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BIOMASS STOCKS IN GHANAIAN COCOA ECOSYSTEMS: THE EFFECTS OF REGION, MANAGEMENT AND STAND AGE OF COCOA TREES

Askia M. Mohammed[1*], James S. Robinson[2], David Midmore[2], Anne Verhoef[2]

[1]CSIR-Savanna Agricultural Research Institute, PO Box 52, Nyankpala, Tamale, Ghana.
[2]School of Archaeology, Geography and Environmental Science, University of Reading, UK.

ABSTRACT: *Determination of biomass produced in cocoa ecosystems is an important step towards quantifying the carbon sequestration potential of cocoa production systems. This study provides data on the biomass of cocoa systems being influenced by management, cocoa stand ages and region. Eight cocoa farms were sampled on the basis of three variables: region (Eastern, Western region), shade management (shaded, unshaded) and stand age (<15, >15 years). Allometric equations (R^2 > 0.94) were developed to estimate the biomass of live cocoa trees, while the biomass of non-cocoa trees was estimated using an existing equation by FAO. Generally, biomass stocks were higher in the Eastern than Western region, shaded than unshaded, and in stands >15 years than those <15 years. The total cocoa ecosystem biomass range was, 48.1 ± 6.5 to 101.6 ± 12.6 Mg/ha. The high biomass estimates reveals a potential of system to restore appreciable biomass losses resulting from deforestation and forest degradation in Ghana.*

KEYWORDS: Cocoa ecosystem, biomass, region, shade trees, stand age

INTRODUCTION

Cocoa cultivation in Ghana takes place in the forest regions where farmers shift with the crop from one region to another at a rate dependant on the accessibility of forest lands. Traditionally, cocoa is noted as shade-loving crop and so grows well under remnant taller trees from thinned forest. With this practice, cocoa seedlings can grow into productive trees by utilising the built-up nutrients in forest soils and the protection from the full impact of sunlight by the remnant forest trees.

Planting cocoa seedlings under taller shade-providing trees regenerated either naturally after clear-felling, or planted artificially makes cocoa cultivation environmentally preferable to many other forms of agriculture in the tropics (Greenberg, 1998; N'Goran, 1998; Power and Flecker, 1998). Other benefits derived from growing cocoa in the presence of other trees are conservation of forest biodiversity and ecological benefits of forests while still allow farmers to obtain their cocoa produce (Rice and Ward, 1996; Greenberg *et al.*, 1997; Moguel and Toledo, 1999; Greenberg *et al.*, 2000; Rice and Greenberg, 2000).

However, cocoa intensification in the tropics is gradually displacing the inclusion of shade-providing non-cocoa trees leading to the practice of full-sun or monoculture cocoa systems (Anim-Kwapong, 1994). Recent data on cocoa production from Cameroon, Côte d'Ivoire,

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Ghana and Nigeria showed that 8.1, 27.9, 28.1 and 3 %, respectively, are cocoa farms without shade trees (Gockowski and Sonwa, 2011). This practice invariably leads to huge biomass depletions of native forest trees. Accordingly, cocoa expansion over the years has been implicated and estimated to have played a major role in the deforestation and degradation of about 80 % of the natural forest sites in Ghana (World Bank, 1987; Cleave, 1992; Ministry of Environment and Science, 2002). Notwithstanding, the cocoa sector is still highlighted in the January 2010 Readiness Preparation Proposal of Ghana submitted to the United nation Framework on Climate Change as pivotal in the development of a national strategy for reducing greenhouse gas emissions from deforestation and forest degradation (Chagas *et al*., 2010). It is therefore, a pre-requisite to quantify the amount of biomass produced in cocoa systems with or without shade trees as a step to producing a sustainable carbon-friendly cocoa sector in this country.

Previous methods of biomass quantification have been time-consuming activities, especially the measurement of certain biomass components, such as foliage or branch biomass. However, a number of allometric relationships exist for conversion of easily measurable tree biometrics (e.g. stem diameter at breast height, DBH, or tree height, H) to above ground biomass for many forest tree species. For most of the allometric relationships, researchers combined other regression equations to produce either species-specific allometry for *Betula papyrifera* (Schmitt and Grigal, 1981), for black spruce (*Picea mariana*) (Grigal and Kernik, 1984), for some northeast tree species (Pastor *et al.*, 1984), for six boreal tree species or allometry for groups of species of northern Manitoba (Bond-Lamberty *et al*., 2002), for woody biomass in Australia (Keith *et al.*, 1999), for United States tree species (Jenkins et al., 2003); for tree allometry in tropical forests (Chave *et al.*, 2005), and for some tree species in Europe (Muukkonen, 2007).

This paper sought to provide reference data on total biomass production and distribution in cocoa systems under different regions, shade managements and cocoa stand ages. Therefore, cocoa trees were selected and harvested to estimate the biomass produced from two shade management options; cocoa farms (1) with shade trees (shaded system) and (2) without shade trees (unshaded system). The above ground biomass of all adjacent non-cocoa trees was estimated using the allometric relation developed by FAO (1997) based on trees harvested from moist tropical forest sites around the world.

The primary objectives were: (i) to develop an allometric function based on a simple biometric variable to predict cocoa tree biomass to estimate the total biomass stock and distribution in the cocoa ecosystems (iii) to evaluate the effects of region, shade management and cocoa stand age on the total system's biomass and its distributions. These objectives were set out to test the hypotheses that; (a) cocoa tree biomass could be determined simply by measuring simple biometric variables of the standing cocoa tree, (b) the distribution of the total biomass differs among the cocoa components and within the cocoa tree, and (c) the total biomass differs between regions, shade managements and tree stand ages.

MATERIALS AND METHODS

Cocoa farms selection and factor combinations

Cocoa systems from farmers' fields were selected with respect to location, age of planting and management system. Four farms were selected at Duodukrom community in the Suhum

District of the Eastern region (6^o 2' N, 0^o 27' W). Of the four farms, two were shaded farms and the other two were farms without shade trees. The shaded farms were of 14 and 25 year-old cocoa stands while the farms without shade trees were of 10 and 28 year-old cocoa stands. These cocoa farms were further grouped into two age categories *viz.* farms with less than 15 year-old cocoa stands and farms with greater than 15 year-old cocoa stands. In that grouping, the 14-year-shaded and 10-year-unshaded farms represented the category of less than 15-year-old cocoa stands and the greater than 15 –year category consisted of the 25-year-shaded and the 28-year-unshaded cocoa farms in the Eastern region (ER). In the Western Region (WR), farms were selected in the Anyinabrim community within the Sefwi-Wiawso District (6^o 57' N, 2^o 35' W). Similarly, four farms comprising two shaded and two farms without shade trees were selected for this study. The shaded farms were of 7 and 17 years old stands while those without shade trees were of 13 and 27 years. As in the ER, the farms were further categorised to two age groups, namely, farms with less than 15 years old cocoa trees and those with greater than 15 years old cocoa trees regardless of the system of production. This put the 7-year- shaded and 13-year-unshaded farms into the less than 15-year age group while the 17-year-shaded and the 27-year unshaded belonged to the greater than 15-year age group.

Data collection

At each farm site, a 30 m x 90 m (0.68 acre or 0.27 ha) plot was laid out. Two 30 m transects dividing the plot into three of 30 m x 30 m (~0.23 acre or 0.09 ha) sub-plots were demarcated a plot as pseudo replicates of the selected farms. All plant species including cocoa and non-cocoa trees within the plots were tagged with small paper-sellotapes and serially numbered using a pen marker. The circumference at breast height (CBH, 1.37 m) of all the labelled-trees were then measured and recorded. The diameters at breast height (DBH) were later calculated for each tree from the measured CBH.

The cocoa tree stands did not have uniform spacing from simple visual observations and some random plot measurement results. A total of 16 cocoa trees, comprising of two trees from each farm, were felled and each separated into component trunks or stem, branches and foliage (leaves, fruits/buds). Prior to cutting down the selected trees, the CBH was measured again and recorded with the tree number, farm identity and region. When appropriate, the parts were cut to smaller pieces, weighed in batches and then summed to give total component weight. The total fresh weights of the different components (FW_c) were determined in the field immediately after cutting using a pan top weighing scale. To effectively manage the large amounts of the harvested tree components, known weights (approx. 200 g) of fresh component samples (FW_s) were carried to the CRIG laboratory and oven-dried at 70 ^oC until a constant weight, dried sample weight (DW_s) was obtained. The ratio, DW_s: FW_s, was used to convert the FW_c to the dry weight of the tree component DW_c using the relation below as in Snowdon *et al.* (2002):

$$DW_c = \left(\frac{DW_s}{FW_s}\right) \times FW_c \qquad \ldots[1]$$

Based on the measured DBH and the biomass per tree of the 16 trees that were destructively sampled across all the study sites, an allometric relation was developed using regression techniques to estimate standing cocoa tree biomass. Due to the vast number of shade trees encountered, as well as the lack of species-specific allometric equations for each shade tree species in the literature, the general equation from FAO (1997), recommended by UNFCCC (2006) was used to estimate the above-ground biomass of adjacent non-cocoa trees in this study. This equation was appropriate for the precipitation zone of this study as has been prescribed by FAO (1997).

$$AgB = \exp[-2.134 + 2.530 \ln(DBH)], \qquad \ldots[2]$$

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where: AgB is = above-ground biomass, kg tree^{-1}, and DBH is = diameter at breast height, cm.

Roots were sampled by carefully excavating the soil around the felled trees from the base to half the distance between the immediate adjacent trees. The depth of excavation was approximately to 80 cm though it also depended on the site conditions. The roots removed were separated in the field by brushing off attached soil or by washing in the case of fine/tiny roots and then weighed. Known weights of fresh root subsamples were also sent to CRIG laboratory where they were oven-dried at 70 ^oC for 72 hours and used to determine the dry weight to fresh weight conversions (Snowdon *et al.*, 2002). Litter sampling was done from 50 cm x 50 cm micro-plots established at random within the sampling plots. All litter gathered from the micro-plots was immediately weighed. Most of the measured stumps were the remains of previously felled cocoa trees. From measurements of stump diameter (d, cm) and height (h, cm), the stump volumes (V, cm^3) were calculated from:

$$V = \frac{\pi \times d^2 \times h}{4}, \qquad \ldots[3]$$

Dry mass of stumps were then calculated by multiplying the estimated volume by the specific gravity of cocoa tree of 0.42 g/cm^3, which other studies have also used (e.g. Chave *et al*., 2006; Wade *et al.*, 2010). Also, the mean root-to-shoot ratio value of 20% established by this study was used to estimate the root biomass of the stumps. The total stump biomass was then estimated as the sum of the mass of stumps and their root biomass.

Statistical analysis of data

Cocoa tree circumferences, CBH, at breast height were converted to diameter at breast heights, DBH. A box plot of the DBH values revealed that the cocoa trees in the selected farms were wide-ranging with respect to size distribution (Figure 1). This was considered to be a major source of variation to data normality. As such, the box-plot statistical summaries were used to exclude the outliers before performing any further statistical analysis. The number of cocoa trees per plot excluding the outliers were further extrapolated to give cocoa tree stands per ha for each farm.

To assess the response of cocoa stand properties in farmers' fields as a function of site, production system and cocoa stand ages, the data from the two regions (Eastern and Western regions) were analysed statistically as a 2 x 2 x 2 factorial experiment. The pooled data produced a total of 3260 trees on which the CBH was measured and converted to DBH. Taking the cocoa densities and DBH values as the response variables to the influence of shade management, region, and cocoa stand age, an analysis of variance (ANOVA) was carried out, using GENSTAT release 16 software, on (i) the regional data as a two factor (stand age x system) experiment and the combined data from the regions as a three factor experiment (stand age x system x region), to evaluate the variations in stand densities and in DBH values between different management of shade, region and cocoa stand age category. Fisher's least significant difference (LSD) test at 0.05 level of significance was used to separate means among the farms.

Figures were produced by Excel and SigmaPlot 10.0 using the mean values of the parameters (DBH, and number of trees/ha). To examine the relationship between cocoa tree biomass (kg/tree) and the DBH, a regression analysis was carried out on the dry biomass data from the destructively sampled cocoa trees against the DBH values. Models tested included linear, logarithmic, exponential and power functions and the best fit was selected based on the biological logic of the equation generated and the coefficient of determination (R^2) value.

Finally, biomass per hectare was calculated using the allometric models developed herein. First, the leaf, branch, root and stem biomass of cocoa trees in each farm was calculated and extrapolated to a per hectare basis. Secondly, the biomass of shade trees was also estimated per farm and extrapolated to per hectare. The total ecosystem biomass particularly, for shaded farms was then estimated as the sum of the biomass of cocoa trees and shade trees per hectare.

RESULTS AND DISCUSSION

Effects of region, system and stand age on tree stand properties of cocoa ecosystem components

The mean density of tree stands and their DBH values in cocoa ecosystem components as presented in Figures 2 - 7 appeared to be affected by region, shade management, and the age group of the cocoa trees. The main live stand components of cocoa ecosystem are cocoa trees, shade trees and stumps.

Typically, the cocoa ecosystems densities comprise approximately 78 - 85% as cocoa trees, 2 - 11% as shade trees and 6 - 10% as stumps. The stumps are mostly the standing remains of felled cocoa trees. The data on cocoa ecosystem components indicated considerable variations in the stand densities and their DBH values with respect to region, shade management and cocoa stand age category (Figures 2 - 7). Cocoa stand density did not differ significantly ($P > 0.05$) between regions and between the shade management options (Figures 3, and 4). Cocoa stands in the age group below 15 years were denser compared to stands in the above 15 -year-old category (Figure 4). These results conform to those reported by (Isaac *et al*., 2007) in Ghana on cocoa agroforestry, and Smiley and Kroschel (2008) in Indonesia on Cocoa-*Glyricidia* agroforestry. With the range of cocoa stands being 1409 - 1656 trees/ha, the current data agree with previous work carried out in Ghana by Ofori-Frimpong *et al.* (2011) on cocoa plant densities. It thus implies cocoa farmers in Ghana somehow achieve the standard cocoa density over time (Manu and Tetteh, 1987; Lachenaud and Montagnon, 2002; Wade *et al.*, 2010).

Although the mean cocoa stands per hectare did not vary between regions and between shade management options, their DBH values varied considerably (Figure 5, and 6). Cocoa trees in the Eastern region farms developed larger trunks than in the Western region and farms without shade also developed cocoa trees with larger trunks than farms with shade trees. The significantly larger cocoa trees in unshaded systems suggest that cocoa trees received closer to optimal light from the sun for development via photosynthesis (Oke and Olatiilu, 2011). As expected, cocoa trees below 15 years had narrow trunks compared to the stands in farms above 15 year-old (Figure 7).

Considerable interactions of region x system; region x age group; system x age group; and region x system x age group were observed to have significant effects on the stand densities of the cocoa ecosystem components (Table 1). With respect to cocoa tree density, only the system and age group showed significant interactions such that the stand densities in unshaded system were the same under <15 and >15 years but for the shaded system, the stand density under <15 years group was significantly higher than that under >15 years group (Table 1). Thus, unshaded farms appeared to have high stability to changes in cocoa stand density as the stand age progresses.

Due to the extensive cultivation of cocoa in Ghana (for example approximately 1.75 million ha being cultivated) measurement of DBH of representative cocoa tree samples is not feasible.

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Thus, a model to predict the mean cocoa DBH of farms based on cocoa tree stand ages was developed as:

$DBH = 4.9305 \times (age)^{0.2451}$, …[4]
where, *DBH* is = diameter at breast height (in cm), and *age* is = age of cocoa tree (in years). Although the R^2 value (0.72) of equation [4.4] reflects an appreciable level of variability using stand age to estimate cocoa DBH, the cocoa stands age in a farm still explains about 72% of the observed variations in the DBH measurements.

The DBH of the cocoa trees ranged from 6.7 - 11.6 cm (Table 1). Compared to previous similar studies (Isaac et al., 2007; Smiley and Kroschel, 2008), the present study found generally lower DBH values for cocoa trees in Ghana (Table 1). However, in the case of Smiley and Kroschel (2008), their stockings ranged from 370 to 1111 trees/ha, the stand age ranged from 1 to 9 year-old, and was based on cocoa-*Gliricidia* agroforestry systems. These differences make it difficult to directly compare their study to the current work.

Shade tree densities in cocoa ecosystems varied dramatically between regions with the Eastern region containing denser shaded systems than Western region (Figure 2). Whereas the ER had about 11% shade trees, the WR contained only 2% shade trees with respect to standing trees in the cocoa ecosystems selected in the respective regions. This suggests that farmers in the Western regions are more inclined to cultivate cocoa without shade trees. Shade tree density did not appear to be affected by the age group of the cocoa trees (Figure 4). This lack of significant effect of stand age group on shade tree density partly supports the previous assertion in here that existing stumps in the ecosystem are not the remains of shade trees but of cocoa trees that were felled over time.

With respect to the shade tree species, the mean DBH values generally ranged from 13.5 to 22.4 cm, which indicates that the shade trees were larger than the cocoa trees (Table 1). Unlike cocoa tree sizes, the shade tree sizes were neither affected by region nor cocoa stand age group (Figure 5, and 6). This unexpected non-significant effect of age group on shade tree size could be possible where the cocoa farms were established under existing forest remains as in the case known as rustic cocoa plantation (Rice and Greenberg, 2000). The high variability of shade trees as indicated by the coefficient of variation of 51.6% (Table 1) suggests that mixtures of very large (forest remains) and narrow (from recent plantings) shade trees might have been present in the shaded cocoa ecosystem across regions and age categories. This practice is very common in the Western region where cocoa cultivation is a recent farming system and mostly takes place by clearing or thinning out new forest lands.

Appreciable proportion of cocoa stumps (6 - 10%) was found in the cocoa ecosystems of Ghana. The stump density did not differ significantly between regions and between systems of production (Figure 2, and 3). The stumps in the ER were significantly ($P < 0.05$) taller than those found in the WR (Figure 8). Taller stumps were also found on farms without shade when compared to those on farms with shade. There was no difference in stump height with respect to stand age (Figure 8).

Significantly, more stumps were found in farms with cocoa stands below 15 years old as compared to stands that were more than 15 years old (Figure 2). The density of stumps correlated positively with cocoa density in farms ($r = 0.7911$, $P = 0.0022$, Table 2). Thus, the larger density of cocoa trees in farms less than 15 years old resulted in more stumps found in those farms. However, the greater number of stumps in farms with stands less than 15 years is

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partly also due to the existence of a negative correlation between stump density and cocoa DBH (r = -0.6548, P = 0.0208, Table 2) indicating that as the stump density declines as cocoa tree size or DBH value increases with stand age.

Figures 5 - 7 also reveal considerable variations in stump diameter. The ER had significantly ($P < 0.05$) larger stumps than the WR (Figure 5), unshaded system contained larger stumps than shaded system (Figure 6), and stand age group >15 years developed larger stumps than that in stand age group <15 years (Figure 7). Thus, the variation in stump diameter with respect to region, shade management and cocoa stand age category was similar to that observed for cocoa trees' mean DBH values (Figure 5, and 6). In addition, the mean diameter range of 6.4 to 12.1 cm of the stumps is similar to that for the cocoa tree supporting the claim that the tumps were largely (> 90%) the remains of previously felled cocoa trees (Table 1). Indeed, the DBH values of cocoa trees and stumps were positively correlated (r = 0.8040, P = 0.0016, Table 2). Also the density of stumps correlates negatively with the stumps DBH (Table 2).

Biomass stocks and partitioning in cocoa ecosystems

The main live biomass components in cocoa ecosystem are cocoa trees, shade trees, stumps and surface litter. Allometric relations, often developed from destructive sample data have been used to estimate standing tree biomass and carbon sequestered (FAO, 1997; Dossa *et al*., 2008). Similarly, the biomass of cocoa and its distribution within the cocoa trees for this study was estimated using allometric modelling. The biomass was estimated as a function of DBH from the total destructive sampling of 16 cocoa trees from the farms evaluated (Figure 9). Similar models that utilise DBH as the independent variable were developed by Smiley and Kroschel (2008) for a cocoa-*Gliricidia* agroforestry system at Sulewesi, Indonesia. Among the tested models, the power function had consistently higher coefficients of determination with R^2 ranging from 79 to 95% and was considered as the best fit or model for the cocoa tree components. Dossa *et al.* (2008) reported similarly high R^2 values when data from shaded and open-grown coffee plantations were fitted to a power function.

Based on the models' estimations of aboveground (stem, branches and leaves) and below ground (roots) biomass, estimated root-to-shoot (R/S) ratios of cocoa trees ranged from 19 to 21%. A similar trend for R/S ratios was observed for other tree species by Ritson and Sochacki (2003). The root-to-shoot biomass ratios estimated in this study (0.19 - 0.21) are within the range of 0.18 to 0.35 commonly reported for forest tree species (Cairns et al., 1997) although lower than the standard root to shoot biomass ratios range of 0.23 to 0.26 as reported by Kurz *et al.* (1996) and Cairns *et al.* (1997) for tropical forests trees. However, our roots were sampled by digging soil pits and this does not capture many fine roots as was also observed by Resh *et al*. (2003). Thus, the actual root-to-shoot ratio of cocoa tree would expectedly be higher because the present study did not include the component biomass of fine roots. These results agree with previous studies reported by Dickson (1989) and Tobin and Nieuwenhuis (2007) in which root biomass is noted to stabilize at around 20% of the aboveground dry weight.

For the shade trees, the biomass was estimated using a general equation from FAO (1997), developed for this specific precipitation zone and recommended by the UNFCCC (2006) for above-ground biomass of tree species. The ratio of root to shoot for the shade trees was assumed to be 24%. Similar root to shoot proportions have been used by other researchers (Cairns *et al*., 1997).

The amount of biomass produced in any ecosystem is dependent on the stand densities, the stands sizes (DBH and/or heights of trees) of existing ecosystem components and the floor

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litter. Figures 10 - 12 present the total cocoa ecosystem biomass and its distribution according to regions, system of production and age category of cocoa stands. There was significantly higher biomass contribution from cocoa in the ER than in the WR (Figure 10). The biomass contributions of cocoa trees to the ecosystem biomass ranged between 29.2 Mg/ha to 40.2 Mg/ha for shaded and unshaded farms, respectively (Figure 11). This study contradicts earlier reports from Ghana and elsewhere that suggest cocoa biomass benefits from shade trees (Beer *et al*., 1997; Isaac *et al*., 2005; Isaac *et al*., 2007). The higher mean cocoa biomass stocks in the Eastern region relative to the Western region is attributable to the significantly ($P < 0.05$) large cocoa tree sizes in the former (Figure 3). Similarly, the larger cocoa tree sizes produced on farms without shade largely explains why the cocoa biomass stock is greater than that from shaded systems. This is likely a consequence of greater light incidence on cocoa in the unshaded system, suggesting that light interception and competition for water and nutrients by the shade trees might create conditions that are suboptimal for cocoa development (Clough *et al.*, 2011; Oke and Olatiilu, 2011). Some previous studies have also mentioned the negative impact of shading on cocoa tree development (Ahenkorah *et al*., 1987). Also, the mean biomass stocks from cocoa trees were higher in farms where the stands were more than 15 years old than stands with age group below 15 years (Figure 12). Obviously, the older a cocoa tree is, the larger is its DBH, which in the main determines the amount of biomass that accumulates.

The biomass contribution of shade tree species to the cocoa ecosystems ranged between 14 Mg/ha to 53 Mg/ha with a mean of 30.75 Mg/ha (Table 3). Shade tree biomass stocks varied according to the region and the stand age category of cocoa trees (Figure 10, 12). Due to the high variability of shade tree biomass as illustrated by the large coefficient of variation (cv = 111.8%, Table 3), comparison of treatment effects is best determined in terms of order of magnitude. Thus, shade trees contributed more to ecosystem biomass in the ER than in the WR and did so dramatically (about 4-fold) on farms with cocoa stands older than 15 years when compared to stands less than 15 years old (Figures 10, and 12; Table 3).

With respect to cocoa ecosystem components, stumps contributed the least to total cocoa ecosystem biomass stocks. The biomass contribution from stumps varied significantly between systems and between stand age category but not so between regions (Figures 10 - 12). Unshaded systems were characterised by more biomass from stumps than shaded systems which is a reflection of the larger stump diameters and heights found in the former (Table 1). Significantly, only stumps contributed large biomass in farms with stand age less than 15 years relative to farms with stand age above 15 years among the ecosystem components (Figure 12). The high biomass contribution of stumps in stand age category below 15 years is a reflection of its density rather than the diameters and heights as was so for the effects of shade management. Considerable interactions between regions, shade management and age groups impacted differently on stump biomass (Table 3). Generally the biomass contribution from stumps to the cocoa ecosystems ranged between 60 kg/ha in shaded cocoa farms in the ER with cocoa stands older than 15 years to 740 kg/ha under unshaded cocoa farms in the ER with cocoa stands less than 15 years of age (Table 3).

As shown in Table 3, the total litter production by cocoa ecosystems ranged from 4.55 Mg/ha in farms with cocoa stands less than 15 years to 8.52 Mg/ha under farms with cocoa stands beyond 15 years of age. Similar ranges of litter biomass produced under cocoa systems in Ghana and elsewhere have been reported (Wessel, 1985; Beer, 1988; Owusu-Sekyere *et al*., 2006; Ofori-Frimpong *et al*., 2011). The current results indicated significant variations in litter biomass stocks between regions and between stand age category but not so between systems

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(Table 4.3). According to Wood and Lass (1985), relatively more leaves fall from older cocoa plants. The lack of significant difference in litter biomass with respect to system of cocoa production suggests that the shade trees had a minimal contribution to the litter-fall of the system. Ofori-Frimpong *et al.* (2007) estimate that about 3% of the total litter fall under shaded cocoa farms comes from shade trees.

In this study, the mean total cocoa ecosystem biomass reached 26.5 Mg/ha to 101.6 Mg/ha under shaded cocoa systems of stands less than 15 years in the WR and under shaded system of stands greater than 15 years in the ER, respectively (Table 3). As expected, biomass production in the shaded cocoa system exceeded that in the unshaded one. Furthermore, approximately 45% of the bulk of the biomass in the shaded cocoa systems was contributed by shade trees. However, the results indicated high variability with a coefficient of variation of 46.6%, probably due to the differences in shade tree species, density and whether those shade trees were planted with cocoa or were the result from a thinned forest, the latter practice termed as rustic. Thus, the differences in total ecosystem biomass are better compared in terms of magnitude. Farms in the Eastern region produced higher total biomass than the Western region farms. Among the ecosystem components, only the shade trees indicated significant positive correlation to total system's biomass ($r = 0.9672$, $P < 0.001$, Table 4).

Biomass distribution in cocoa trees

The biomass distribution of cocoa trees among roots, stem, branches and leaves in Ghana is presented in Table 5. It is evident that the biomass stocks of cocoa tree components are influenced by the system of production and the stand age category but not the region. This study estimated cocoa tree biomass as ranging between 17.38 kg/tree in farms with planting that were less than 15 years, and 27 kg/tree from cocoa trees planted over 15 years. However, under any given factor of influence, the biomass change of a component is consistent. This suggests possibility of a genetic control on cocoa tree biomass distribution other than the factors under study.

The woody stem and branches of cocoa trees were the major biomass pools in each cocoa tree. Each of these pools was consistently higher than the sum of the root and leaf pools in a cocoa tree, irrespective of the region, system of production and the stand age category. However, the sum of the root and leaf biomass pool constitute approximately one-third of the total biomass and therefore needs to be included in large scale biomass accounting of cocoa ecosystems. Aside, these pools provide the prominent nutrient transfer mechanisms in the cocoa ecosystem through litter fall and root decomposition. Another study however reported a high biomass allocation to cocoa leaves (Anglaaere, 2005). The current work indicates an increase in leaf biomass pool in more recently established farms but not so much as to produce higher biomass relative to the stem and branches, as was the case in Anglaaere (2005).

CONCLUSION

Ghana is currently the second largest producer of cocoa beans in West Africa with an estimated total cultivation area of about 1.75 million hectares. Cultivation of cocoa is restricted to six forest regions holding farms with cocoa stand ages most of which range from less than 15 years to 30 years; these are either with or without shade trees. Although cocoa stockings were within the recommended plant population, planting distances were found to be variable in farmer fields. A simple biometric measure of cocoa diameter at breast height (DBH, 1.37 m) appeared dependable ($R^2 = 89$) at predicting standing cocoa biomass. Cocoa tree root-to-shoot ratios

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ranged from 19 to 21% depending on the tree DBH, and the ratio decreased with increasing cocoa tree sizes. Presence of shade trees affected cocoa biomass stocks negatively but contributed significantly to the bulk of the total biomass of cocoa ecosystems. The results showed that the unshaded system produced the least biomass production. Standing biomass was higher in the Eastern than Western region and in stand age >15-year old systems than in those <15 years. It was recommended that research on optimal shade management to reduce its impacts on cocoa biomass accumulation is required.

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Table 1: Variations in stand density and diameter at breast height (DBH) of cocoa trees, shade trees and stumps as affected by the interactions between region (Eastern (ER), Western (WR)), system (shaded (S), unshaded (U)) and age group (< 15 years, > 15 years)

Factor	Treatment interaction	Tree density (trees/ha)			Tree DBH (cm		
		Cocoa	Shade	Stump	Cocoa	Shade	Stump
Region * System	ER * S	1630a[1]	207.4	104a	9.7a	16.4	8.2a
	ER * U	1530a	n.a[2]	143a	10.7a	n.a.	10.2a
	WR * S	1363b	42.6.	117a	8.7a	20.6.	7.9a
	WR * U	1607a	n.a.	187a	10.2a	n.a.	8.3a
Region * Age group	ER * <15	1744a	244a	230a	9.4a	13.5a	7.6a
	ER * >15	1417a	170a	17a	11.0a	19.3a	10.9a
	WR * <15	1569a	44a	209a	8.1a	18.9a	7.1a
	WR * >15	1402a	41a	94a	11.0a	22.4a	9.2a
System * Age group	S * <15	1713a	105.6	178a	7.8a	13.5.	6.6a
	S * >15	1280c	144.4	43a	10.5a	19.3.	9.5a
	U * <15	1598b	n.a.	261a	9.6a	n.a.	8.1a
	U * >15	1539b	n.a.	69a	11.2a	n.a.	10.5a
Region * System * Age group	ER* S*<15	1959a	170.4	185a	9.0d	13.5	6.7a
	ER*S*>15	1300a	244.4	22a	10.3bc	19.3.	9.7a
	ER*U*<15	1530a	n.a.	274a	9.7bcd	n.a.	8.4a
	ER*U*>15	1533a	n.a.	11a	11.6a	n.a.	12.1a
	WR*S*<15	1467a	40.7	170a	6.7e	18.9	6.4a
	WR*S*>15	1259a	44.4	63a	10.7ab	22.4	9.4a
	WR*U*<15	1670a	n.a.	248a	9.5cd	n.a.	7.7a
	WR*U*>15	1544a	n.a.	126a	10.8ab	n.a.	8.9a
Coefficient of variation (%)		10.0	55.4	46.9	8.7	73.0	10.9

[1]Different letters within same factor and column indicate significant difference at $P < 0.05$.
[2]Not applicable.

Table 2: Correlation coefficient (r) for properties of live stand cocoa components in cocoa ecosystems[a]

	Cocoa density	Cocoa DBH	Shade Density	Shade DBH	Stumps density	Stumps DBH
Cocoa DBH	-0.3339					
Shade density	0.2647	0.3223				
Shade DBH	-0.4356	0.1604	-0.1730			
Stumps density	**0.7911****	**-0.6548***	-0.2248	-0.3354		
Stumps DBH	-0.5405	**0.8040****	0.2973	0.2271	**-0.6770***	
Stumps height	0.5624	0.0064	0.1718	-0.1379	0.1760	-0.4992

[a]Values with '**' are significant at $P < 0.01$, with '*' are significant at $P < 0.05$, and without symbol are not significant, (2 – tailed test).

Table 3: Variations in total ecosystem biomass partitioned into cocoa, shade, stump and litter components in region (Eastern (ER), Western (WR), system (shaded (S), unshaded (U)) and age group (< 15 years, > 15 years).

Factor	Treatment interaction	Biomass (Mg/ha)				
		Cocoa	Shade	Stump	Litter	Ecosystem
Region * System	ER * S	34.5a[1]	39.5	0.24a	7.0a	81.2a
	ER * U	41.9a	n.a[2]	0.42a	7.1a	49.4c
	WR * S	23.8b	26.7	0.16a	6.1a	56.8bc
	WR * U	38.5a	n.a.	0.51a	6.0a	45.0c
Region * Age group	ER * <15	34.9a	19a	0.58a	4.4c	49.3a
	ER * >15	41.6a	60a	0.08c	9.7a	81.4a
	WR * <15	24.3b	8a	0.37b	4.7c	33.6a
	WR * >15	38.0a	45a	0.30b	7.4b	68.2a
System * Age group	S * <15	25.4a	13.6	0.29a	4.4a	43.7a
	S * >15	33.0a	52.6.	0.11a	8.7a	94.4a
	U * <15	33.9a	n.a.	0.66a	4.7a	39.2a
	U * >15	46.6a	n.a.	0.27a	8.3a	55.2a
Region * System * Age group	ER*S*<15	36.6a	18.8.	0.42a	5.0cd	60.8ab
	ER*S*>15	32.5a	60.1	0.06a	9.0ab	101.6a
	ER*U*<15	33.2a	n.a.	0.74a	3.8d	37.7c
	ER*U*>15	50.7a	n.a.	0.11a	10.4a	61.1ab
	WR*S*<15	14.1a	8.4	0.17a	3.8d	26.5d
	WR*S*>15	33.5a	45.1	0.16a	8.5b	87.2ab
	WR*U*<15	34.5a	n.a.	0.57a	5.7c	40.7bc
	WR*U*>15	42.5a	n.a.	0.44a	6.3c	49.2bc
Coefficient of variation (%)		4.9	111.8	24.8	16.0	21.0

[1]Different letter within same factor and column indicate significant difference at $P < 0.05$.
[2]Not applicable.

Table 4: Correlation coefficients (r) for biomass components in cocoa ecosystems[a]

	Ecosystem	Cocoa	Shade	Stumps
Cocoa	0.5195			
Shade	**0.9672****	0.2895		
Stump	-0.1866	0.2943	-0.2608	
Litter	0.5174	0.5402	0.3813	-0.4871

[a]Values with '**' are significant at $P < 0.01$, and without symbol are not significant, (2 – tailed test).

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Table 5: Influence of by region, system and cocoa stand age category on total cocoa biomass (kg/tree) and its distribution.

Factor	Treatment	Branch	Leaf	Root	Stem	TOTAL
Region	Eastern	8.69a	3.08a	4.01a	8.32a	24.10a
	Western	7.42a	2.70a	3.45a	7.10a	20.67a
System	Shaded	7.01b	2.59b	3.27b	6.71b	19.58b
	Unshaded	9.10a	3.20a	4.19a	8.70a	25.19a
Age group	<15 years	6.19b	2.35b	2.91b	5.93b	17.38b
	>15 years	9.92a	3.44a	4.55a	9.49a	27.40a
	cv %	21.9	16.7	20.5	21.9	21.0

Different letters in a column within the same factor indicate significant difference at $P < 0.05$.

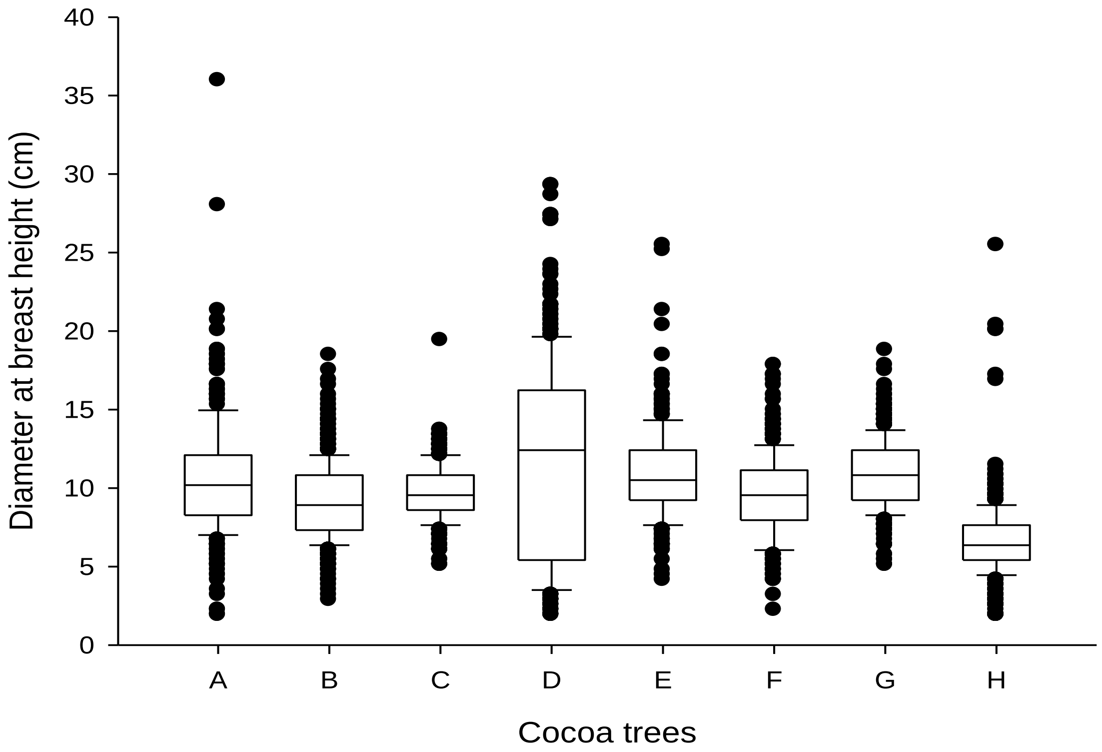

Figure 1: Box-plot of the diameter at breast height showing the distribution of cocoa tree sizes in the selected farms.

LEGEND

Farm ID	Region	System	Age (years)
A	Eastern	Shade	25
B	Eastern	Shade	14
C	Eastern	No shade	10
D	Eastern	No shade	28
E	Western	Shade	17
F	Western	No shade	13
G	Western	No shade	27
H	Western	Shade	7

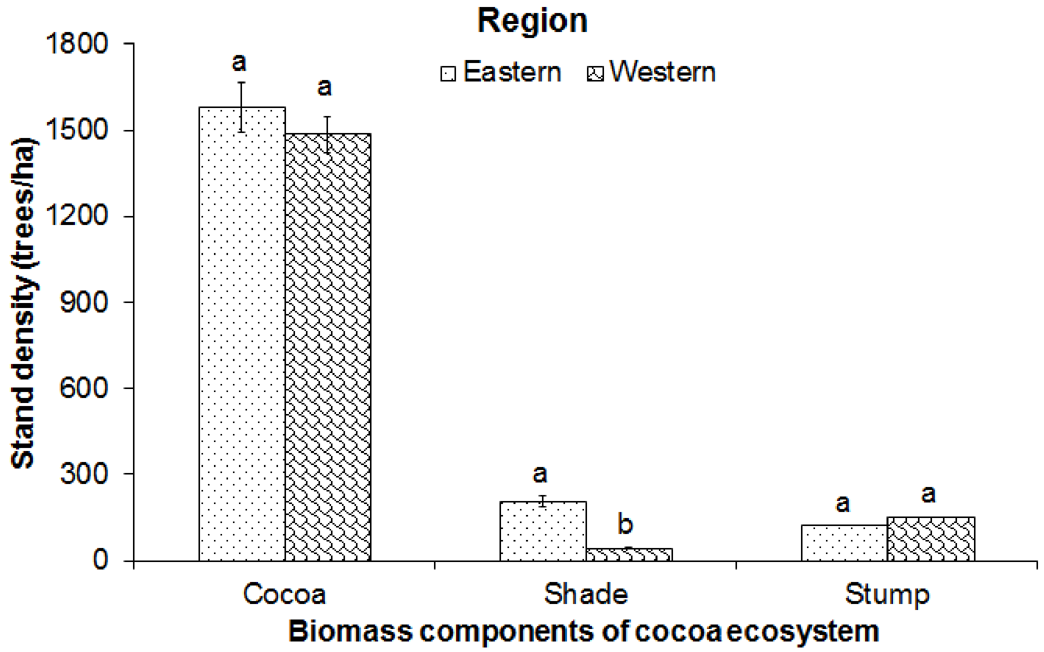

Figure 2: Variations in tree densities as influenced by the region of cultivation. Error bars are standard errors. Different letters on bars within a component indicate significant difference at $P < 0.05$.

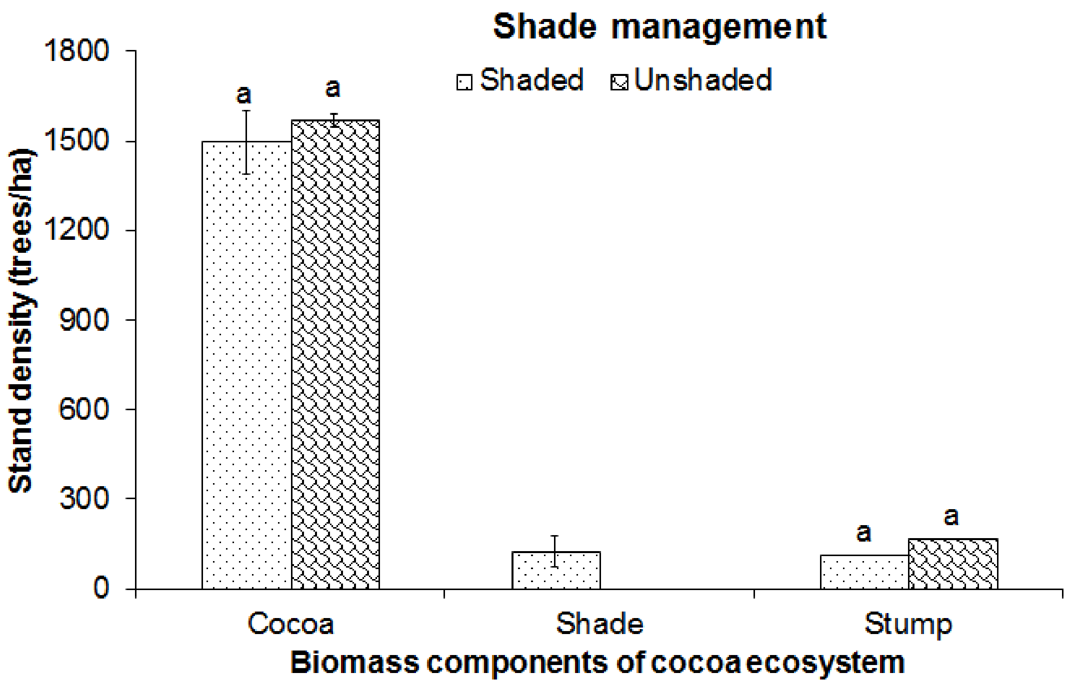

Figure 3: Effects of shade management on tree densities in cocoa ecosystems of Ghana. Error bars are standard errors. Different letters on bars within a component indicate significant difference at $P < 0.05$.

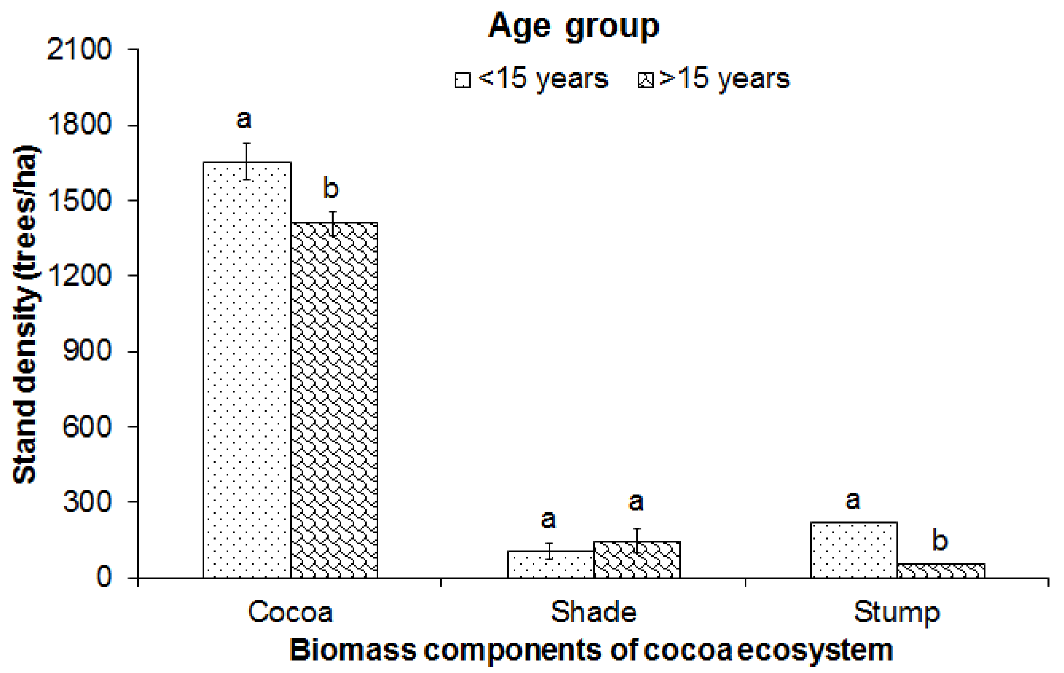

Figure 4: Effects of stand age group on tree densities in cocoa ecosystems of Ghana. Error bars are standard errors. Different letters on bars within a component indicate significant difference at $P < 0.05$.

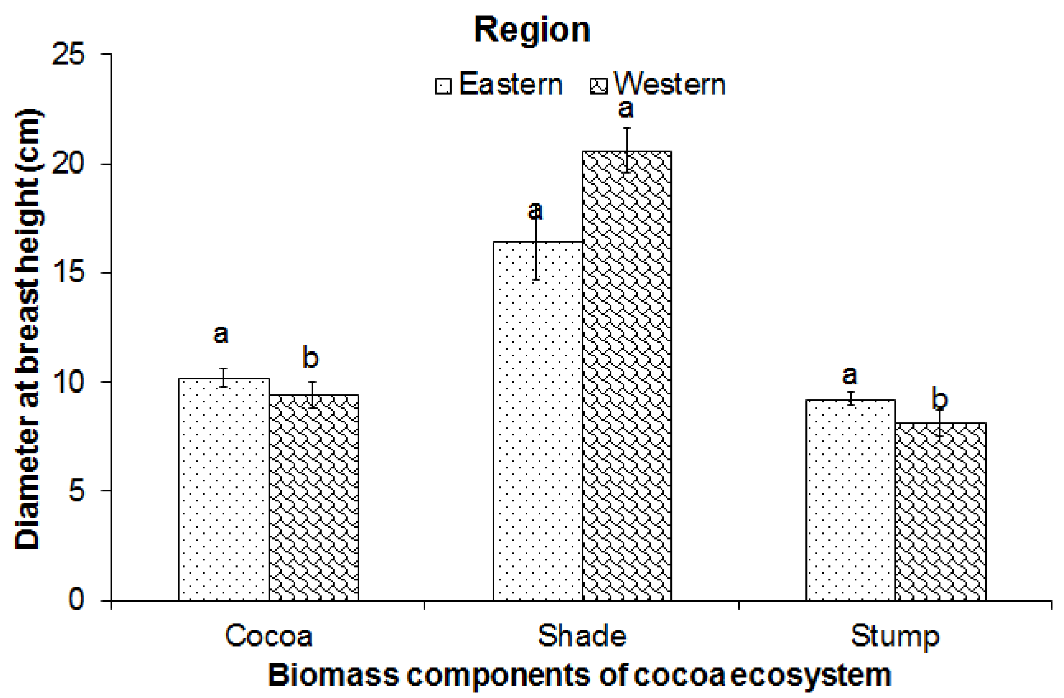

Figure 5: Effects of region on diameter at breast height of trees in cocoa ecosystems of Ghana. Error bars are standard errors. Different letters on bars within a component indicate significant difference at $P < 0.05$.

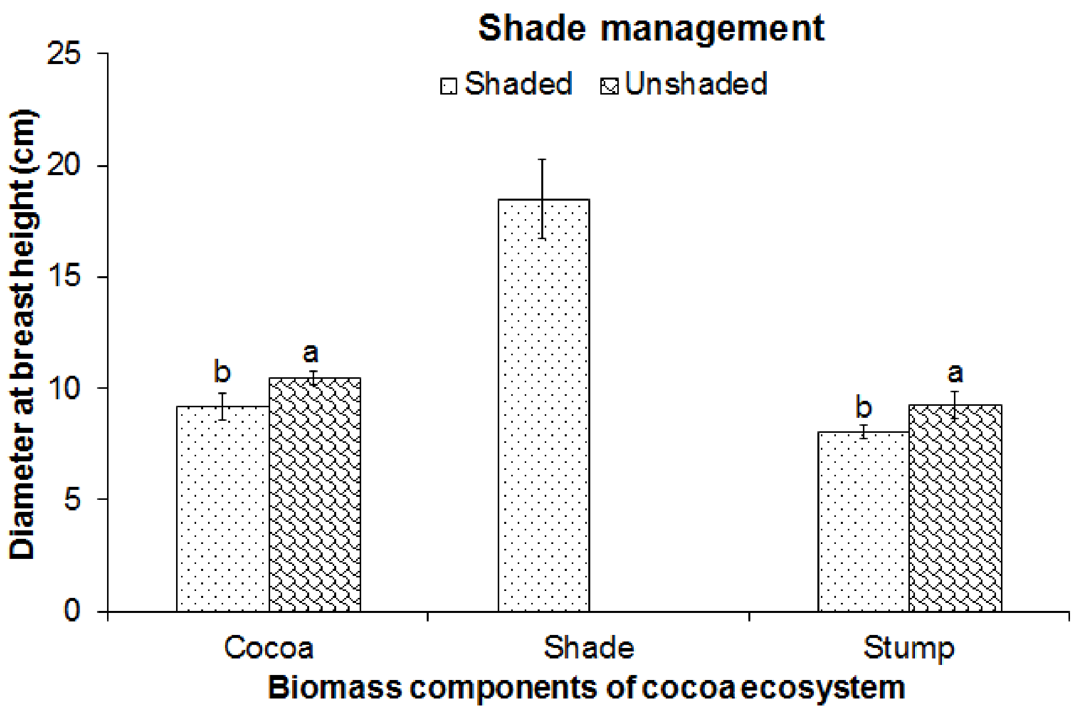

Figure 6: Effects of shade management on diameter at breast height of trees in cocoa ecosystems of Ghana. Error bars are standard errors. Different letters on bars within a component indicate significant difference at $P < 0.05$.

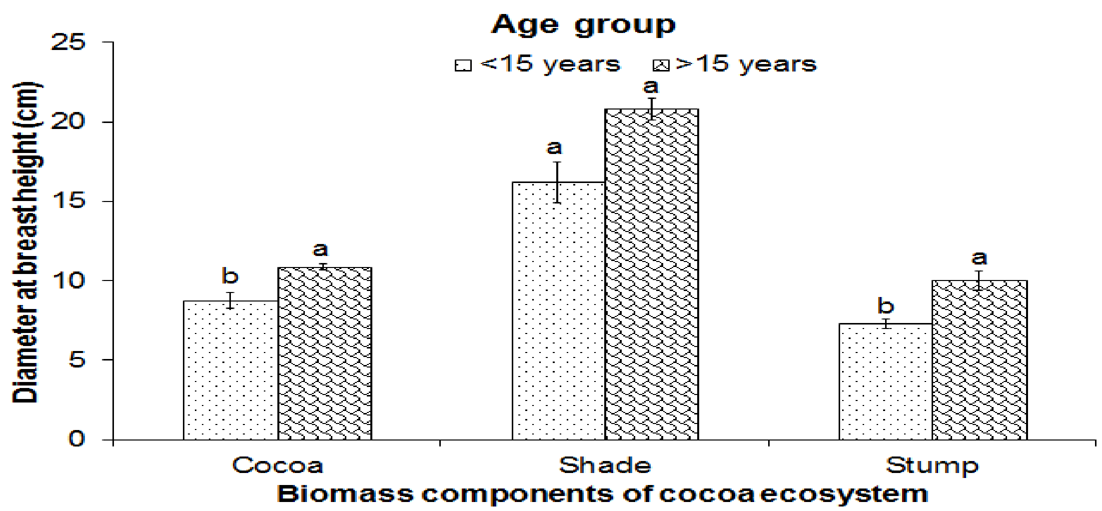

Figure 7: Effects of cocoa stand age group on diameter at breast height of trees in cocoa ecosystems of Ghana. Error bars are standard errors. Different letters on bars within a component indicate significant difference at $P < 0.05$.

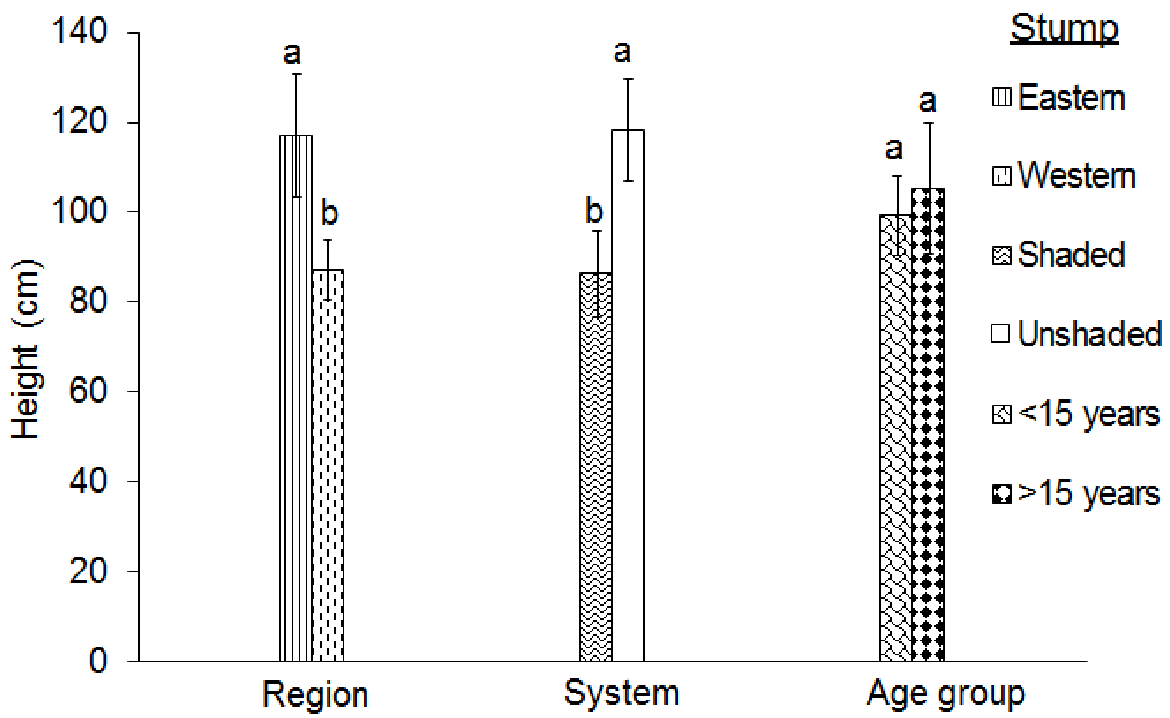

Figure 8: Variations in stump height with region, system and stand age group in cocia ecosystems of Ghana. Error bars are standard errors. Different letters on bars within a component indicate significant difference at $P < 0.05$.

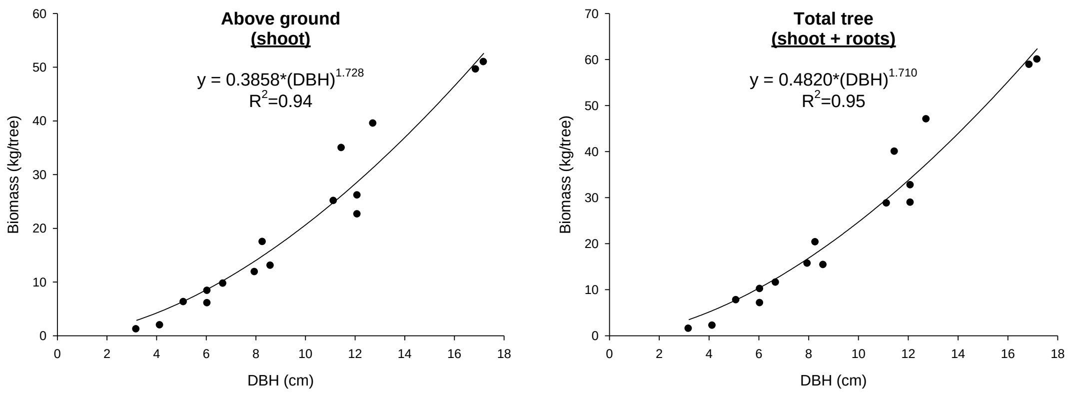

Figure 9: Models developed for estimating biomass (y; in kg/tree) for cocoa tree components as a function of its diameter at breast height (DBH, cm).

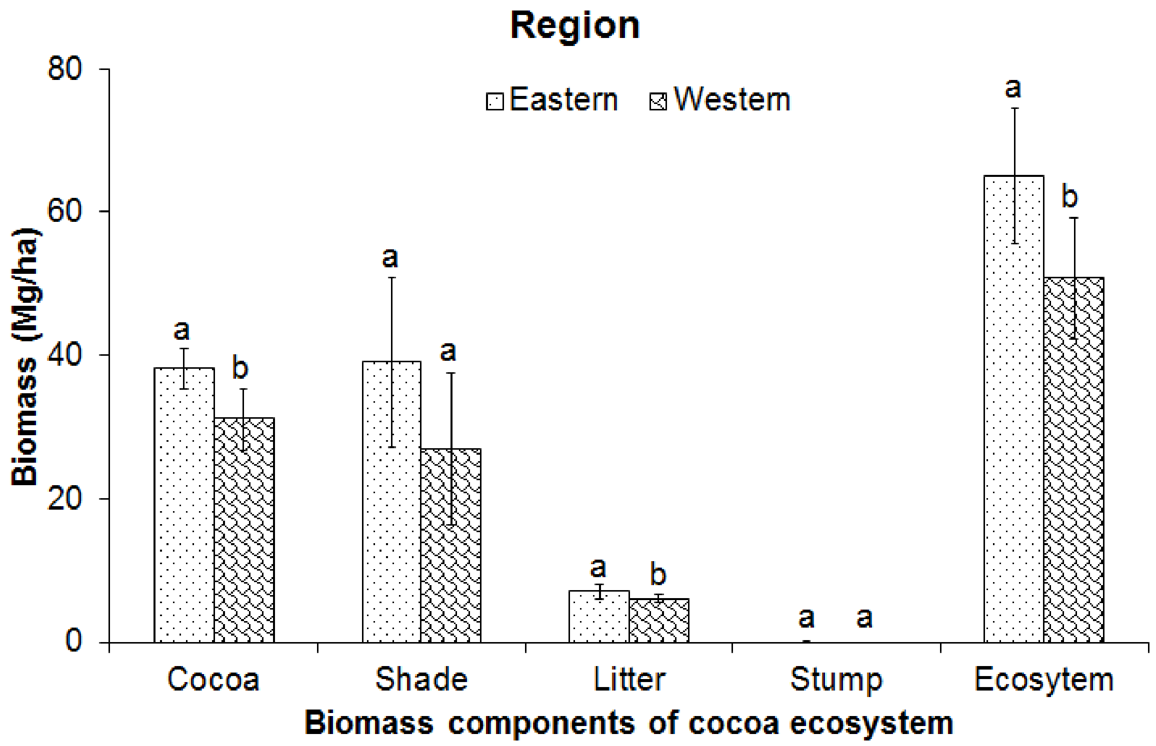

Figure 10: Effects of region on biomass of the components of cocoa ecosystem in Ghana. Error bars are standard errors. Different letter within the same component indicate significant differences at $P < 0.05$.

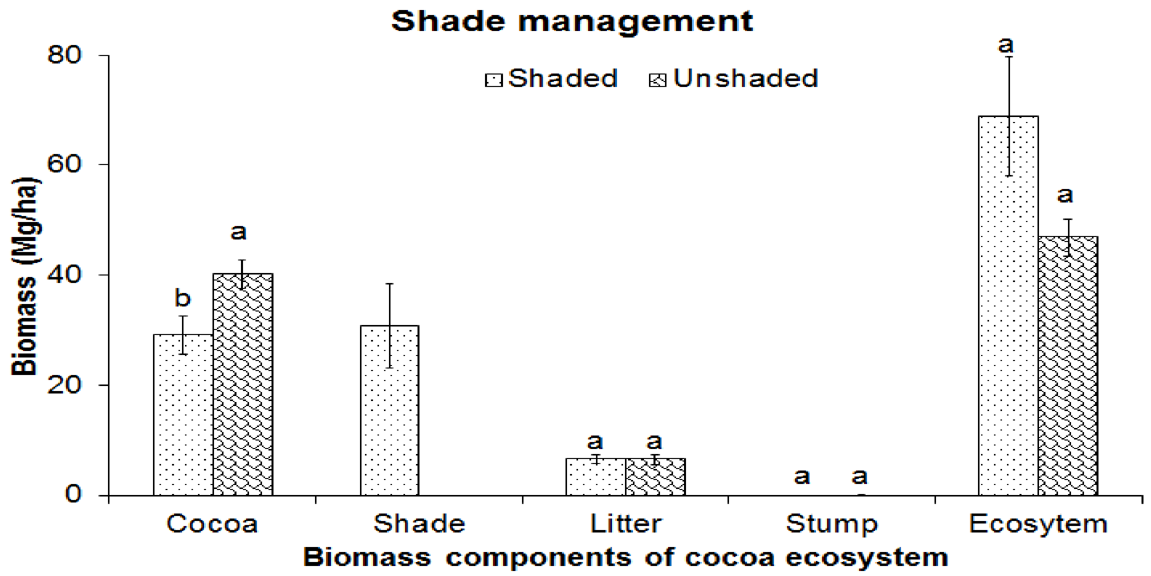

Figure 11: Effects of shade management on biomass of the components of cocoa ecosystem in Ghana. Error bars are standard errors. Different letter within the same component indicate significant differences at $P < 0.05$.

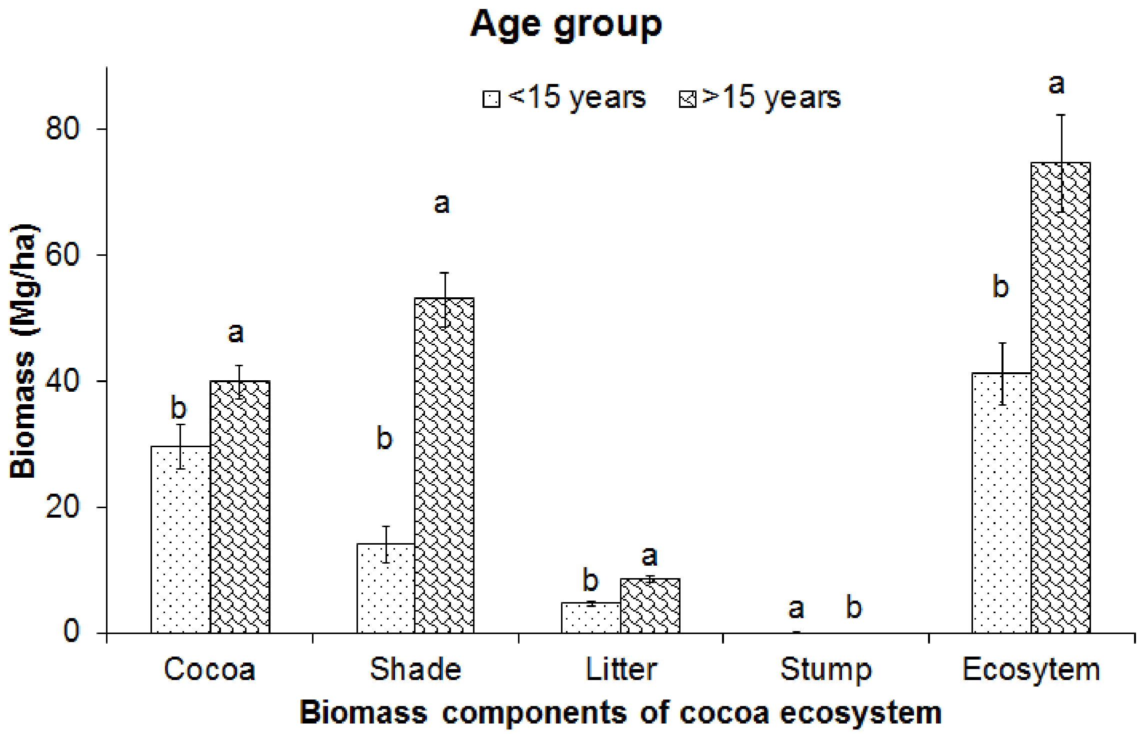

Figure 12: Effects of cocoa stand age group on biomass of the components of cocoa ecosystem in Ghana. Error bars are standard errors. Different letter within the same component indicate significant differences at $P < 0.05$.