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Evaluation of cacao in fruit tree species' shade system in Ghana

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Abstract

A study was undertaken in 2008 at Afosu, Ghana, to evaluate impact of fruit species shade tree density and complementarities in a cacao farm ecosystem on resource availability, soil carbon stock and cacao standing biomass and to assess the cost effectiveness of the tree species' diversification. The study contributes information on system productivity and ecosystem resilience, in a controlled study of agro-ecosystem and economic benefits of a multi-strata cacao/diversified tree system. Two each of *Allanblackia parviflora, Ricinodendron heudelotii, Persea americana* and *Tetrapleura tetraptera* integrated as a mixed stand into cacao at shade tree density of 92, 69 and 44 trees ha^{-1} for three evaluated treatments and 37 trees ha^{-1} of mix *Terminalia ivorensis* and *T. superba* as control. These treatments were planted in a randomized complete block design with four replications. Seventy-eight months after transplanting cacao, no significant treatment differences were recorded for dry cacao bean yield. Fluctuating mean annual dry cacao bean yields of 312, 241, 775 kgha^{-1} for 2014/15, 2015/16, 2016/17 crop years respectively were recorded for the three-year period. LAI and percent ground cover recorded statistically different values, ranging from 0.53-0.7 and 0.28–0.42 respectively. Shade tree biomass estimated in fragments (above-ground and root) recorded significant treatment differences that also contributed to significant carbon stock differences with values of 49.25 - 73.96 MgCha^{-1}. Significant differences were recorded in the carbon content of above-ground parts of cacao trees. Treatments did not differ in soil carbon stock. Differences in total carbon stock values resulted from tree (cacao and shade) biomass treatment differences. No significant treatments impact was recorded on pH, OM, N, P, K, Mg and Ca in April 2016 soil samples. Results from the study showed ample space was still available for exploitation by the competing tree species and therefore optimal spatial arrangement for the system could not be determined at this stage.

Introduction

The cacao sector is mainly supported by smallholder cacao farmers with about 90% of farmers holding between 2-3 hectares on the average (Fountain and Hütz-Adams, 2015). Cacao farming is rarely profitable due to limitation of scale exacerbated by low farm gate cacao bean price, estimated at 6% of consumer price (Fountain and Hütz-Adams, 2015), inefficient land use, low crop yields resulting from poor soil nutrient availability, high inputs cost to manage pests, diseases and plant nutrients as well as increasing climate variability. The sustainability of the cacao industry is thus seriously threatened. The arduous challenge to obtain living income from cacao farming must be confronted with multifaceted approach. These approaches have to be pragmatic yet simple for ease of farmer adoption. One such approach is the diversification of cacao system on-farm through incorporation of economic shade trees (Amoah *et al.*,1995; Osei-Bonsu *et al*., 2002; Anim-Kwapong *et al*., 2009) Increasing temperature and erratic rainfall patterns resulting from climatic change in the tropics where cacao production is concentrated have further highlighted the need for intense exploitation of shade trees in cacao farms. Appropriate cacao compatible shade trees regulate temperature and moisture, recycle soil nutrients from lower soil depth beyond the reach of the relatively shallow-rooted cacao (80% of root system at ≈ 40cm deep), provide wood for fuel and lumber, sequester carbon from the environment, various organs serve for alternative medicine, food, esthetic products and many more ecosystem services. Shade trees also regulate population dynamics and incidence of pests and diseases that reduce yields of both cacao and its companion species (Schroth *et al*., 2000).

Cacao shade canopies are species rich and structurally complex, with several vertical strata and diverse spatial and temporal configurations. The choice for shade trees for cacao farms is therefore motivated by any or a combination of the above factors. Several options (mono/multi) shade tree species have been studied (Amoah *et al.*,1995; Osei-Bonsu *et al*., 2002). *Terminalia ivorences and T. superba* have been choice shade trees in Ghana due to a combination of factors including good tree architecture, fast growth and economic value as timber. However these lack the supply of regular income support which farmers need during off-cacao season and before economic yields of new cacao farms are realized (*circa* 4 years). *Allanblackia parviflora, Ricinodendron heudelotii, Persea americana* and *Tetrapleura tetraptera* are very useful economic trees with actual ready market and potential economic values in Ghana. Although one or more of these species may be found isolated in cacao farming systems, their purposeful integration based on reliable scientific data (evidence of economic sense, compatibility and ecosystem sustainability) is lacking. This study was therefore undertaken to evaluate the impact of fruit species shade tree density and complementarities in a cacao farm ecosystem on resource availability, soil carbon stock and cacao standing biomass and to assess the cost effectiveness of the tree species' diversification.

Materials and methods

The study was conducted at Afosu Sub-station of the Cacao Research Institute of Ghana. The Sub-station is located in the Birim North District of the Eastern region of Ghana and lies within Latitude 6.384243 °N and longitude -0.99964°W. The rainfall pattern is bimodal with monthly mean of nine wet days. Most wet periods are in May-June and August-September. Mean annual total rainfall is 1346 mm (20 years data: 1998 to 2016), with mean minimum and maximum temperatures of 22.2°C and 31.4°C, respectively. Mean relative humidity at 0900 GMT and 1500 GMT are 86.4% and 65.6%, respectively. Total mean sunshine per annum is 160 hours. The soil at Afosu is Orthic-ferric acrisol, well-drained reddish clay loam with pH between 5.0 and 5.5.

Treatments design:

The treatments were: i. two each of *Allanblackia parviflora, Ricinodendron heudelotii, Persea americana* and *Tetrapleura tetraptera* integrated as a mixed stand into cacao at a spacing of 12 m x 9 m (T1); ii. same species composition as T1 integrated as a mixed stand into cacao at a spacing 12 m x 12 m (T2); Same species composition as T1 integrated at a mixed stand into cacao at a spacing of 15 m x 15 m (T3); and iv. two each of *Terminalia superba, T. ivorensis* integrated as a mixed stand into cacao at a spacing of 15 m x 18 m (control treatment) (T4). Cacao was planted, a year after planting the shade trees, at a spacing of 3 m x 3 m in all the treatments. Plantain was also planted at 3 m x 3 m to provide temporary shade in all the treatments. Randomized complete block design was used with four replications.

Soil sampling

Soil samples were taken at random from four locations at depths of 0–15 cm and 15–30 cm from the three treatment plots and the control plot. Three samples for each treatment were collected as baseline sample in 2008 and thereafter yearly intervals. For each treatment, the four samples collected from the respective soil (0-15 or 15-30) depth were analyzed in bulk. Soil pH, organic carbon, total nitrogen, available phosphorus, potassium, magnesium and calcium were determined for each year that the samples were collected, following the methods described by Andersen and Ingram (1993). The gravimetric method was used to determine bulk density from four random samples (0-15 cm and 15-30 cm depth) per plot.

Light interception

Radiation interception by the shade trees' canopy was measured in August 2016 at 84 months after transplanting (MAT) by means of hemispherical photography after Moser *et al.* (2010). This involved taking photographs below the cacao plants using an SLR camera fitted with a fish eye lens. Four images were taken per treatment and these were then analyzed using HemiView Software (Delta-T Devices, Cambridge, UK) to obtain a light transmission value (T). Percentage light interception was calculated as $(1-T)*100$. Groundcover and LAI were also derived from calculated hemispherical image data. Calculated LAI was not corrected due to the fact that all trees in the studied system were broad-leaved species and clumping factor would approximate unity (Chen and Cihlar, 1995: Chen *et al.*, 1995 cited by Rich, *et al.* (1999).

Tree biomass estimation

The following allometric equations: i. $\text{Log } B = (-1.684 + 2.158 * \text{Log}(d30) + 0.892 * \text{Log}(alt))$ was used to estimate biomass of *T. cacao biomass;* ii. $\text{Log } B = (-1.11 + 2.64 * \text{Log}(dbh))$ was used to estimate biomass of *A. parviflora, R. heudelotii, P americana* and *T. tetraptera* and iii. $B = (21.3 - 6.95 * (dbh) + 0.74 * (dbh2))$ used for the estimation of *Terminalia superba* and *T. ivorensis* biomass after Somarriba *et al.* (2013), where B= biomass (kg); Log= logarithm base 10; dbh= trunk diameter (cm) at breast height (1.3 m); d30=trunk diameter at 30 cm; alt= total height (m); AB= aboveground biomass. Tapes were used to measure tree trunk girth and converted to diameter. Clinometers were used for the height measurements of trees above six meters. Soil carbon content was estimated using soil organic matter and bulk density data. Root biomass was estimated indirectly from above ground biomass using model proposed by Cairns *et al.* (1997)

Results and discussion

Shade tree growth

Descriptive growth data (girth and height) of the plant species interplanted in a cacao based fruit and timber species system are presented in Figure 1A. *T. ivorensis* and *T. superba,* recommended timber species for shade in cacao plantations in Ghana and used as a control, grew taller than all the other shade species with an average of 17 ± 6.5 m. *R. heudelotii* also developed wider (96 ± 5.0 cm, species mean across T1, T2 and T3) stem than all the interplanted species Figure 1B. *A. parviflora* was the slowest growing in both stem girth (24 cm) and tree height (3.2 m species mean for T1, T2 and T3). Most stands of *A. parviflora* did not functionally constitute overhead shade for cacao at this stage as average tree height of 3.2 ± 1.1 m and 4.8 ± 1.4 m for *A. parviflora* and *T. cacao*, respectively, meant that cacao trees were generally taller.

Soil nutrients and physical properties

Shade tree composition and density made no significant ($p>0.05$) impact on soil pH, OM, Total N, available P, K, Mg and Ca sampled in April 2016 (Table 1). A sharp decline in N content (ranging from 45 to 53%) across treatments is observed from 2015 to 2016 (Table 1). There was a significant treatment difference in K in 2015 when the highest value of T1 was recorded in the range of 4.56 – 50 Cmolkg^{-1}. This may have contributed to relative improvement in pH value in 2016 even though there were no significant ($p>0.05$) treatment differences (Table 1).

The shade tree density did not significantly ($p>0.05$) impact soil bulk density and no significant change had occurred between 2008 and March 2017. The least density increment of 0.12 gcm^{-3} occurred in T3 and the highest of 0.27 gcm^{-3} was recorded in T4 (Table 2).

Biomass and carbon

Both cacao and shade tree species biomass influenced by composition and density, contributed to treatment differences in carbon stock for the eight-year old cacao-based farm system with. Cacao trees shaded with *T. ivorensis and T. superba* (T4, control) amassed 4-fold (12.35 tons ha^{-1}) of above ground biomass of T1 (2.27 tons ha^{-1}) (Table 3). The higher biomass advantage of T4 contributed to 73.96 MgCha^{-1} of total carbon stock, the highest in a range of 49.25 - 73.96 MgCha^{-1}. Above ground biomass of cacao trees ranged between 5.65 and 6.38 tons ha^{-1} with significant ($p=0.05$) treatment differences (Table 3). The higher shade tree density in T1 favoured better development of the cacao tree which is well known to be shade tolerant, especially in younger cacao farms where the canopy was yet to close. It was difficult to compare the values of carbon stock recorded in this study due to the fact that the system that was investigated was novel and relatively young. The aboveground carbon value of T4, the control shade species recommended for cacao in Ghana however compared favourably with reported aboveground carbon values of 18, 19 and 14 MgCha^{-1} for 8-year old Cacao-*Albizia*, Cacao/*Milicia* and Cacao/*Newbouldia* systems respectively as reported by Isaac *et al.* (2007), cited by Somarriba *et al.* (2013).

Considering an annual rate of 3.6, the carbon values obtained in T4 are comparable with 54 MgCha^{-1} reported by Isaac *et al.* (2005) cited by Somarriba *et al.* (2013) for 15-year old multilayer shaded cacao system in Sefwi Wiawso, Ghana. This study's mean soil carbon stock of 48.0 MgCha^{-1} was within the range of 38 -50 MgCha^{-1} reported for 0-30 cm soil layer (Edwin and Masters, 2005). The higher levels of soil carbon stock recorded for first ten years of establishment of cacao farm system are mainly explained by higher OM deposit from cleared vegetation.

Leaf area and cacao bean yield

LAI and percent groundcover (GRC) had strong positive correlation ($r=0.85$) but these did not correlate ($r=0.24$) with cumulative dry cacao bean yield (Table 3). This is attributed to the fact that LAI was estimated for both cacao and shade trees and the captured leave area would not necessarily impact cacao bean yield alone. The LAI values ranging from 0.53 - 0.78 and the GRC which ranged from 0.28- 42% were indicative of abundant space for growth before canopy close after which there would be competition for space in the interplanted system.

No significant ($p>0.05$) treatment differences were recorded for dry cacao bean yield of three consecutive crop seasons corresponding to 54, 66 and 78 months after transplanting cacao (Table 4). Relative higher coefficient of variation usually associated with yield in young cacao farms planted with seedlings gradually reduced with years after transplanting. Crop year mean dry cacao bean yield for 2015/16 was relatively higher than those of previous crop years 2014/15 and 2015/16 (241 kgha^{-1} and 312 kgha^{-1}, respectively) (Table 4). The highest crop year mean cacao bean yield of this study (775 kgha^{-1}) was relatively higher than 500 ±107 kgha^{-1}y^{-1} average yield for hybrid cacao in Ghana as reported by Edwin and Masters (2005). This may be attributed to favourable local environment.

Only two shade species (*P. americana* and *T. tetraptera*) have started fruiting so far. The shade tree's characteristics point to mixed varieties except *A. parviflora* that has reasonable uniformity.

Available data show that integrating *A. parviflora, R. heudelotii, P. americana* and *T. tetraptera* into cacao agro forestry system as an alternative system to the purely timber species shaded cacao system is feasible. Arguments to the effect that it is possible to design cacao and shade tree systems to obtain good yields as well as reasonable carbon sequestration (Somarriba *et al*., 2013) appears to be plausible from initial cacao yields and carbon stock obtained in the relatively young cacao tree system of this study. It is however predicted based on a sharp decline of N levels from year 2015 to 2016, that the proposed system, even before the best shade tree density is determined over time, would be highly soil nutrient extractive owing to the fruit bearing nature of the five species in the system. Organic means of nutrient replenishment for the system should be discussed as proposed by Scialabba and Mu¨ller-Lindenlauf (2010) to preempt excessive dependence on inorganic fertilizer.

Conclusion

Consistent records showing no significant differences in dry cacao beans yield among the treatments is a pointer to an acceptable performance of the proposed novel shade system as an alternative to the traditional timber species shade system for cacao.

The studied farm system is quite young. Further data collection is required, especially of fruits from the shade species, to ascertain the true potentials of the experimented system.

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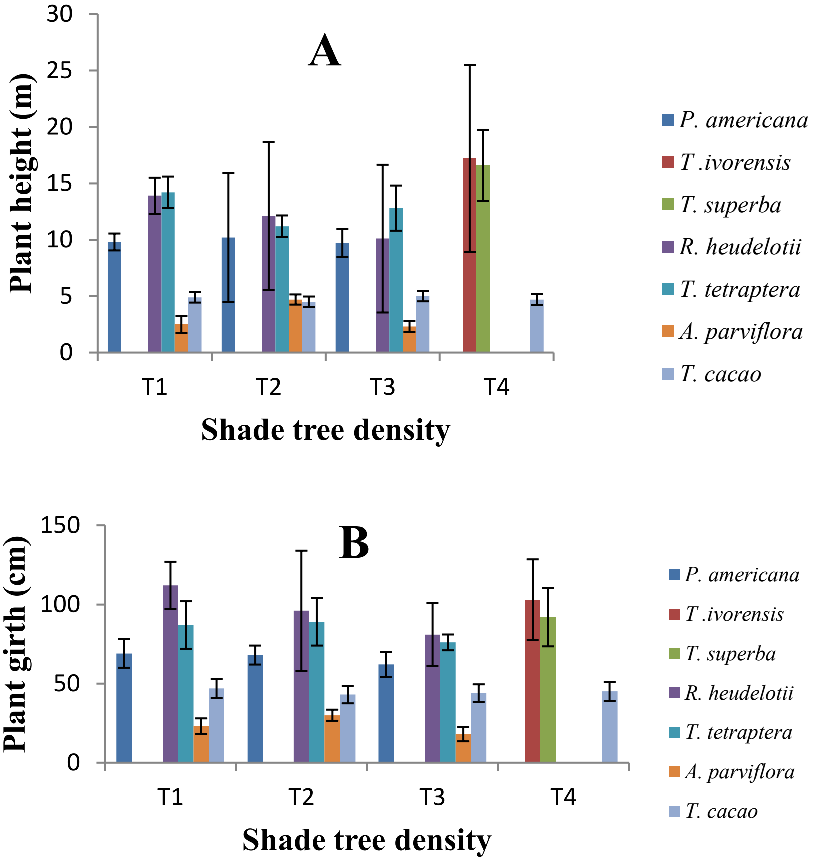

Figure 1: Height (A) and girth (B) statistics of 78 months old shade trees interplanted with cacao (66 months) at different spacing at Afosu, Ghana.

T1: Two each of *A. parviflora*, *R. heudelotii*, *P. americana* and *T. tetraptera* integrated into cacao at plant density of 92 trees.ha^{-1} T2: Two each of same species of T1 at 69 trees.ha^{-1}, T3: Two each of same species of T1 at 44 trees.ha^{-1}, T4: *T. ivorensis and T. superba* at 37 trees.ha^{-1}

Table 1. Effect of spacing and shade tree species composition on some soil (0-30 cm) properties 54 and 66 months after transplanting at Afosu, Ghana. Transplanting was done in 2008.

Treatments	pH		OM		Total N (%)		Av P (ngkg^{-1})		K (Cmolkg^{-1})		Mg (Cmolkg^{-1})		Ca (Cmolkg^{-1})	
Shade tree density	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
T1	5.00	5.42	--	0.329	0.140	0.074	9.31	12.43	0.645	0.267	0.37	1.28	1.87	3.33
T2	4.83	4.79	--	0.296	0.137	0.064	9.24	11.62	0.666	0.257	0.49	0.44	1.97	1.36
T3	4.56	5.18	--	0.287	0.138	0.062	7.64	11.44	0.685	0.262	0.33	0.79	1.89	1.73
T4	4.66	4.94	--	0.324	0.159	0.077	9.17	11.84	0.742	0.271	0.43	0.66	1.82	2.31
Soil depth (cm)														
sd (0-15)	4.91	5.14	--	0.422	0.170	0.099	11.29	16.42	0.716	1.060	0.53	1.06	2.52	2.85
sd (15-30)	4.62	5.03	--	0.196	0.117	0.040	6.38	7.24	0.653	0.503	0.28	0.53	1.26	1.52
p-value (std)	0.083	0.194	--	0.542	0.079	0.145	0.668	0.928	0.006	0.841	0.330	0.343	0.992	0.055
p-value (sd)	0.026	0.631	--	<.001	<.001	<.001	<.001	<.001	0.002	0.002	0.002	0.125	0.002	0.014
SE (std)	0.121	0.211	--	0.024	0.0063	0.0053	1.101	1.111	0.018	0.0117	0.067	0.328	0.350	0.499
SE (sd)	0.085	0.15	--	0.017	0.0044	0.0037	0.779	0.785	0.013	0.0082	0.048	0.232	0.247	0.353

Std: signify shade tree density; sd: soil depth, T1: Two each of *A. parviflora*, *R. heudelotii*, *P. americana* and *T. tetraptera* integrated into cacao at plant density of 92 trees.ha^{-1} T2: Two each of same species of T1 at 69 trees.ha^{-1}, T3: Two each of same species of T1 at 44 trees.ha^{-1}, T4: *T. ivorensis and T. superba* at 37 trees.ha^{-1}

Table 2. Effect of spacing and shade tree species composition on soil bulk density 78 months after transplanting at Afosu, Ghana.

Shade tree density	Initial (2008)			2017		
	0-15	15-30	total	0-15	15-30	total
T 1	1.73	1.42	1.57	1.58	1.98	1.78
T 2	1.44	1.62	1.53	1.62	1.85	1.73
T 3	1.86	1.51	1.68	1.78	1.81	1.80
T 4	1.63	1.60	1.61	1.82	1.95	1.88
F-Test	ns	ns	ns	ns	ns	ns
SE	0.06	0.06	0.08	0.05	0.05	0.07

ns: F-test $_{(0.05)}$ not significant, T1: Two each of *A. parviflora*, *R. heudelotii*, *P. americana* and *T. tetraptera* integrated into cacao at plant density of 92 trees.ha^{-1} T2: Two each of same species of T1 at 69 trees.ha^{-1}, T3: Two each of same species of T1 at 44 trees.ha^{-1}, T4: *T. ivorensis and T. superba* at 37 trees.ha^{-1}

Table 3. Effect of spacing and shade tree species composition on tree biomass and carbon stocks 78 months after transplanting at Afosu, Ghana.

	Shade tree			Cacao tree			Soil C	Total C
Shade tree density	AGSTB	AGSTC	STRC	AGCTB	AGCTC	CTRC		
T1	2.72	1.36	0.44	12.75	6.376	1.465	46.3	55.94
T2	0.80	0.4	0.15	11.30	5.651	1.312	45.2	52.71
T3	0.18	0.09	0.04	12.06	6.029	1.393	41.7	49.25
T4	12.35	6.17	1.71	11.82	5.911	1.367	58.8	73.96
p-value	0.006	0.006	0.004	0.018	0.018	0.018	0.056	
SE	0.039	0.091	0.024	0.464	0.164	0.344	4.32	

AGSTB: Above ground shade tree biomass (tons.ha^{-1}), AGSTC: Aboveground shade tree carbon (MgCha^{-1}), AGCTB Aboveground cacao tree biomass, AGCTC: Aboveground cacao tree carbon, STRC: Shade tree root carbon, CTRC: Cacao tree root carbon, T1: Two each of *A. parviflora*, *R. heudelotii*, *P. americana* and *T. tetraptera* integrated into cacao at plant density of 92 trees.ha^{-1} T2: Two each of same species of T1 at 69 trees.ha^{-1}, T3: Two each of same species of T1 at 44 trees.ha^{-1}, T4: *T. ivorensis and T. superba* at 37 trees.ha^{-1}.

Table 4. Effect of spacing and shade tree species composition on dry cacao bean yield, LAI and percent groundcover 78 months after transplanting at Afosu, Ghana.

	Dry cacao bean yield (tons.ha^{-1})				LAI	GRC(%)
Shade density	2014/15 (54 MAT)	2015/16 (66 MAT)	2016/17 (78 MAT)	Cum		
T1	369.0	255.0	919.0	1543	0.72	0.40
T2	303.0	206.0	715.0	1224	0.53	0.28
T3	325.0	249.0	632.0	1206	0.78	0.42
T4	251.0	254.0	834.0	1326	0.70	0.31
Mean	312.0	241.0	775.0	1325	0.68	0.35
p-value	0.792	0.891	0.41	--	0.008	<.001
SE	82.9	52.4	122.9	--	0.052	0.026

MAT: Months after transplanting, Cum: Three years cumulative yield, LAI: Leaf area index, GRC: Ground cover. T1: Two each of *A. parviflora*, *R. heudelotii*, *P. americana* and *T. tetraptera* integrated into cacao at plant density of 92 trees.ha^{-1} T2: Two each of same species of T1 at 69 trees.ha^{-1}, T3: Two each of same species of T1 at 44 trees.ha^{-1}, T4: *T. ivorensis and T. superba* at 37 trees.ha^{-1}