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Growth Performance, Undergrowth Diversity and Carbon Sequestration Potentials of Tree Species Stand Combinations, Ghana

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Abstract

The limited number of studies on mixed plantations makes it difficult to accurately predict success of mixed-species combination especially with regards to growth, undergrowth diversity and carbon sequestration potentials. This study therefore provides information on the effects of *Ceiba pentandra*, *Terminalia superba*, *Cedrela odorata* and *Khaya anthotheca* in three different stand combinations on growth, undergrowth diversity and carbon sequestration potential. A 15-year-old coupe of 32 ha of mixed tree species stand combinations was selected for the study. The coupe was stratified based on the species combinations. Nested sub-plots (25 m × 25 m) were randomly laid in different species stand combinations for growth data collection. In each nested sub-plot, 1 m × 1 m plots were also randomly laid for undergrowth diversity study. The results revealed that two species stand combination of *Ceiba pentandra* and *Terminalia superba* performed better in terms of growth, carbon sequestration and carbon content as compared to the other species stand combinations. The saplings on the other hand, were more diverse under the three species stand combination plots. Also, the effective number of species, species richness, evenness, and dominance were higher in the four species stand combination plots. Generally, *Ceiba pentandra* and *Terminalia superba* are compatible as it produced the highest growth and carbon sequestration potential.

Keywords

Species Combination, Growth, Floristic Composition, Carbon Content, Saplings

1. Introduction

Forests play an important role in the advancement of a nation. Aside from their contribution to national GDP, they assume an extremely key role in the livelihood of the populace who depend directly or indirectly on it for their survival (Angelsen et al., 2014). Forests are the most fundamental natural and financial assets that help the prosperity of human social needs. Food, nutrition, income, energy and shelter are the benefits rural people in developing countries derived directly and indirectly from forests (Jamnadass et al., 2011).

Forests also provide non-timber forest products (NTFPs) which make up 0.6% of all nourishment globally (FAO, 2014). Forest provides fuelwood as the main energy option for 2.4 billion individuals for cooking and 750 million individuals who boil water to diminish the dangers of water-borne diseases (FAO, 2014). The forest sector formally employs approximately 13.2 million individuals whereas 41 million people are informally engaged in the sector and create basic earnings to enable access to food (World Bank, 2016).

Despite its importance, forest cover has been declining over the years (FAO, 2015). Studies have established that the most ideal approach to recover lost forest is through the establishment of plantations either as pure or mixed stands. However, there have been debates among researchers on the best combinations of tree species and their impact on saplings and undergrowth diversity. Likewise, undergrowth diversity of plantations has been a subject of much discussion particularly for quick growing plantations (Tang et al., 2007). A study by Montagnini et al. (1995) revealed that mixed-species plantations create more biomass per unit zone since competition among individuals is lessened and the site is utilized optimally.

Parrotta & Knowles (1999) additionally expressed that for indigenous species, mixed plantation appears to be the most appropriate for providing a more extensive scope of choices, for example, production, protection, biodiversity protection, and restoration of degraded areas (Piotto, 2008). Likewise, various studies have recorded an extensive variety of native forest plants and animals in mixed plantation (Barbaro et al., 2005; Carnus et al., 2006). According to Carnevale & Montagnini (2002), the biodiversity of the mixed plantation is more prominent than that of the pure plantation.

The drive for the establishment of a mixed plantation can be ascribed to its marketing opportunities, biodiversity protection or tolerant to diseases and pest (Vanclay, 2006).

Forrester et al. (2006) stated that there is a lack of adequate information on mixed plantations which makes precise prediction of their growth dynamics, undergrowth diversity and their carbon sequestration potentials very difficult. Also, limited studies exist on species combination of native plant species in mixed plantations and their impacts on undergrowth diversity as well as their carbon sequestration potentials. Mixed plantations findings have been reported without regard to the species combinations. Some species could have allelopathic properties which could be detrimental in mixed plantations. Therefore, it is necessary to contribute to the debate by examining the growth performance of different species stand combinations of *Ceiba pentandra* (Ceiba) and *Terminalia* *superba* (Ofram), *Ceiba pentandra* (Ceiba), *Terminalia superba* (Ofram) and *Cedrela odorata* (*Cedrela*), *Ceiba pentandra* (Ceiba), *Terminalia superba* (Ofram), *Khaya anthotheca* (Mahogany) and *Cedrella odorata* (*Cedrella*) in different mixed forest stands at the Ayum Forest Project Limited's plantation in Amama Forest Reserve of the Sunyani Forest District. These species are the most commonly used in mixed plantations in Ghana. Information on how these species perform in mixed planation is vital for the industry.

2. Materials and Methods

Description of the study area

The study was carried out in the Amama Forest Reserve in the Sunyani Forest District, Brong Ahafo Region. The area is located about 12 km southwest of Sunyani and approximately between latitude 7˚00'N and 7˚15'N and longitude 2˚05'W and 2˚30'W. It covers an area of 44 km^2 (**Figure 1**). Ecologically, the reserve forms part of the north-western block of the moist semi-deciduous forest zone of Ghana (Hall & Swaine, 1981; Hawthorne & Abu-Juam, 1993).

Experimental plot layout

The study was conducted in a 32 ha (coupe 2003) with different species combination of *Ceiba pentandra* and *Terminalia superba* (Treatment 1), *Ceiba pentandra*, *Terminalia superba* and *Cedrella odorata*, (Treatment 2), Ceiba *pentandra*, *Terminalia superba*, *Khaya anthotheca* and *Cedrella odorata* (Treatment 3) in the Ayum Forest Project Limited's plantation in Amama Forest Reserve of the Sunyani Forest District. The coupe was stratified based on the species combinations.

Each stratum was further divided into nested sub plots of 25 m × 25 m plots, from which three plots were randomly selected for growth assessment. In each nested sub plot of 25 m × 25 m plot, a 1 m × 1 m square quadrat was laid

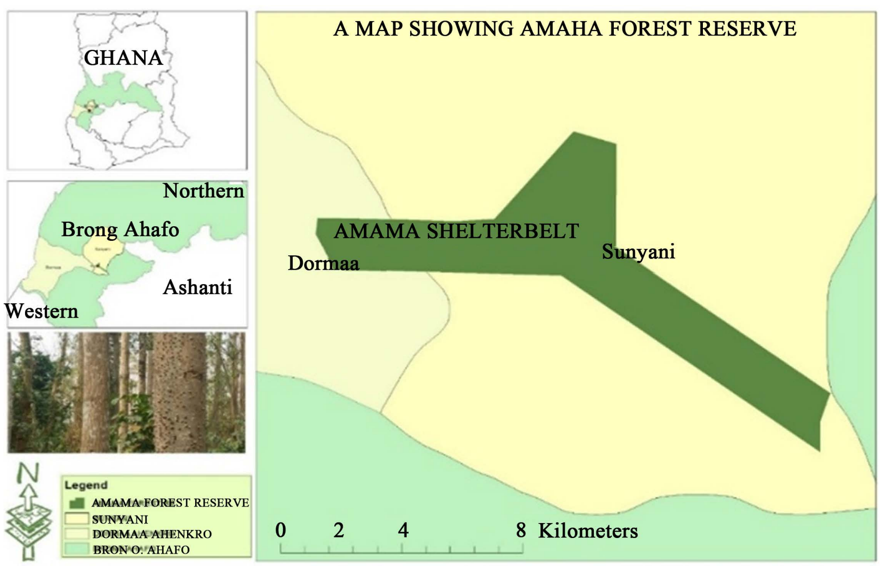

Figure 1. Location of the Amama Forest Reserve, study area.

randomly for undergrowth diversity assessment. This procedure was repeated for the various tree species combinations (Figure 2).

Data collection

In each 25 m × 25 m plot, all the trees species >10 cm diameter were measured and enumerated. Data was collected on diameter at breast height (*dbh*), and total height. In each 1 m × 1 m quadrat undergrowth identification and enumeration for diversity assessment was done. All saplings within each plot were also measured and enumerated.

Growth performance of the different species stand combinations

Height (m) of each tree (above ground level) was measured using measuring rod. Other parameters such as volume, survival percentage, stand density, mean annual increments and the basal area were estimated using the following formulae:

$$\text{Tree Volume} = a \times Bdbh \times H \quad (1)$$

where,

a is the stem form factor.

$Bdbh$ is the diameter at breast height.

H is the total height.

The value of "a" was set to 0.5 (Ugalde, 2000).

Stand density, survival rate and the basal area were estimated as reported by Nkyi (2007)

$$\text{The basal area} \left(\text{m}^2/\text{ha}\right) = 0.00007854 \times dbh^2 . \quad (2)$$

0.00007854 is a constant,

$$\text{Stand Density} = \frac{\text{Number of trees in a plot}}{\text{The area of Plot}} \times 10000\ \text{m}^2 \quad (3)$$

$$\text{Survial\%} = \frac{\text{Number of trees survived}}{\text{Total number of trees planted}} \times 100 . \quad (4)$$

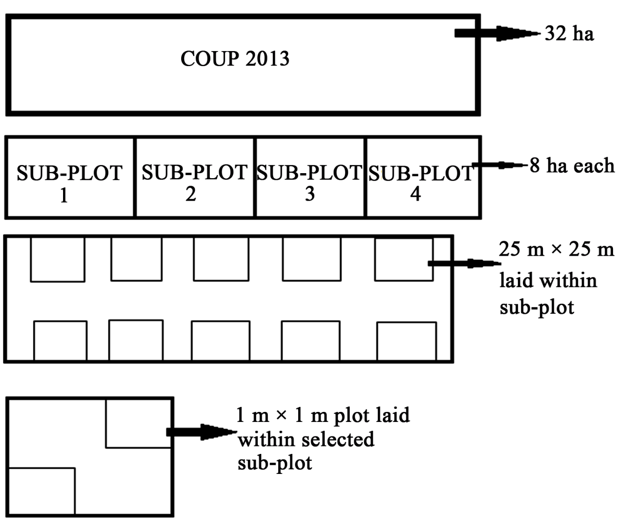

Figure 2. Design for the selection of coupe, sample and sub plots.

Understory floristic composition and diversity of the mixed species stand combinations.

Within the 25 m × 25 m plot, trees < 10 cm diameter (saplings) were enumerated and species composition assessed to determine the sapling diversity in each of the plots. The saplings and undergrowth plant species collected were sent to the Forest Research Institute of Ghana (FORIG) for identification. Also, the field guide (classification catalogue) was used to identify plant species in-situ. The diameter of all identified trees was measured over-bark at breast height (1.3 m) with a girth tape and height (m) measured with a measuring rod.

The Shannon Wiener's diversity index (*H*) was used as a measure of diversity. This index takes both species abundance and species richness into consideration (Heusèrr, 1998) and is the most commonly used index (Kent & Coker, 1996). The Shannon Wiener's diversity index (*H*) was calculated using the formula:

$$H' = -\Sigma\left(pi \ln pi\right) \tag{5}$$

where, *pi* is the proportion of individuals found in species *i*. For a well-sampled community, we can estimate this proportion as *pi* = *ni*/*N*, where *ni* is the number of individuals in species *i* and *N* is the total number of individuals in the community.

The Simpson's index of dominance was measured and calculated using the formula:

$$D = \frac{\Sigma n\left(n-1\right)}{N\left(N-1\right)} \tag{6}$$

where; *n* = the total number of organisms of a particular species, *N* = the total number of organisms of all species.

Simpson's Index of Diversity = 1 − *D*.

The coefficient of similarity of Sorensen (*K*) was determined by the formula:

$$K = \frac{2c}{a+b} \times 100 \tag{7}$$

where, *a* = number of species of the statement 1, *b* = number of species of the statement 2, *c* = number of species common to the two statements (Ngueguim et al., 2010).

Carbon sequestration potentials of the various mixed species stand combination

The biomass estimation method was used to calculate the per unit amount of carbon sequestered. The above-ground biomass (AGB) of trees was measured by the regression equation of biomass as a function of diameter at breast height (Brown et al., 1989).

$$\text{AGB} = \exp\left\{-2.4090 + 0.9522 \ln\left(D^2 HS\right)\right\} \tag{8}$$

where: AGB is the above-ground biomass in average dry matter per hectare.

H is the height of the trees in meters (average height);

D is the diameter at breast height (1.3 in cm);

S is the wood density per hectare.

For calculating the below ground biomass (BGB), the allometric equation developed by Kuyah et al. (2012) was used:

$$\text{BGB}_{\text{est}} = 0.048 \times (dbh)^{2.303}. \quad (9)$$

The carbon content of each tree in the plots was calculated by multiplying the modelled dry weight biomass by 0.5 (IPCC, 2006).

$$\text{Biomass carbon content} = \text{Biomass weight}(\text{tdm/ha}) * 0.5\ \text{tC/tdm} \quad (10)$$

where: tC stands for tons of carbon and tdm for tons of dry matter.

The carbon dioxide equivalent (CO_2) was estimated by multiplying the carbon stock by 3.67 (Kauffman & Donato, 2012).

The monetary value of carbon sequestered by the various stand combinations is calculated as:

1 tonne of carbon = $10 (USD).

Data analysis

The one-way Analysis of Variance (ANOVA) was performed to test the differences in the growth parameters between the various species combinations.

The diversity of understory species in the forest plantation stands were determined using the Shannon-Wiener species diversity index, Simpson index of dominance and the effective number of species (Blanc et al., 2000; Parthasarathy, 2001; Krebs, 2001; Addo-Fordjour et al., 2009).

3. Results

Survival percentage of tree species

The findings of the study indicate a high survival percentage of 81.5% and 61.7% for *Terminalia superba* and *Ceiba pentandra* respectively in the two species stand combination compared to three species stand combination in which *Terminalia superba* and *Ceiba pentandra* survival percentage were 55.6% and 35.2%. In the four species stand combination the percentage survival for *Terminalia superba* and *Ceiba pentandra* were 44.4% and 51.9% respectively (**Figure 3**).

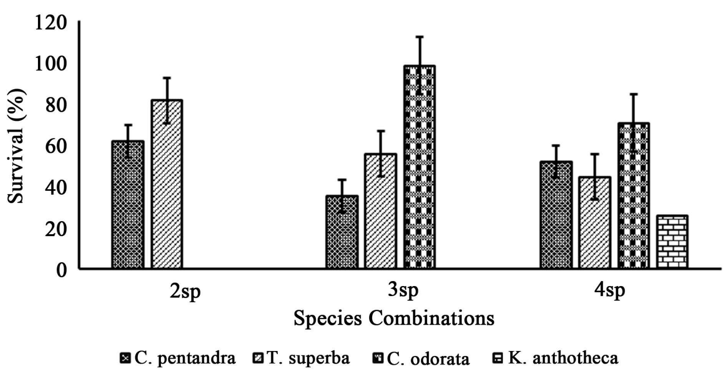

Figure 3. Survival percentage of the individual Species in the various species combinations.

The lowest survival percentage for *Terminalia superba* and *Ceiba pentandra* was recorded in the three species combinations ($p < 0.05$). *C. odorata* in three species combination of *C. pentandra*, *T. superba* and *C. odorata*, recorded the highest survival percentage 98.1% as compared to 70.4% survival percentage in four species stand combination for *C. odorata*, *K. anthotheca*, *C. pentandra and T. superba* (Figure 3).

Stand density of species

The average stand density for two species combination was highest, whilst four species combination was lowest (Figure 4).

Within the two species combination, *T. superba* recorded the highest stand density of 352 trees/ha as compared to *C. pentandra* of 267 trees/ha. Also, in the three species combination *C. odorata*, *T. superba and C. pentandra*, *the C. odorata* had the highest stand density of 283 trees/ha but this reduced to 203. trees/ha in four species combination of *C. odorata*, *T. superba*, *C. pentandra*, *and K. anthotheca* (Figure 4).

Generally, stand density was highest in the two species combination and was significantly different from the three and four species combinations.

Volume of tree species

The highest average volume (242.8 m^3/ha) was obtained from *Ceiba pentandra* in the two species combination. The volume of *Ceiba pentandra* volume was 208.9 m^3/ha in the four species combinations and 201.0 m^3/ha in three species combination (Figure 5).

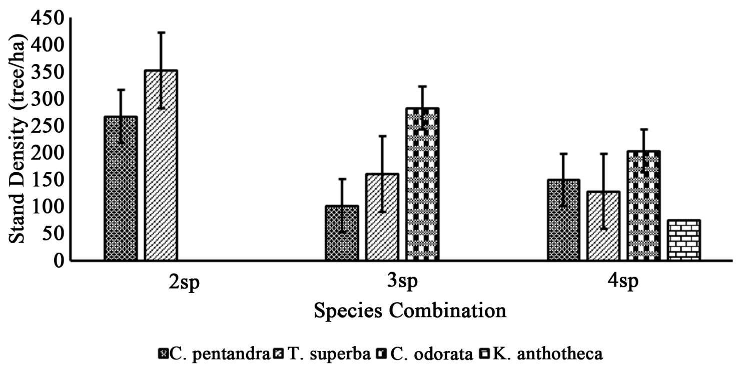

Figure 4. Stand density of the various species stand combinations.

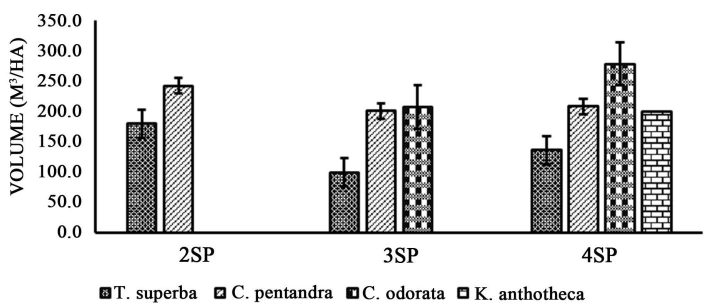

Figure 5. Mean volume of the individual species in the various species stand combinations.

Similarly, the volume of *Terminalia superba* volume was highest (180.5 m^3/ha) in the two species combination and was significantly different from *Terminalia superba* in the three and four species combinations. Further, the results showed that *Cedrela odorata* in the four species combination had higher average volume of 279.1 m^3/ha which was significantly different from *Cedrela odorata* in the three species combination ($p < 0.05$) (**Figure 5**).

Mean Diameter of species

The mean diameter of *Terminalia superba* was generally higher in two species combination 25.0 cm than *Terminalia superba* in three species combination which was 19.0 cm and four species combination of 19 cm (**Figure 6**).

Generally, the mean diameter of *Ceiba pentandra* recorded in the two species combination had the highest diameter of 32 cm. The diameter of *Ceiba pentandra* in the three and four species combinations was 29.4 cm and 29.3 cm respectively. On the other hand, *Cedrela odorata* recorded 39.3 cm in the four species combination against 30.4 cm in the three species combination but showed no significant difference in their mean diameter ($p < 0.05$) (**Figure 6**).

Mean Height

The mean height of Ceiba pentandra in two species combination was 16.0 m followed by three species combination of 13.6 m and four species combination of 13.1 m.

The highest mean height of *Terminalia superba* was 14.5 m in two species combination compared to 13.8 m in three species combination and 13.8 m in four species combination (**Figure 7**). Cedrela odorata grew better in four species combination with mean height of 14.7 m compared to 13.6 m estimated in three species combination (**Figure 7**).

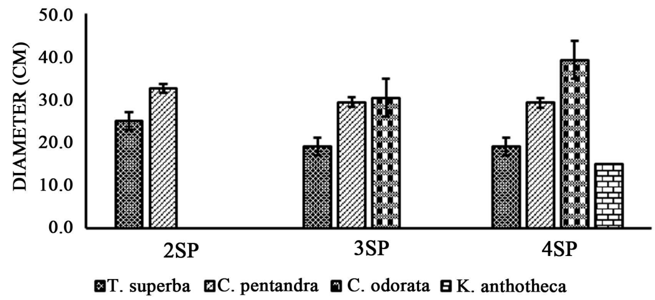

Figure 6. Mean diameter of the individual species of the various species combinations.

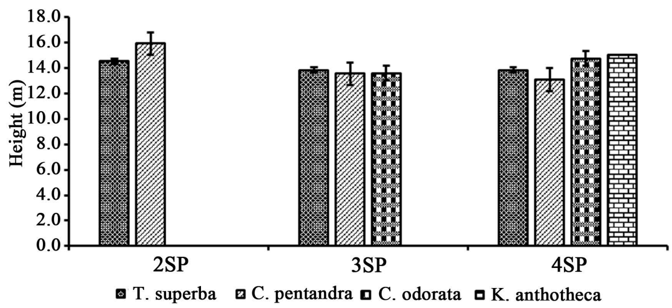

Figure 7. Mean height of the individual species of the various species combinations.

Saplings Families Diversity

The total count of saplings by families in the various species combinations were 73, 133 and 77 for two, three and four species combinations respectively. Two species combination had saplings belonging to 11 different families, three species combination had saplings belonging to 12 different families and four species combination had 7 families in the identified saplings. *Fabaceae* was the most abundant family in the various species combinations which were 41.10%, 53.3% and 50.6% in two, three and four species combinations respectively. It was followed by *Sterculiaceae*, *Apocynaceae*, *Bignoniaceae*, *Combretaceae*, *Griseliniaceae*, *Malvaceae*, *Meliaceae*, *Pandaceae*, *Rubiaceae*, *Sapindaceae*, and *Urticaceae* families (Table 1).

Coefficient of similarity of Sorensen (K)

The results in Figure 8 indicate that two and three species combinations had the highest coefficient of similarity of Sorensen (*K*) of 48.65%. Three and four species combinations had the least similarity of 45.71% and 47.06% respectively.

Shannon Weiner Diversity Index

In Figure 9, diversity index was high in the four species combination followed by two species combination and least in three species combination.

Effective Number of Species

The effective number of species in four species combination was highest and lowest in two species combination (Figure 10).

Simpsons Diversity Index

Table 1. Saplings families diversity under the various species combinations.

COUNT OF FAMILY	2 SPECIES	3 SPECIES	4 SPECIES
Apocynaceae	4	4	14
Bignoniaceae	0	0	1
Bombacaceae	0	1	0
Combretaceae	3	1	0
Euphorbiaceae	8	0	0
Fabaceae	30	71	39
Griseliniaceae	11	0	0
Malvaceae	0	8	1
Meliaceae	9	8	4
Moraceae	6	8	4
Pandaceae	5	1	0
Rubiaceae	0	0	1
Sapindaceae	9	15	3
Sterculiaceae	2	1	8
Urticaceae	0	0	1
Total	**73**	**133**	**77**

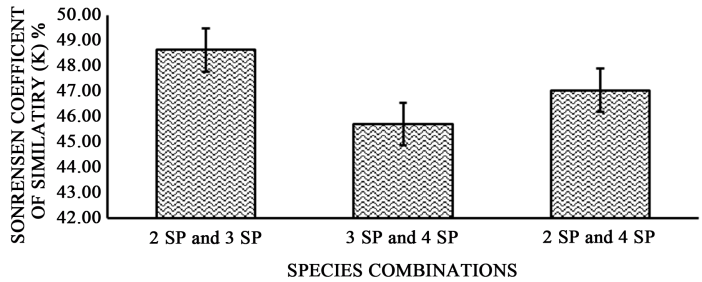

Figure 8. Sorensen coefficient of similarity for the various species.

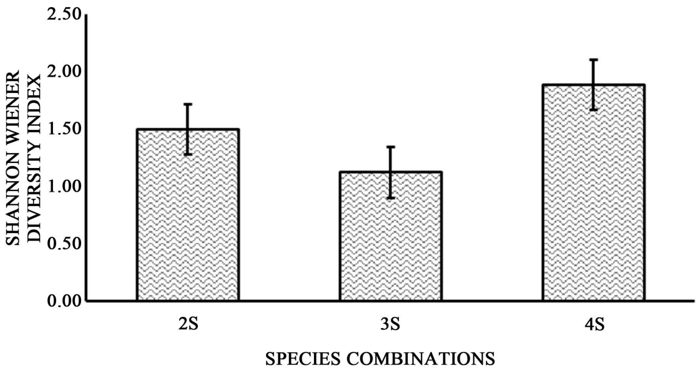

Figure 9. Shannon Weiner diversity index of the various species combinations.

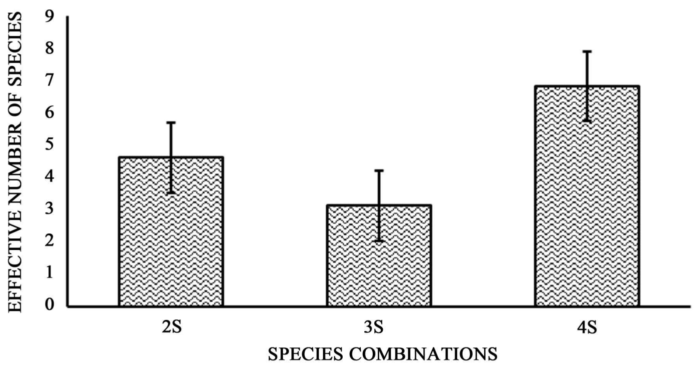

Figure 10. Effective number of species for various species combinations.

Measure of dominance recorded an ascending order from two, three and four species combinations. Four species combination occupied the highest dominance followed by three species combination with two species combination having the least (Figure 11).

Saplings Height and Diameter

Saplings within two species combination had the highest mean height which was significantly different ($p < 0.05$) from the other species combinations. Three species combination had the least mean height but not significantly different ($p < 0.05$) from the four species combination. Two species combination had the highest mean diameter followed by three species combination. Two species combination was not significantly different ($p < 0.05$) from three species combination but different ($p < 0.05$) from four species combination (Table 2).

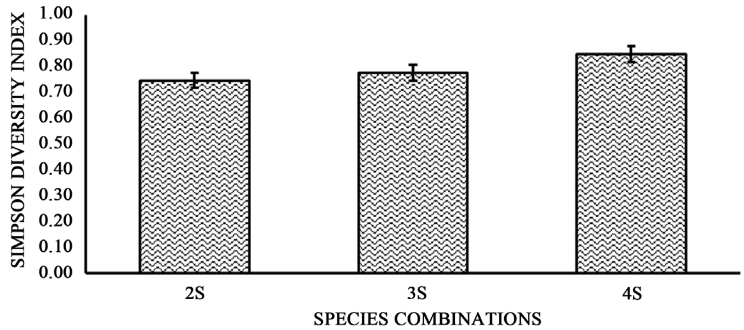

Figure 11. Simpson's diversity for the various species combinations.

Table 2. Species homogeneity for mean height and mean diameter of the species combinations.

Groups	Mean Height (m)	Homogeneous Groups	Mean Diameter (cm)	Homogeneous Groups
2 SPECIES	5.1418	A	6.2386	A
3 SPECIES	3.2492	B	5.1153	AB
4 SPECIES	3.4929	B	3.9145	B

Means along the column with the same letter are not significantly different ($p < 0.05$).

Estimation of Above Ground Biomass (AGB), Below Ground Biomass (BGB), Total Carbon Storage (TCS), Biomass Carbon Content (BCC), Carbon Dioxide (CO_2) and Monetary Values of the various Species combinations

Within two species combination, *Terminalia superba* recorded the highest aboveground biomass of 306.7 t/ha as against 216.1 t/ha for *Ceiba pentandra*. *Ceiba pentandra* recorded the highest belowground biomass (BGB) estimate of 169.1 t/ha within two species combination. It was also higher when compared to three and four species combinations (Table 3).

Cedrela odorata also recorded the highest above and below ground biomass of 465.2 t/ha and 259.0 t/ha respectively in four species and three species combination.

Again, *Terminalia superba* in the two species combination had the highest total carbon storage (TCS), biomass carbon content (BCC), carbon dioxide (CO_2) and monetary value compared to *Ceiba pentandra* within the two species combination. It also recorded the highest compared to three and four species combinations.

Cedrella odorata (*Cedrella*) within four species combination performed well compared to other species in terms of total carbon storage (TCS), biomass carbon content (BCC), carbon dioxide (CO_2) and monetary value (Table 3).

Estimation of Total above Ground Biomass (AGB), Below Ground Biomass (BGB), Total Carbon Storage (TCS), Biomass Carbon Content (BCC), Carbon Dioxide (CO_2) and Monetary Values of the various Species combinations

Generally, the total aboveground biomass of 9846.69 t/ha, total belowground biomass of 5595.48 t/ha, total carbon storage of 15,442.17 t/ha, total CO_2 stock of 28,310.65 t/ha, and monetary value of $214,457.8 t/ha was highest in four species combination followed by two and three species combinations respectively (Table 4). However, the two, three and four species combination were not significantly different ($p < 0.05$).

Table 3. Above Ground Biomass (AGB), Below Ground Biomass (BGB), Total Carbon Storage (TCS), Biomass Carbon Content (BCC), Carbon Dioxide (CO_2) and monetary values of the various species combinations.

	2 Species		3 Species			4 Species			
	C. pentandra	*T. superba*	*C. pentandra*	*T. superba*	*C. odorata*	*C. pentandra*	*T. superba*	*C. odorata*	*K. anthotheca*
AGB (t/ha)	216.1	306.7	68.6	55.3	313.7	105.7	75.2	465.2	32.4
BGB (t/ha)	169.1	111.3	55.5	19.5	153.8	85.1	25.8	259.0	7.9
TCS (t/ha)	385.3	418.0	124.	74.8	467.6	190.8	101.0	724.2	40.3
BCC (t/ha)	192.6	209.0	62.0	37.4	233.8	95.4	50.5	362.1	20.2
CO_2 (t/ha)	706.3	766.4	227.	137.2	857.2	349.9	185.2	1327.7	73.9
Monetary value ($)	7060	7660	2270	1370	8570	3490	1850	13270	730

Table 4. Total above ground biomass, total below-ground biomass, total carbon stock, total CO_2 stock and monetary value of the various species combinations.

Groups	Above Ground Biomass (t/ha)	Below Ground biomass (t/ha)	Total carbon Stock (t/ha)	Total CO_2 Stock (t/ha)	Homogeneous Groups	Amount ($)
2SPECIES	8909.78	4750.95	13,660.73	25,044.67	A	2,504,467
3SPECIES	7293.46	3814.267	11,107.73	20,364.17	A	2,036,417
4SPECIES	9846.69	5595.481	15,442.17	28,310.65	A	2,831,065

Means along the column with the same letter are not significantly different ($p < 0.05$).

4. Discussion

Growth performance and productivity of the various species combinations

The differences in growth parameters of the tree species in plantation such as height, diameter, basal area and volume could be ascribed to species morphological and physiological differences, genetic adaptations as well as the physical environment (Oliver and Larson, 1990). Tree species make use of available space, soil resources and environmental factors to grow. Therefore, mixed plantations with large gaps or spaces create less competition between species. The performance of *Ceiba pentandra* and *Terminalia superba* points to their compatibility. Their morphological and genetic adaptation are good in mixed plantation.

Generally, growth performance with respect to average diameter, average height, average basal area, average volume, for *Terminalia superba* in two species combination was higher compared to other species combinations. This is because *Terminalia superba* is a fast-growing species compared to *Khaya antho-*

theca and Cedrela odorata which are pioneer species (Hawthorne & Abu-Juam, 1993; Orwa et al., 2009). Consequently, competitions amongst them in mixed stands for growth resources have the potential to lessen the growth of the other species (Petit & Montagnini, 2006). The result of this study shows a declining trend in productivity of *Terminalia superba* as the species combination increases. Thus, the greater the inter-specific competition between the *T. superba* and other species in mixed combinations, the lesser their productivity (Forrester et al., 2004).

Also, the *Ceiba pendandra* recorded the highest in all the growth parameters. This is because less inter-specific competition between *Ceiba pendandra* and *Terminalia superba*. *Ceiba pendandra* growth reduced as the component trees increases in the various species combinations.

Tree species competition for growth resources (both soil and environmental resources) in mixed plantations is a key factor that determines the growth and productivity of species. Many of these factors accounted for differences observed in the study in relation to their stand density, survival rate, height, diameter and volume. The interrelation of trees species in which one species exerts a negative effect on growth or mortality of the other explains competition (Furuta & Aloo, 2009; Boyden et al., 2008).

Khaya anthotheca is a light-demanding species which need good amount of sunlight radiations to grow well, therefore the inter-specific competition between *Khaya anthotheca* and other species for particularly light and other growth resources may have reduced its growth performance accounting for its poor performance in the four species combination (Potvin & Dutielleul, 2009; Petit & Montagnini, 2006).

Likewise, increase structure and biological resemblances of *Khaya anthotheca* and other tree species could intensify competition between these species which caused a reduction in growth and productivity of *K. anthotheca* in the mixed plantation (Boyden et al., 2008). Opoku (2012) affirms that *Khaya anthotheca* might not do well when it is planted in combinations with fast growing species. Its interaction with *Ceiba pentandra*, a fast-growing species was detrimental to its growth.

According to Oliver & Larson (1996), when species lack competitive vigour they slow their growth performance. Orwa et al. (2009) indicated that *Cedrela odorata* has the ability to displace indigenous plants by blocking out sunlight with its leaves. The gaps created by the *Khaya anthotheca* as a result of poor survival percentage and stand density generated less competition between the species. The study agrees with Lamprecht (1989) who observed that tree species make use of available space, soil resources and environmental factors to grow. Nketia (2002), emphasized that the correct spacing of trees in plantations affects the total output in growth parameters such as tree diameter, tree height, basal area and volume.

One of the major traits of *Khaya spp.* in the mixed plantation is the attack by *Hypsipyla robusta*, shoot borers, that kill the main stem of young trees and cause extreme branching which contributes to mortality (Opuni-Frimpong, 2008).

Therefore, the incident of *Hypsipyla robusta*, may have accounted for the low survival percentage recorded by *Khaya anthotheca.*

According to Orwa et al. (2009), fast-growing species like *Cedrela odorata* faces less competition in mixed plantations and therefore utilized the available environmental factors and resources to grow. Less competition for resources in the four species combination as results of low survival percentages of *Khaya anthotheca* might have led to the good performance of *Cedrela odorata.* For better productivity and improvement in growth of mixed species, the required resources for growth should be supplied whiles decreasing competition among species (Piotto, 2008; Forrester et al., 2006).

Floristic Composition and Diversity Assessment

Forest floristic diversity and structure composition is an instrument for sustainability of forests because they contribute to the conservation of plant species and the treatment of forest ecosystems as a whole (Tilman, 1988; Ssegawa & Nkuutu, 2006).

Fabaceae was the most abundant family in the plots making up 41.10%, 53.38% and 50.65% in two, three and four species combinations. This is because *Baphia nitida* species was the most abundant in all the plots. This may signify their broader variety of ecological adaptation. Results by Senbeta et al. (2005); Addo-Fordjour et al. (2008), follow the same trend where ten tree species, three lianas and two shrubs were identified in all the three forest blocks.

Apocynaceae, *Bignoniaceae*, *Combretaceae*, *Griseliniaceae*, *Malvaceae*, *Meliaceae*, *Pandaceae*, *Rubiaceae*, *Sapindaceae*, *Sterculiaceae and Urticaceae* were the other families identified in the study area. Asase & Oteng-Yeboah (2007) and Asase et al. (2009) stated that *Leguminosae and Combretaceae* families were the main understory tree families. Lawson (1986) opines that most of these families are among those identified as common in the forest vegetation of West Africa.

The study revealed that *leguminous* trees such as *Baphia nitida*, *Pterocarpus erinaceus*, *Baphia pubescens*, and *Albizia adianthifolia* were high in the study area. The presence of these species in the various species combinations may show their broader range of ecological adaptation (Senbeta et al., 2005; Addo-Fordjour et al., 2008).

The coefficient of similarity of Sorensen (K) was used to quantify the range of similarity in floristic composition amongst the plots. The similarity of understory species composition between two and three species combinations was 48.65%. This shows that about 51.35% of species between the two plots are different. Three and four species combinations had the Sorenson's coefficient of similarity index value of 45.71%, which showed that 54.29% of species between the two plots are different whiles two and four species combinations had 47.06% percent of the saplings available in both combinations. Krebs (2001) stated that, when the similarity index value between two combination treatments is below 0.5, the two areas are measured as dissimilar in terms of species composition. This study's findings are consistent with that of Akoto et al. (2015) who found species composition amongst *Cedrela odorata* and natural forest to be dissimilar.

The variation in the species composition between the various species combinations could be attributed to changes in environmental conditions and species composition of the various plots. The intensity of sunlight that touched the plantation floor to induce maximum regeneration could have been influenced by canopy closure. The microsites vary as a function of gap size, shape and orientation in relation to the height of neighbouring trees (Canham et al., 1990). The creation of gaps by the mortality of *K. anthotheca* could have affected the diversity in the species combination.

Otsamo (2000) affirmed that when plantation canopy closes, the physical considerations for forest tree seeds germination are controlled and aggressive grasses are shaded out.

Carbon sequestration potentials of the various treatments

Carbon sequestration of *Ceiba pentandra and Terminalia superba* were high in two species combination, followed by four species combination. Similarly, *Ceiba pentandra*, *Milicia excelsa*, *Terminalia superba and Terminalia ivorensis* recorded the highest carbon sequestration per tree in a study (Stanley & Montagnini, 1999; Shepherd & Montagnini, 2001). This phenomenon could be influenced by species wood density and growth pattern (Redondo-Brenes, 2007). On the other hand, *Khaya anthotheca* attained the least carbon as a result of low stand density in four species combination. The outcome of this study supports Redondo-Brenes & Montagnini (2006) findings that quick-growing tree species accumulates high above ground biomass and carbon content.

Cedrela odorata is an exotic and fast-growing species. Carbon sequestration largely depends on the height and tree diameter at breast height. Therefore, the higher the height and diameter, the better the sequestration potential. The study revealed that the highest aboveground biomass for *Cedrela odorata* in three and four species combinations were 313.73 t/ha and 465.21 t/ha respectively. Since aboveground biomass was higher in *Cedrela odorata* than other tree species in three and four species combinations, it may infer that photosynthesis could have been higher in *Cedrela odorata* than the other tree species. Although aboveground respiration was not measured, it could be a huge constituent of complete principal production (Ryan, 1991).

Furthermore, the study showed that the growth performance in terms of survival percentage, trees density, average basal area, average volume, average diameter and the average height of *Cedrela odorata* was higher in two species than three and four species combinations. This affected both above and below ground biomass, overall carbon stock, total CO_2 stock and the monetary value of the *Cedrela odorata*, *Terminalia superba and Khaya anthotheca* species. It reported that the phenology of roots or shoots growth may differ, therefore competition for soil resources will be less compared to the pure stand plantations. This means that the competition for soil resources between *Cedrela odorata*, and other tree species in plantation will be greater.

Values of carbon per hectare for plantations were lower (0.0250 $Mg{\cdot}ha^{-1}$, 0.0203 $Mg{\cdot}ha^{-1}$, 0.0283 $Mg{\cdot}ha^{-1}$) for two, three and four species combinations respectively compared to values obtained by Montagnini & Nair (2004) in the study which focused on the overall above ground carbon content of ten plantation-tree species at La Selva, Costa Rica (i.e. 17.3 to 82 $Mg{\cdot}ha^{-1}$). Also, carbon values per hectare recorded from this study were lower than the values stated for tree plantations in the tropical which range between 8 and 78 Mg C ha^{-1} (Schroeder, 1992). The planting distance from this study allowed a limited number of trees to be selected which influenced carbon stock.

Growth performance was generally better in the two species combination compared to those in the other combinations. The floristic composition and diversity in three species combination recorded the highest families followed by the two species combination and four species combination. The different species combination was largely dissimilar. The study revealed that carbon sequestration was highest in the four species combination compared to three and two species combinations.

5. Conclusion

The integration of two or more species in plantation forestry could be detrimental if the species are not compatible. The choice of tree species which are compatible is vital for plantation forestry. *Terminalia superba* and *Ceiba pentandra* thrived well in mixed plantations. They also promoted plant diversity and enhanced carbon sequestration. Generally, the composition of the mixed plantation is important to enhance its productivity.

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Conflicts of Interest

We the authors declare that there is no conflict of interest regarding the publication of this manuscript.

Data Availability Statement

Data would be made available when requested.

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