.13	$CA = 152.32 \times ^{\circ}dbh^{0.96}$	0.62
Lannea welwitschii	17	0.36	70.54	$CA = 182.51 \times ^{\circ}dbh^{1.18}$	0.48
Morinda lucida	49	0.33	38.38	$CA = 160.13 \times ^{\circ}dbh^{1.52}$	0.61
Petersianthus macrocarpus	13	0.62	49.65	$CA = 76.07 \times ^{\circ}dbbh^{0.79}$	0.57
Pterygota macrocarpa	10	0.82	112.88	$CA = 124.41 \times ^{\circ}dbh^{0.63}$	0.58
Rauvolfia vomitoria	14	0.16	28.64	$CA = 387.11 \times ^{\circ}dbh^{1.44}$	0.55
Spathodea campanulata	27	0.39	41.25	$CA = 199.10 \times ^{\circ}dbh^{1.30}$	0.65
Sterculia tragacantha	33	0.31	46.00	$CA = 202.99 \times ^{\circ}dbh^{1.32}$	0.67
Triplochiton scleroxylon	18	0.68	84.82	$CA = 104.76 \times ^{\circ}dbh^{0.79}$	0.68

Discussion

Understanding the factors influencing variability in tree density, diversity and canopy cover

The smallholder nature of cocoa production in terms of farm size as captured in this study is a reflection of the current situation across Ghana (Anim-Kwapong and Frimpong 2005). The revelation that men had larger farm sizes than women is also documented by Otsuka et al. (2003) who in a study to determine women's right with regards to land ownership and its implications for tree resource management in Ghana, noted that forest clearance is traditionally a male activity. Hence, male households have an advantage in acquiring forest land through forest clearance compared to their female counterparts, who according to this study inherited their farm lands.

The density of trees per ha recorded in this study was less compared to other studies (Osei-Bonsu et al. 2003; Anglaaere et al. 2011) that found densities of trees of between 33 and 111 and 15 and 43 per ha respectively on young and mature cocoa farms in Ghana. Those studies included smaller trees in the analysis compared to this study that only considered shade trees with relatively large DBH and significant canopy cover. As documented by Rolim and Chiarello (2004), the weeding process contributes to the elimination of a large number of tree species with small DBH from cocoa farms as reported in the Atlantic forests in Brazil. Ruf (2011) measured trees >10 cm in DBH on cocoa farms in the Western and Eastern regions of Ghana and recorded 1–14 trees per hectare. The reduced number of shade trees can be attributed to deliberate attempts to favour cocoa production since recent varieties of cocoa are noted to give higher yields under full sun conditions (Padi and Owusu 1998).

The occurrence of trees on farms as shown in this study is the result of natural regeneration as stated by 96 % of respondents who indicated that trees on their farms were not planted. This is consistent with Asare (2010) who in her analysis of shade establishment and management in cocoa farms in the Ashanti region of Ghana showed that farmers primarily rely on natural regeneration to include shade trees on farms. This practice allows farmers to establish trees in a cost effective manner that promotes species already in the landscape. However, the practice also limits tree diversification options since it only allows trees already in the system to generate easily and thrive.

The fact that men had higher tree density on their farms than women can be attributed in part to policies on tree tenure in Ghana. The law entrusts naturally occurring timber trees in the President, acting on behalf of the landholding authority as enshrined in the Concession Act, No. 124, 1962, Section 16 (4). Hence, cocoa farms with naturally regenerated timber trees can be given in concession to timber companies for extraction. This puts pressure on cocoa farms (Hansen and Treue 2008) to supply valuable timber to the wood processing sector (Owubah et al. 2001). In spite of the fact that forestry policies require cocoa farmers to be compensated for damage incurred from harvesting of timber by logging companies, there is no official mechanism for determining compensation (Asare 2006b). Yet as the data shows, most of the common species found on farms, including the 10 most frequent species, are timber trees. Hence, possession of such valuable trees on one's land means having the ability to protect them from powerful timber concessionaires or negotiate for compensation when such trees are harvested by the state. During focus group discussions almost all the women indicated their vulnerability in terms of customary rights to protect or negotiate for compensation of tree resources on their farms. This situation has also been documented by Rocheleau and Edmunds (1997) who argue that African women are subordinates in terms of access to trees and forest resources, stemming from their exclusion from formal tenure regimes. Consequently, there is a high tendency for women to limit the number of valuable shade trees when creating the farms to avoid being targets of confrontations with timber concessionaires.

Shade tree density per ha recorded had an inverse relationship with farm size, which Asare (2010) also observed. Here, we argue that there could be two possible reasons for this. First, it is possible that in order to avoid undue attention from timber extractors that might cause damage to their farms, large size farmers may restrict the number of timber trees on their farms by retaining just a few that they need. The disincentive nature of the tree tenure policies has created a situation where farmers have adopted *de-facto* user-rights to satisfy their needs (Asare 2010) by either harvesting mature timber trees illegally (Ruf 2011) mainly on large farms that have the resources to employ chainsaw operators or by devising ways and means of eliminating these trees before they reach a stage when they are more likely to be harvested by timber merchants.

Second, many trees species are also perceived to be incompatible with cocoa and for this reason are often eliminated from cocoa plantations. Cocoa Research Institute of Ghana (CRIG) published a manual citing desirable and undesirable tree species (Manu and Tetteh 1987). Even though the list in the manual was generated based upon farmers' perceptions and without any robust evidence supporting which species are favourable for cocoa production or not, it appears to have had an influence on cocoa systems. Farmers who have access to this information, or who have made their own observations about tree compatibility may have selected or removed species based on this knowledge. It is striking that despite the large number of native tree diversity in the two regions and agro-ecological zones, 48 % of the recorded trees in this study constituted the 12 recommended species. This indicates that farmers to a large extent follow the recommendations by removing non-recommended species. Farmers' perception of shade and the productivity of their farm also influence diversity and density. In her study, Asare (2010) documented that 72 % of respondents expressed their intentions to decrease tree density in their cocoa farms as a result of the perceived negative effect of these trees on cocoa yield.

Elimination of trees from cocoa systems has over time resulted in the reduction of diversity in the landscape. However, this study shows that large farms tend to be more diverse in terms of tree species as confirmed by the Shannon and Simpson indices. The interpretation is that as farm sizes increase there is the likely effect that more species can enter into the available space, germinate and grow, resulting in a high diversity on these farms. This could also partially explain why male managed farms had more diversity compared to their female counterparts.

The relationship between crown area and diameter at breast height of shade trees in cocoa systems

The present study shows that as farm size increases, both tree density and canopy cover decrease. However, data also clearly show that the canopy cover depends on the species and the size of trees. As the trees grow, their crowns expand and create more cover (Fig. 2). Although this is well known, it is not reflected in the current recommendations and means that if a constant number of trees are maintained, the canopy cover will vary substantially over the life time of a plantation. Keeping a constant canopy cover is probably only possible by having relatively many shade trees at young age, which are sequentially thinned as the cocoa and shade trees develop.

However, allometric relationships developed on the structural parameters of a few frequently used shade trees in cocoa systems in Indonesia (Tiralla et al. 2013) are the only information available on the subject. In their work Tiralla and colleagues found a strong correlation between height and crown diameter of *Aleurites moluccana* and *Gliricidia sepium*. They suggested that the equations used to derive the relationships can be transferred into other regions of the area. Similarly, equations provided in this study can be used to obtain information on differences in the canopy cover of different shade tree species in cocoa systems by farmers, extension agents, NGOs, civil societies, chocolate manufacturers and consumers who wish to promote shade trees for sustainable cocoa production across Ghana and West Africa.

For instance, a tree with a large crown like *Pycnanthus angolensis* (crown area of 131 m^2) is capable of providing the same amount of canopy cover as 10 individual *Newbouldia laevis* trees whose mean CA is 13 m^2. However, the quality and quantity of light transmitted through different crowns will vary as a result of the size, orientation and the number of leaves per unit area of the branches. It also varies according to the size of the branches as large extensive branches will negatively affect the shade quality (Asare and Asare 2008). This highlights the importance of further research to measure light penetration through the canopies of these species. Clearly there is a need to revise current recommendations, which only focus on number of shade trees, to take into account both the differences between species and their allometric relationships. Using the DBH to estimate the crown area of trees would be a simple and easy way of assessing the canopy cover on a farm basis. The relationships expressed in Fig. 2 and Table 2 would be the first step in a process of developing a tool for farmers and extension workers to help assess the canopy cover of shade trees in cocoa agroforestry systems.

Conclusion

The integration of suitable and valuable trees in cocoa growing systems is a practice that is widespread in smallholder cocoa farms. This has resulted in the promotion of diverse tree species in cocoa growing systems in Ghana. This work shows that gender of the farmer plays an important part with men having relatively large farm size and high tree density per ha compared to women in Ashanti and Western regions of Ghana. In addition, species diversity was found to increase with farm size, with farms owned by men having more diversity compared to farms owned by women. Yet, more trees do not necessarily translate into greater canopy cover as it is dependent on species and tree characteristics.

Using characteristics like the DBH and CA of species like *Terminalia superba, T. ivorensis Newbouldia laevis, Milicia excelsa, Persea americana, Ficus exasperata, Antiaris toxicaria, Amphimas pterocarpoides, Albizia zygia and Morinda lucida*. *Persea americana*, *Cola nitida* and *Ricinodendron heudelotii* it is possible to estimate the canopy cover on a given farm. However, the relationship between DBH and CA varies with species and calculations have to be performed according to species.

This work hence provides farmers, extension agents and researchers in Ghana and across West Africa an opportunity to use the equations provided in this study to help prescribe appropriate canopy cover of shade trees in cocoa systems.

Acknowledgments We wish to gratefully thank the International Institute of Tropical Agriculture for its support to this research.

Appendix

See Table 3.

Table 3 Tree species as recorded on 86 cocoa farms in Ashanti and Western regions of Ghana

Species	Family	Local name	Freq. in region	
			Ashanti	Western
Albizia adianthifolia	Leguminosae	Pampena	6	5
Albizia ferruginea	Leguminosae	Awiemfoasamina	8	3
Albizia glaberrima	Leguminosae	Okoroankoa	1	1
Albizia zygia	Leguminosae	Okoro	14	8
Allanblakia parvifloria	Guttiferae	Sonkyi	0	3
Alstonia boonei	Apocynaceae	Sinuro	9	10
Amphimas pterocarpoides	Leguminosae	Yaya	15	9
Anacardia occidentalis[a]	Anacardiaceae	Cashew		1
Aningera robusta/Pouteria altissima	Sapotaceae	Asanfuna	0	6
Anthocleista nobilis	Cecropiaceae	Bontodie	7	3
Antiaris toxicaria	Moraceae	Kyenkyen	26	2
Antrocaryon micraster	Sapindaceae	Aprokuma	1	2
Baphia pubensis	Leguminosae	Odwen kobiri	1	
Berlinia tomentella	Leguminosae	Kwatafompaboa		1
Blighia sapida	Sapindaceae	Akye	2	2
Bombax buonopozense	Bombacaceae	Akata	19	14
Brousonnetia papyrifera/Gmelina arborea	Lamiaceae	Gmelina	1	
Carapa procera	Meliaceae	Kwakuobese		1
Cedrela odorata	Meliaceae	Cedrela	8	
Ceiba pentandra	Bombacaceae	onyina	7	12
Celtis mildbraedii	Ulmaceae	Esa		5
Celtis philippensis	Ulmaceae	Prepresa		1
Celtis zenkeri	Ulmaceae	Esakokoo	2	
*Citrus sinensis*a	Rutaceae	Akutu	2	7
Cola chlamydanta	Sterculiaceae	Tananfere		2
Cola gigantea	Sterculiaceae	Watapuo	1	3
Cola millenii	Sterculiaceae	Ananse-dodowa		1
Cola nitida	Sterculiaceae	Besi	2	24
Cordia millenii	Boraginaceae	Tweneboa	1	3
Daniellia ogea	Leguminosae	Hyedua		4
Dialium dinklagei	Leguminosae	Dwedweedwe	1	2
Discoglypremna caloneura	Euphorbiaceae	Fetefre	1	1
Distemonanthus benthamianus	Leguminosae	Bonsamdua	1	5
Dracaena mannii	Dracaenaceae	Ntome	0	1
Entandrophragma angolense	Meliaceae	Edinam	4	19
Entandrophragma cylindricum	Meliaceae	Penkwa	1	0
Entandrophragma utile	Meliaceae	Efoobrodedwo	0	1
Erythrina vogelii	Rubiaceae	Osore	1	1

Table 3 continued

Species	Family	Local name	Freq. in region	
			Ashanti	Western
Ficus capensis	Moraceae	Odoma	8	3
Ficus exasperata	Moraceae	Nyankerene	17	13
Ficus sur	Moraceae	Nwadua	8	9
Funtumia elastic	Apocynaceae	Funtum	6	5
Gliricidia sepium[a]	Fabaceae	Gliricidia	0	1
Hannoa klaineana	Simaroubaceae	Fotie	1	3
Harungana madagascariensis[a]	Guttiferae	Kosowa	0	1
Heritiera utilis	Malvaceae	Nyankom	0	1
Holarrhena floribunda	Apocynaceae	Sese	18	0
Holoptelea grandis	Ulmaceae	Nakwa	0	1
Khaya ivorensis	Meliaceae	Mahogany	2	7
Klainedoxa gabonensis	Irvingiaceae	Kroma	1	0
Lannea welwitschii	Anacardiaceae	Kumanini	11	6
Lonchocarpus sericeus	Leguminosae	Sante	8	4
Mangifera indica	Anacardiaceae	Mango		2
Mareya micrantha	Euphorbiaceae	Dubrafo	2	1
Margaritaria discoidea	Euphorbiaceae	Pepea	3	2
Milicia excelsa	Moraceae	Odum	21	43
Millettia chrysophylla	Fabaceae	Frafraha	1	0
Monodora myristica	Annonaceae	Wedeaba	0	2
Morinda lucida	Rubiaceae	Konkroma	42	7
Morus mesozygia	Moraceae	Wonton	2	1
Musanga cecropioides	Cecropiaceae	Odwuma	1	0
Myrianthus arboreus	Cecropiaceae	Nyamkuma Beye	0	1
Napoleonaea vogelii	Lecythidaceae	Obua	0	1
Nesogordonia papaverifera	Malvaceae	Danta	8	0
Newbouldia laevis	Bignoniaceae	Sesemasa	30	52
Omphalocarpum elatum	Sapotaceae	Osononodokono	0	1
Parkia bicolor	Leguminosae	Asoma	0	1
Persea americana[a]	Lauraceae	Avocado	15	28
Petersianthus macrocarpus	Lecythidaceae	Esia	2	11
Psydrax subcordata	Rubiaceae	Ntateadopon	1	0
Pterygota macrocarpa	Malvaceae	Kyereye	4	6
Pycnanthus angolensis	Myristicaceae	Otie	8	6
Rauvolfia vomitoria	Apocynaceae	Kakapenpen	8	6
Ricinodendron heudelotii	Euphorbiaceae	Wama	8	5
Spathodea campanulata	Bignoniaceae	Sesemasa	22	5
Spondias mombin	Anacardiaceae	Atoa	3	2
Sterculia tragacantha	Sterculiaceae	Sofo	27	6
Terminalia ivorensis	Combretaceae	Emere	28	39
Terminalia superba	Combretaceae	Ofram	30	69
Tetrorchidium didymostemon	Euphorbiaceae	Anenedua	1	0

Table 3 continued

Species	Family	Local name	Freq. in region	
			Ashanti	Western
Tieghemella heckelii	Sapotaceae	Baku	0	1
Treculia africana	Moraceae	Ototim	0	1
Trema orientalis	Ulmaceae	Sesea	1	0
Trichilia monadelpha	Meliaceae	Tanuro	6	2
Triplochiton scleroxylon	Sterculiaceae	Wawa	8	10
Vernonia amygdalina	Asteraceae	Awonwono	3	0
Vitex ferruginea	Verbenaceae	Otwentorowa	0	1
Vitex micrantha	Verbenaceae	Otwentoraon nini	0	1
Zanthoxylum gilletii	Rubiaceae	Okuo	1	4
Zanthoxylum leprieurii	Rubiaceae	Oyaa	0	1

[a] Planted

References

Anglaaere LC, Cobbina J, Sinclair FL, McDonald MA (2011) The effect of land use systems on tree diversity: farmer preference and species composition of cocoa-based agroecosystems in Ghana. Agrofor Syst 81(3):249–265

Anim-Kwapong GJ (2006) Potential of planted and natural tree fallows for rehabilitation of degraded cocoa farmlands in Ghana. In: Paper presented at the extending cocoa for biodiversity conservation, Kumasi, Ghana, 14–18 Aug 2006

Anim-Kwapong G, Frimpong E (2005) Vulnerability of agriculture to climate change-impact of climate change on cocoa production. In: Final report submitted to the Netherlands climate change studies assistance Programme: NCAP 2

Asare R (2005) Cocoa agroforests in West Africa: a look at activities on preferred trees in the farming systems. Forest & Landscape Denmark (FLD), Copenhagen

Asare R (2006a) A review on cocoa agroforestry as a means for biodiversity conservation. In: World cocoa foundation partnership conference, Brussels, 2006a. p 15

Asare R (2006b) Learning about neighbour trees in cacoa growing systems: a manual for farmer trainers. Center for Skov, Landskab og Planlægning/Københavns Universitet, Copenhagen

Asare RA (2010) Cocoa establishment and shade management in Ghana's Ashanti region: understanding the main factors driving farmers' decision processes and practices. Yale University, New Haven

Asare R, Asare RA (2008) A participatory approach for tree diversification in cocoa farms: Ghanaian farmers' experience. International Institute of Tropical Agriculture, Accra

Asare R, Afari-Sefa V, Osei-Owusu Y, Pabi O (2014) Cocoa agroforestry for increasing forest connectivity in a fragmented landscape in Ghana. Agrofor Syst 88(6):1143–1156

Blozan W (2006) Tree measuring guidelines of the eastern native tree society. Bull East Native Tree Soc 1(1):3–10

Bos MM, Steffan-Dewenter I, Tscharntke T (2007) Shade tree management affects fruit abortion, insect pests and pathogens of cocoa. Agric Ecosyst Environ 120(2):201–205

Crawley MJ (2007) The R book Chichester. Wiley, UK

Dakwa J, Ahenkorah Y, Halm B, Appiah M, Akrofi G, Yirenkyi J (1976) The effects of shade and NPK fertilizers on the incidence of cocoa black pod disease in Ghana. Ghana J Agric Sci 9(3):179–184

Di Falco S, Perrings C (2003) Crop genetic diversity, productivity and stability of agroecosystems. A theoretical and empirical investigation. Scott J Political Econ 50(2):207–216

Duguma B, Gockowski J, Bakala J (2001) Smallholder cocoa (Theobroma cocoa Linn.) cultivation in agroforestry systems of West and Central Africa: challenges and opportunities. Agrofor Syst 51(3):177–188

Ekstrøm CT, Sørensen H (2011) Introduction to statistical data analysis for the life sciences. CRC Press, Boca Raton

FAO (2004) National forest inventory field manual template. In: FAO working paper 94/E. Unite Nation Food and Agriculture Organization, Rome, Italy
Gockowski J, Afari-Sefa V, Sarpong DB, Osei-Asare YB, Agyeman NF (2013) Improving the productivity and income of Ghanaian cocoa farmers while maintaining environmental services: what role for certification?. Int J Agric Sustain (ahead-of-print): 1–16
Hall J, Swaine MD (1976) Classification and ecology of closed-canopy forest in Ghana. J Ecol 64(3):913–951
Hansen CP, Treue T (2008) Assessing illegal logging in Ghana. Int For Rev 10(4):573–590
Krebs CJ (1985) Ecology—the experimental analysis of distribution and abandunce, 3rd edn. Harper & Row Publishers, New York
Magurran AE (2004) Measuring biological diversity. Blackwell Publishing Company, Oxford
Manu M, Tetteh E (1987) A guide to cocoa cultivation. Cocoa Research Institute of Ghana (Ghana Cocoa Board), Tafo
N'Goran K (1998) Reflections on a durable cocoa production system: the situation in Ivory Coast, Africa. In: Conference on shade grown cocoa, Panama, 1998
Nomo B (2005) Farmers' ecological and agronomic knowledge about the management of multistrata cocoa systems in Southern Cameroon. University of Wales, Bangor
Obiri BD, Bright GA, McDonald MA, Anglaaere LC, Cobbina J (2007) Financial analysis of shaded cocoa in Ghana. Agrofor Syst 71(2):139–149
Opoku I, Akrofi A, Appiah A (2002) Shade trees are alternative hosts of the cocoa pathogen Phytophthora megakarya. Crop Prot 21(8):629–634
Osei-Bonsu K, Ameyaw Oduro C, Tetteh J Traditional cocoa agroforestry: species encountered in the cocoa ecosystem of a typical cocoa growing district in Ghana (poster). In: 14th international cocoa research conference, 2003. pp 13–18
Otsuka K, Quisumbing AR, Payongayong E, Aidoo J (2003) Land tenure and the management of land and trees: the case of customary land tenure areas of Ghana. Environ Dev Econ 8(1):77–104
Owubah CE, Le Master DC, Bowker JM, Lee JG (2001) Forest tenure systems and sustainable forest management: the case of Ghana. For Ecol Manag 149(1):253–264
Padi B, Owusu G (1998) Towards an integrated pest management for sustainable cocoa production in Ghana. Cocoa Research Institute of Ghana, Tafo
Rice RA, Greenberg R (2000) Cocoa cultivation and the conservation of biological diversity. AMBIO J Hum Environ 29(3):167–173
Rocheleau D, Edmunds D (1997) Women, men and trees: gender, power and property in forest and agrarian landscapes. World Dev 25(8):1351–1371
Rolim SG, Chiarello AG (2004) Slow death of Atlantic forest trees in cocoa agroforestry in southeastern Brazil. Biodivers Conserv 13(14):2679–2694
Ruf FO (2011) The myth of complex cocoa agroforests: the case of Ghana. Hum Ecol 39(3):373–388
Ruf F, Schroth G (2004) Chocolate forests and monocultures: a historical review of cocoa growing and its conflicting role in tropical deforestation and forest conservation. Agroforestry and biodiversity conservation in tropical landscapes Island Press, Washington, pp 107–134
SAN (2005) Additional criteria and indicators for cocoa production. http://www.rainforest-alliance.org/programs/agriculture/certified-crops/standards_2005.html. Accessed 10 Sep 2007
Schroth G, Harvey CA (2007) Biodiversity conservation in cocoa production landscapes: an overview. Biodivers Conserv 16(8):2237–2244
Somarriba E, Beer J (2011) Productivity of Theobroma cocoa agroforestry systems with timber or legume service shade trees. Agrofor Syst 81(2):109–121
Sonwa DJ, Nkongmeneck BA, 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(8):2385–2400
Taylor CJ (1960) Synecology and silviculture in Ghana. Synecology and silviculture in Ghana, London
Tiralla N, Panferov O, Knohl A (2013) Allometric relationships of frequently used shade tree species in cacao agroforestry systems in Sulawesi, Indonesia. Agrofor Syst 87(4):857–870