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A Comparative Study of Carbon Storage in Two Shade-Types of Cocoa and a Teak Plantation in the Moist Semi-Deciduous Forest Zone of Ghana

Eunice Nimo[1*)], Evans Dawoe[1)], and John Tennyson Afele[1)]

[1)]Department of Agroforestry, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana
*)Corresponding author: eunicenimo20@gmail.com
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Abstract

With the current trends of increasing global warming which has detrimental effects on life, it is important that steps are taken to mitigate its effects. With the intensification of cocoa production, there has been a shift in traditional cocoa farming over the years leading to the removal of shade trees, hence, removal of carbon sinks. This study was carried out to compare the amount of carbon stored in cocoa ecosystems to that of a 20 years teak plantation and to calculate the trade-off of carbon between the two systems. Cocoa farms of similar ages (20 years) were selected in which three-subplots were demarcated on each farm at Piase in the Bosomtwe District. Tree diameter at breast height (DBH) was measured and soils samples were collected and analyzed for organic carbon percentage and bulk density. One-way analysis of variance was used to analyze above and belowground tree carbon and two-way analysis of variance was used to analyze soil organic carbon stored. Teak plantation recorded higher carbon stock (739.33±2.24 Mg C.ha^{-1}) compared to full-sun cocoa (9.36±2.24 Mg C.ha^{-1}). Soil organic carbon across the three farms showed significant ($p = 0.0010$) variations with depths. The 0-20 cm soil depth stored significantly more ($p = 0.0000$) organic carbon compared to 20-40 cm soil depth. Total soil carbon stored revealed significant differences amongst the various farms with the full-sun (40.857±0.52 Mg C.ha^{-1}) being the least whilst the teak plantation stored the highest (72.42±0.52 Mg C.ha^{-1}). Total carbon (above-ground tree carbon + below-ground tree carbon + soil organic carbon) showed significant difference ($p= 0.0000$) between land use types with shaded cocoa farm (74.3±0.89 Mg C.ha^{-1}), full-sun cocoa farm (32.02±0.89Mg C.ha^{-1}) and that of the teak plantation (950.91±0.89 Mg C.ha^{-1}) respectively. Traditional cocoa ecosystem (shaded cocoa farms) has the potential to store carbon significantly higher than that of the full-sun systems.

Keywords: climate change, cocoa, shade types, teak plantation, carbon storage

INTRODUCTION

Carbon is the basic building block of humans, animals, plants and soils (TRD, 2013). Carbon accumulates in the atmosphere at a rate of 3.5×10^9 tons per year, due mostly to fossil fuel consumption and the conversion of tropical forests into land for agriculture and pasture (Coady *et al.*, 2017). The atmospheric concentration of CO_2 and other greenhouse gases increased by 70% between 1970 and 2004 (Solomon *et al.*, 2007). In 1900, the area of high forest was estimated to be between 8 and 9 million hectares but by 1946 the combined area of reserved and unreserved forest was estimated to have halved to 4.4 million hectares (Forestry Commission, 2012) due to forest encroachment.

Ghana is the second major producer of cocoa in the world (Asare *et al.,* 2018). The tree crop contributed about 3.4% to total Gross Domestic Product annually and an average of 29% to total export revenue between 1990 and 1999 (Dormon *et al.*, 2004) and 22% between 2000 and 2002 (Dormon *et al.*, 2004). Cocoa is cultivated in the forest regions of Ghana where an estimated area of 1.45 million hectares of forest land has been displaced (Anim-Kwapong & Frimpong, 2005). Cocoa is an understory crop and is grown after selectively thinning the forest leaving some emergent trees to provide shade (Anim-Kwapong, 2006; Asare *et al*., 2018). Cocoa provides livelihood for over 800,000 farm households and it is the most important agricultural commodity for Ghana (Onumah *et al.,* 2013; Bandanaa *et al*., 2016).

In spite of this, production of cocoa has contributed to rapid conversion of naturally existing forest to farm lands (Boahene, 1998; Tandoh *et al.,* 2015). A substantial volume of literature is replete with evidence that the reduction in forest cover produced net sources of carbon dioxide (CO_2), the main greenhouse gas of the atmosphere (IPCC, 2007). According to the Intergovernmental Panel on Climate Change (IPCC), global C stocks in terrestrial biomass have decreased by 25% over the past century (IPCC, 2001). Cocoa intensification in Ghana for higher yields (Asare *et al*., 2018) has led to a drastic reduction in shade tree density and, on many farms' total elimination of the shade trees in cocoa ecosystems (Padi & Owusu, 1998; Wade *et al.*, 2010) for short term enhanced yield (Wade *et al.,* 2010). In the chosen study area in Ghana, there is inadequate literature comparing carbon storage in the cocoa ecosystem and teak plantation. Teak as a timber species is a very good sink for carbon, this is evidence as it stored 181 $ton.ha^{-1}$ in studies of Milkuri *et al*. (2014). It is therefore important that the carbon storage dynamics in shaded and unshaded cocoa systems are studied and compared to the teak plantation, to be able to estimate and make informed decisions on forest conversion rates to cocoa lands. The study aims to quantify and compare carbon stored in cocoa ecosystems (i.e. shaded and unshaded) and a teak plantation in Piase in the Bosomtwe District of the Ashanti Region–Ghana by estimating above-ground tree biomass (cocoa and shade trees) and soil carbon stocks of a shaded and full sun cocoa ecosystem as well as a teak plantation.

MATERIALS AND METHODS

Description of Study Sites

The study was conducted at Piase in the Bosumtwe District (Figure 1) of the Ashanti Region of Ghana. The District lies within Latitudes 6° 24' South and 6° 43' North and Longitudes 1° 15' East and 1° 46' West (GSS, 2014). It is bounded in the north by Kumasi Metropolitan Assembly, in the east by Ejisu and Juaben Municipalities, the south by Bekwai Municipal and Bosome-Freho District, and in the west by Atwima-Kwanwoma District. The District has a land size of 422.5 km^2 with human population density of 222.3 per sq. km. The District has 66 communities, which have been zoned into three area councils namely, Jachie, Kuntanase and Boneso (GSS, 2014).

The drainage pattern of the study site is dendritic. The rivers flow in a north-south direction and join major rivers or flow into Lake Bosomtwe. With the exception of the lake which has a circular ring of mountains that hedge its boundaries at an elevation of 65 m asl., the rest of the district has no special topographical features (GSS, 2014). The rivers in the district especially around the lake are perennial and form a dense network due to the double maxima rainfall regime. Notable rivers in the district include Rivers

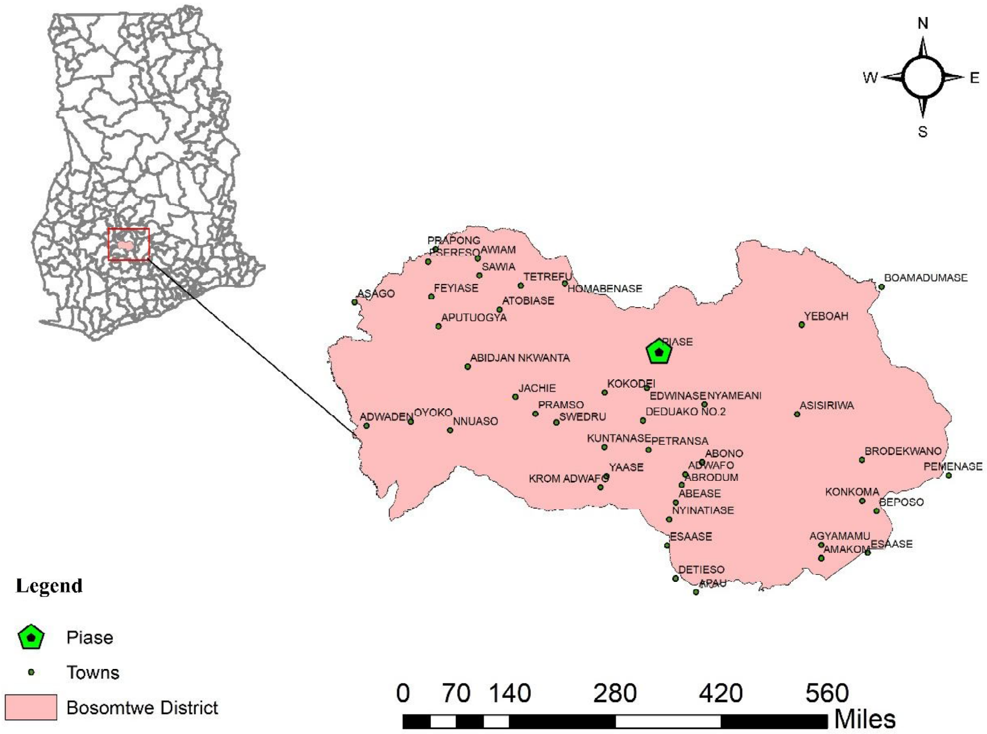

Figure 1. Map of the study site showing piase (star)

Oda, Butu, Siso, Supan, and Adanbanwe (GSS, 2014).

The Bosomtwe District falls within the equatorial zone with rainfall regime typical of the moist semi-deciduous forest zone of the country. There are two well-defined rainfall seasons: the main season, which occurs from March to July and the minor season, which starts from September to November with a peak in October (GSS, 2014). The main dry season occurs in December to March during which the desiccating Harmattan winds blow over the area. Temperature of the area is with an annual mean of around 24ºC. The highest mean temperature, i.e. 37ºC, occurs just before the major wet season in February whilst the mean minimum, i.e. 23ºC, occurs during the minor wet season (GSS, 2014).

The vegetation of the entire district is the moist-semi deciduous forest type. The cultivation of several food crops and cocoa as well as animal rearing has been major agricultural activities in the district. The soil type in the district has developed over a wide range of highly weathered parent materials such as granite, Tarkwaian and Birimian rocks (GSS, 2014).

Plot Demarcation and Experimental Procedure

Two productive cocoa farms of similar ages (20), one shaded and the other unshaded and a 20 years old teak plantation were selected for the study. Farm owners were interviewed to know the age of their farms, management practices undertaken (pruning regimes, fertilizer application, weed and pest control methods) on the farm as well as land preparation methods used before cocoa establishment. On each farm, 20 m × 60 m plots were demarcated for sampling at about 10 m away from the boundary of the farm, this was to help reducing border effect on data to be collected. Each 20 m × 60 m plot was divided into three subplots, each measuring 20 m × 20 m to give three replications of each farm. In each subplot 15 cocoa trees were measured and so for teak plantation. All shade trees within cocoa plots were counted, and their diameters at breast height (DBH) measured. Shade types used in the study were no-shade (0-2 shade trees/ha) and medium shade (9-18 shade trees/ha). The AGB (above ground biomass) of the shade trees was estimated using the allometric model by FAO (1997).

$$AgB = \exp^{[(-2.134+2.530 \text{In(DBH)}0.0736 \times (d30)]}$$

Where AgB = Estimated above ground biomass in kg; D = DBH in cm. Similarly, allometric equation by Torres *et al*. (2014). [$AGB = 1.0408\exp^{0.0736 \times (d30)}$] was used to determine the biomass of cocoa trees on farms. Below ground biomass of the cocoa and shade trees is estimated by the equation by Cairns *et al*. (1997).

$$BGB = \exp^{[1.0587 + 0.8836 \ln(AGB)]}$$

Carbon stored in cocoa trees was estimated by multiplying AgB by 0.475 (Saj *et al.*, 2013). Above-ground biomass was converted to tonnes per hectare from the equation from Macias *et al.* (2017), as follows:

$$AGB = \sum \frac{SB}{1000} \text{ x } \left(\frac{10000}{AREA}\right)$$

Where ΣSB = sum of tree biomass of all the measured cocoa trees in the area. Factor 1000 = conversion of sample units in kilograms to tonnes and factor 10,000 = conversion of measuring area (m^2) to hectares.

Soil samples were randomly collected at 0-20 cm and 20-40 cm soil depths from selected cocoa farms and the teak plantation for analysis. In each subplot, four soil samples were collected from the two different depths (two samples for %C and two samples for bulk density), giving a total of 12 soil samples per farm and 36 soil samples in total. Soil samples collected was used to determine soil bulk density by core sampler method and % organic carbon concentration Walkley-Black chromic acid wet oxidation method at the Department of Agroforestry Laboratory (Kwame Nkrumah University of Science and Technology-Kumasi). Soil organic carbon stored (SOC) ton/ha was estimated:

$$SOC = \%C*D*\rho d$$

Where D is soil depth (m), ρd is the soil bulk density ($Mg.m^{-3}$); C is the carbon concentration (%). Carbon dioxide sequestered was estimated by multiplying the amount of carbon stored by the molecular mass of CO_2 (3.6667).

Data Analysis

Data from the study was subjected to two-way analysis of variance (ANOVA) using Statistix 7.0 software with an alpha level of 5%. Fisher's Least Significant Difference (LSD) test was used to separate means. Total carbon stored in the various systems, i.e. in the soils and above ground trees biomass of the shaded, unshaded and the teak plantation were estimated and compared. Microsoft excel was used for data cleaning, presentation of results was in the form of figures and tables.

RESULTS AND DISCUSSION

Soil Organic Carbon Storage

Soil organic carbon stock was influenced significantly by shade type (A), soil depth (B) and the interaction between shade type and depth of soil (A*B), all with p-values of 0.0000, however there was no significant difference between replicates (C) and the

Table 1. Analysis of variance table for carbon sequestered in full sun and shaded cocoa as well as a teak plantation at two different depths

Source	df	SS	MS	F	P
Shade-type(A)	2	797.569	398.785	948.04	0.0000
Depth(B)	1	467.059	467.059	1110.35	0.0000
Reps(C)	2	2.360	1.180	2.81	0.1079
A*B	2	47.882	23.941	56.92	0.0000
A*B*C	10	4.206	0.421		
Total	17				

interactive effect of A*B*C and as observed in (Table 1).

Shade Type Effect

Mean soil organic carbon stored in the shaded cocoa system, the full-sun cocoa system and the teak plantation was 24.77± 0.37, 20.42±0.37, and 36.21±0.37 Mg C.ha^{-1} respectively and significantly differed from each other (p = 0.0000). The teak plantation amassed a higher amount of carbon whiles the full-sun cocoa system stored the least (Figure 1).

Carbon stored in the different cropping systems, i.e. full-sun cocoa, shaded cocoa and teak plantation were significantly different (p = 0.0000) in respect to the two different depths thus 0–20 and 20–40 cm. From Figure 2, it is observed that the sum of the mean carbon stored in the upper depths of all systems were higher (32.32 ± 0.31) than the lower depths (22.04 ± 0.31) Mg C.ha$^{-1.}$

Comparing carbon stored in all systems with regards to the two different depths, soil depths significantly influenced the soil organic carbon stored. Soil organic carbon stored at a depth of 0–20 cm in the teak plantation was significantly the highest 39.04±0.52 Mg C.ha^{-1}, followed by 20–40 cm in the same system with 33.38±0.52 Mg C.ha^{-1} and these were significantly different from each other. However, the shaded system with depth (0-20 cm) stored 30.61±0.52 Mg C.ha^{-1} whiles 0-20 cm stored 27.03±0.52 Mg C.ha^{-1} in the full-sun system. The lower depths (20–40 cm) stored 18.92±0.52 Mg C.ha^{-1} in the shaded system and 13.82±0.52 Mg C.ha^{-1} in the full-sun system which was the least. All depths were significantly different from each other (Figure 3).

The average SOC stored in the cocoa ecosystem was 22.60 ± 0.37 Mg C.ha^{-1} and that of the teak plantation was 36.21 ± 0.37 Mg C.ha^{-1}. SOC stocks recorded in cocoa systems in this study agree with stocks found in Asase & Tetteh (2016), where soil organic carbon stored in secondary forest was higher than that of the cocoa ecosystem. With reference to shade type, there was significant difference observed between the cocoa systems and the teak plantation. The shaded cocoa system stored a higher amount of carbon 24.77±0.37 Mg compared to the unshaded cocoa system 20.42±0.37 Mg C. ha$^{-1.}$. In Ghana, Mohammed *et al.*, (2016) did not record significant differences between the different aged shaded cocoa farms (99.8±5.5 Mg C.ha^{-1}) and unshaded system (83.7± 5.5 Mg C.ha^{-1}). Possible explanation for the observed difference in this study is due to the presence of high number of shade trees that help to add organic matter to the soil to increase SOC (Gama-Rodrigues *et al.*, 2010). The observed difference between the teak plantation (36.21± 0.3Mg C.ha^{-1}) and all the cocoa shade systems is similar to results of Asase & Tetteh (2016), this is due to the ability of timber species to enhance soil carbon stocks and nutrient cycling (Hoosbeek *et al.*, 2018).

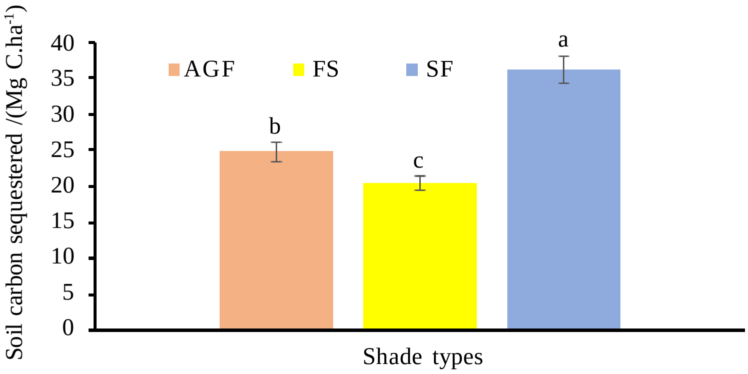

Figure 1. Soil carbon stored in two shade types of cocoa and a teak plantation. AGF (shaded cocoa production system), FS (full-sun cocoa production system), SF (teak plantation); Error bars with different alphabets are significantly different from each other

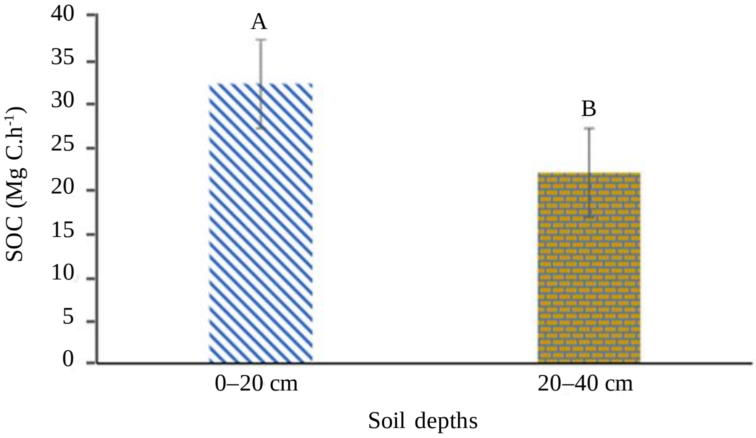

Figure 2. Effect of cocoa and teak on SOC stocks at different soil depths at Piase; Error bars with different alphabets are significantly different from each other

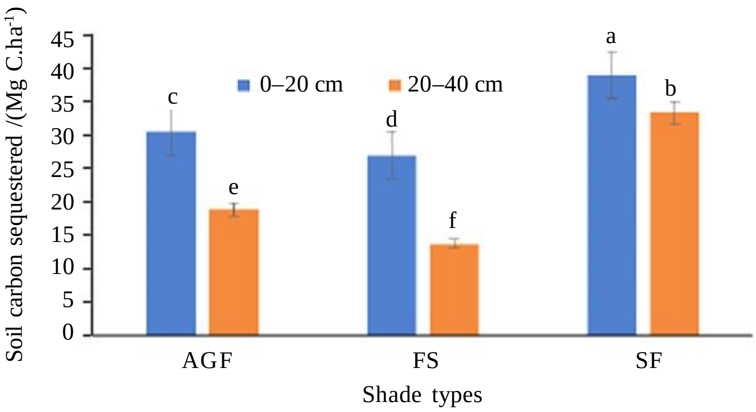

Figure 3. Soil carbon stored at the 0–20 and 20–40 cm soils depths across all shade types AGF (shaded cocoa production system), FS (full-sun cocoa production system), and SF (teak plantation); Error bars with different alphabets are significantly different from each other

Soil Depth and Farming System Interaction

Generally, there were significant differences in soil organic carbon stored in the different systems with respect to the different depths. In the shaded cocoa system, carbon in the 0–20 cm soil depth 30.61 ± 0.63 Mg C.ha^{-1}) was higher than that of the 20–40 cm, 18.92±0.63 Mg C.ha^{-1} and differences were significant (p = 0.0000). In Table 2, all systems recorded higher carbon in 0–20 cm than 20–40 cm. Comparing the upper depths (0–20 cm) across all systems, the teak plantation amassed more carbon 39.04±0.63 Mg C.ha^{-1} with the full sun cocoa system being the least with 27.03±0.63 Mg C.ha^{-1}, the different systems were significantly different with p-value of 0.0000. Similar trends were recorded in the 20–40 cm depth with the teak plantation storing more carbon (33.38± 0.57 Mg C.ha^{-1}) than the different cocoa shade types where the full sun system (13.08 ± 0.57 Mg C.ha^{-1}) accumulated the least amount of carbon and all these differed significantly (p = 0.0000).

With a p value of 0.0000 there was an observed significant difference in SOC stocks between two different depths of all shade types (cocoa and teak plantation). At 0–20 cm soil depth, SOC stored was 32.32± 0.31 Mg C.ha^{-1} for the shaded cocoa system and at a depth of 20–40 cm SOC stored was 22.04± 0.31 Mg C.ha^{-1} for the shaded cocoa system. This shows a decreasing carbon stored with increasing depth in all the systems, and agrees with studies of Gama-Rodrigues *et al.* (2010) and Mohammed *et al.* (2016) where significantly higher soil carbon in the upper depth (30 cm depth) was recorded. This is because litter fall and its decomposition helps in the accumulation of organic carbon in the upper depths of the soil (Hoosbeek *et al*., 2018).

Considering the individual depths of all the systems, the unshaded cocoa system stored the least soil carbon in both depths 0–20 cm = 27.03±0.63 Mg C.ha^{-1}, 20–40 cm = 13.08±0.51 Mg C.ha^{-1} compared to the rest and the teak plantation stored the highest in both depths at a depth of 0–20 cm = 39.04 ±0.63 Mg C.ha^{-1}, at a depth of 20–40 cm = 33.38±0.57 Mg C.ha^{-1}. This is due to the presence of shade trees leading to more carbon accumulation in the teak plantation (Nadege *et al.,* 2018).

Above and Belowground Tree Carbon Stored

Shade type significantly (p value = 0.0000) influenced the aboveground and belowground tree carbon stock in the three systems. Carbon accumulated above-ground in the teak plantation system (739.33 ± 2.24 Mg C.ha^{-1}) was significantly different from the two cocoa systems (88.62±2.24 Mg C. ha^{-1} and 9.36±2.24 Mg C.ha^{-1}), for shaded and full-sun systems respectively. These were also significantly (p value = 0.0000) different from each other.

Belowground carbon stocks showed similar trends with teak plantation accumulating the highest 175.37± 2.13 Mg C.ha^{-1}, shaded cocoa systems 21.27 ± 2.13 Mg C. ha^{-1} and the full-sun system storing 2.23 ± 2.13 Mg C.ha^{-1}, where all systems significantly differed from each other (Figure 4).

The total aboveground biomass carbon in both the shaded and the unshaded cocoa system was 97.98 ± 2.24 Mg C.ha^{-1}. This agrees with studies of Wade *et al*. (2010) where it was recorded that carbon in above ground biomass varied between 39 to 131 Mg C.ha^{-1} due to the topography of the land. There was significant difference recorded in the results obtained between the above-ground tree carbons of the two cocoa systems. The aboveground tree carbon of the shaded cocoa system recorded 88.62± 2.24 Mg C.ha^{-1} and the full-sun 9.36±2.24 Mg C.ha^{-1}. This result

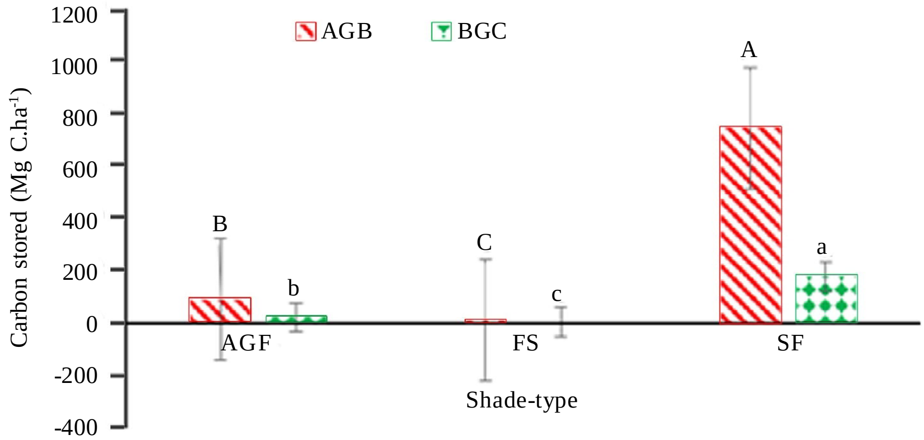

Figure 4. Above and below-ground tree carbon stored in shaded and full-sun cocoa systems and a teak plantation. AGF (shaded cocoa production system), FS (full-sun cocoa production system), SF (teak plantation), AGC (aboveground tree carbon stored), BGC (belowground tree carbon stored). Error bars with different alphabets are significantly different from each other. Upper cases are for above ground biomass whiles lower cases are for below ground biomass

agrees with studies of Mohammed *et al.* (2016) where a higher amount of carbon was equally observed in the shaded system compared to the unshaded. This is probably due to the presence of shade trees in the shaded system which accounts for the higher carbon in such systems (Nadege *et al*., 2018). Nadege *et al.* (2018) stated that associated trees in agroforestry systems store up to about three times the carbon stored in the cocoa trees. Results shows the teak plantation stored significant amount of carbon as compared to the two cocoa systems and this agrees with studies of Dawoe *et al*. (2016) and Owusu *et al*. (2018). In the study of Dawoe *et al.* (2016) aboveground carbon in cocoa was 7.45± 0.41 Mg C.ha^{-1} and that of the shade trees was 8.32±1.15 Mg C.ha^{-1} and they were significantly different. In the studies of Owusu *et al.* (2018) the carbon stored in the above-ground tree cocoa biomass was 6.26±1.27 Mg C.ha^{-1} and that of *Gliricidia sepium* was 24.12±5.53 Mg C.ha^{-1} and they were also significantly different. Generally, carbon stored in shade trees is higher than that of cocoa because of higher DBH of shade trees in the same age class with the cocoa trees.

Below-ground tree biomass stored recorded significant differences between the different cocoa shade types and the teak plantation. The shaded cocoa system recorded 21.27± 2.13 Mg C.ha^{-1} and the full-sun cocoa system recorded 2.23±2.13 Mg C.ha^{-1}, these follows a similar pattern recorded in Mohammed *et al*. (2016), and supports Nadege *et al*. (2018) which states that the inclusion of associated trees causes increase in carbon stored. Due to the use of the formula by Cairns *et al.* (1997) values here are comparatively lower because the above-ground tree biomass was reduced to about 24%. Teak plantation accrued 175.35±2.13 Mg C.ha^{-1} and was significantly the highest amongst all the shade types. Results in the below-ground tree carbon followed the same pattern as that of the above ground tree carbon hence, similar explanations. Teak plantation and cocoa shade types are of similar age (20 years), but teak tend to store more carbon below ground. This is because teak has a faster growth rate and is able to accumulate more below-ground biomass hence higher carbon stored (Nadege *et al*., 2018; Kenzo *et al*., 2019).

Total Carbon Stored in the Systems

Total carbon (SOC + aboveground tree carbon + belowground tree carbon) in all systems (shaded cocoa, full-sun cocoa and teak plantation) were all significantly different from each other with the teak plantation storing the highest 950.91 Mg C.ha^{-1} and the least stored in the full-sun system (32.02 Mg C.ha^{-1}) (Figure 5).

The total carbon (aboveground tree carbon + belowground tree carbon + soil carbon) accumulated in the teak plantation was 950.91 Mg.ha^{-1} and this was significantly different from that of the shaded and unshaded cocoa system i.e. 134.67 Mg C.ha^{-1} and 32.02 Mg C.ha^{-1} respectively. Soils in all systems stored relatively higher carbon than the tree biomass. This agrees with Dixon (1995), that the amount of carbon in soils is about 2.25 times the amount of carbon stored in vegetation. Relatively, higher amount of carbon was stored in the teak followed by the shaded cocoa system due to the presence of timber species (Nadege *et al.*, 2018).

CONCLUSIONS

The incorporation of trees on farm lands improves the carbon storing potential of the soil and also the addition of shade trees in cocoa production systems increases the carbon capturing potential of the system. Generally, soil carbon was higher than the carbon stored in above and below ground tree biomass. Teak plantation accumulated the highest amount of carbon which was seven times more i.e. 950.91 Mg C.ha^{-1} than the shaded system i.e. 134.67 Mg C.ha^{-1} and unshaded i.e. 32.02 Mg C.ha^{-1}.

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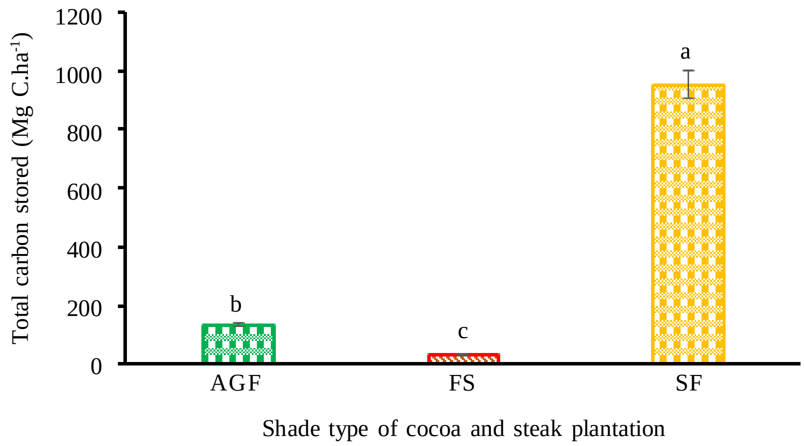

Figure 5. Total carbon (SOC + aboveground tree carbon + belowground tree carbon) in all systems (shaded cocoa, full-sun cocoa and teak plantation) in Piase; AGF (shaded cocoa production system), FS (full-sun cocoa production system), SF (teak plantation), AGC (aboveground tree carbon stored), BGC (belowground tree carbon stored); Error bars with different alphabets are significantly different from each other

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