

Silvicultural Systems for Restoration of Mahogany in Degraded Landscapes in Africa: Influence of Mixed Rainforest Plantation on Growth and Pest Damage

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Abstract

African mahogany, one of the world's most valuable timber species is threatened by over-exploitation in natural forests and failure of plantations due to attacks by the shoot borer *Hypsipyla robusta*. Mixed-species plantations has been reported to be an effective component of integrated pest management of major pest in other crops; but there is very limited empirical data on its use for managing *Hypsipyla* in mahogany mixed stands in West Africa. The aim of this study was to assess the effect of mixed-species stands as management intervention, on the growth of *Khaya grandifoliola* and *Khaya ivorensis* in relation to *Hypsipyla robusta* attack in a 10 ha experimental plantation in the wet evergreen forest type in Ghana. *Khaya grandifoliola* recorded faster growth than *Khaya ivorensis* in this forest type though the later naturally grow in this forest type while the former is introduced from the dry forest. Two years after planting, diameter and height growth were greater in the mixed-species stand than the pure stands for *K. grandifoliola* and *K. ivorensis*. *Hypsipyla* damage was less in the mixed stands of both *K. grandifoliola* and *K. ivorensis* compared to the pure stands, with the 20% and 10% *Khaya* mixed stand recording the lowest attack in both species. It can be recommended that mixed stands of the two *Khaya* species at 20% or lower *Khaya* density might be ideal for reducing the levels of *Hypsipyla* attack in this type of forest.

Keywords

African Mahogany, *Hypsipyla robusta*, Mixed Plantation, Planting Density, *Khaya* Species

1. Introduction

Establishment of plantations of high value tree species such as the mahoganies is being encouraged to help mitigate the effects of tropical deforestation as well as provide future timber for commercial purposes. Restoring degraded lands with tree plantations are recognised as important additions to the natural forest as a means of increasing forest cover on degraded lands (Seymour & Hunter, 1999). Forest plantations are seen as the surest way to achieve sustainable forest management in most tropical countries with high deforestation rates and there is increasing rate of plantation establishment throughout the world accounting for five percent (5%) of global forest cover (FAO, 2001a). The Meliaceae or the “mahogany family”, which includes the genera *Khaya* are among the most valuable timber species in the world (Hawthorne, 1990; Opuni-Frimpong et al., 2008b). This has contributed to an excessive increase in their demand, production and export for plywood and veneer in the last 30 years with little regard to the rate of natural regeneration in most places where it occurs naturally (FAO, 2001b).

The African mahogany plays a major economic role in the international timber trade because of its many desirable qualities, which include its straight grain which is usually free from pockets and voids (Abbiw, 1990). The high demand has led to excessive exploitation threatening the sustainability of its resource base in the natural forest. However, establishment of mahogany plantations in Ghana and elsewhere in the tropics to support the limited resource base in the natural forest has been met with challenges from the shoot borer *Hypsipyla robusta*, which has resulted in reduced interest in mahogany plantations (Newton et al., 1993; Hauxwell et al., 2001; Opuni-Frimpong et al., 2005, 2008a). *Hypsipyla robusta* larvae attack seed and fruit capsules and bore into the fresh, succulent shoots of mahogany species, killing the first few centimetres of the shoots (Griffiths, 2001). The growth rate of the tree is thus reduced; heavy and repeated attacks can result in tree death. *Hypsipyla robusta* larvae destroy the terminal shoot causing the tree to form many side branches which frequently leads to a deformed trunk and stunts growth (Watt, 1994; Mayhew & Newton, 1998). When attacked by *H. robusta* the economic value of the tree goes down considerably since relatively straight stem desired for commercial purposes in mahogany in most situations after attacks get compromised.

Biological, chemical and silvicultural control measures, have been examined for managing *H. robusta* with limited success (Hauxwell et al., 2001; Opuni-Frimpong et al., 2008b). One silvicultural method that has received strong advocacy is the use of mixed species plantation that mimics the natural forest. Available literature indicates that mixed species plantation is likely to be effective in managing *H. robusta* for a number of reasons including; host trees are likely to be more difficult for adult pests to locate in mixed species than in monocultures; plant suitability for larvae may be reduced as a result of shading; and natural enemies may be more abundant or effective in mixed stands as other species could provide a refuge for natural enemies (Watt, 1994; Mayhew & Newton, 1998; Hauxwell et al., 2001; Opuni-Frimpong et al., 2005, 2008a, 2013).

To aid in sustainable forest management and reduce dependency on the natural forest, effective measures to establish mahogany plantations while avoiding the shoot borer menace must be identified. This study was therefore undertaken to: 1) assess the effect of different densities of mixed-species plantation on the growth of the African mahogany, and 2) assess the effect of different densities of mixed-species plantation on *Hypsipyla robusta* attacks on mahoganies. The study was conducted in a ten hectare plot at the Tano-Nimiri Forest Reserve in the wet evergreen forest type in Ghana.

2. Materials Methods

2.1. Site Description

The study area is an experimental plot established by a team of research scientists from the Forestry Research Institute of Ghana in Tano-Nimiri, a degraded forest reserve, which is undergoing reforestation through collaboration between Samartex Timber and Plywood Company limited and surrounding communities. The area is a concession for Samartex located in Samreboi, a town in the western region of Ghana which is within the wet evergreen forest type in Ghana. It lies between altitudes of between 60 m and 180 m with peaks rising to as high as 260 m (Figure 1). The annual rainfall is between 1750 mm and 2000 mm (Hall & Swaine, 1981; Asankragwa, 2006). The average low temperature of the area is 21°C and average high temperature of the area is 32°C. Relative humidity is also between 70% and 85% per season (Forest Management Unit 10, 2001).

2.2. Experimental Design

The experimental site is a ten (10) hectare area, laid out in a randomized complete block design, with four

blocks. Each block was divided into 10 plots with varying percentages of *Khaya grandifoliola* C.DC (Kg), *Khaya ivorensis* A. Chew (Ki), *Heritiera utilis* Sprague (Hu), *Terminalia superba* Engl and Diels (Ts) and *Entandrophragma angolense* Welw. (Ea). All the species grow naturally in the area except *K. grandifoliola*. Each plot had a dimension of about nineteen meters by ninety meters (19 m × 90 m) with a spacing of three meters (3 m) between trees. In each plot, a total of 220 individual trees were planted. The present data were collected when the trees were two years old.

2.3. Data Collection

The key species for this study were *Khaya grandifoliola* and *Khaya ivorensis*, which were planted at relative densities of 100% s (pure stand), 60%, 50%, 40%, 20% and 10% per plot with an even mixture of the 3 companion species (*Heritiera utilis* Sprague, *Terminalia superba* and *Entandrophragma angolense*). A systematic random sampling method was used to collect the data. In each block, an average of thirty (30) trees per plot were selected and assessed for each *Khaya* species. On the other hand 15 trees were assessed for each of the companion trees. The growth measurements taken were total tree height (Ht), diameter at breast height (DBH; measured at a standard height of 1.3 m) and height at first fork (HtF) for the *Khaya* species but only diameter and height were measured for the companion species.

Damage by *H. robusta* was assessed by recording total shoots attacked (TSA), total number of shoots with fresh attack (TFA), total number of dead shoots (TDS), number of total shoots (TS) sprouted in response to *Hypsipyla* attack, and the length of the longest dead shoot (LDS). In all about 746 trees were sampled for *Khaya grandifoliola* and 467 for *Khaya ivorensis*.

2.4. Data Analysis

An analysis of variance (ANOVA) using the General Linear Model (GLM) of the SPSS statistical package (version 16) was used to test for differences between the means of the parameters assessed at the five percent significance level ($P < 0.05$). The model chosen allows for pair-wise and multiple comparisons of the treatments. Tree volume measurements were calculated using Newbould, 1967: $V = 1/2 (B_{dbh} \times Ht)$, where V is volume, B_{dbh} is the basal area of diameter at breast height and Ht is tree height.

3. Results

3.1. Growth of *Khaya* Species

Khaya grandifoliola demonstrated a better growth performance than *Khaya ivorensis* in all planting densities with 10% showing the best growth performance for *K. grandifoliola* (6.44 cm diameter, 4.90 m height and 0.0105 m³ volume) and 60% for *K. ivorensis* (5.27 cm diameter, 4.38 m height and 0.0057 m³ volume) (Table 1). No differences were observed in growth with relative *Khaya* density for both diameter and height of *K. grandifoliola* ($P = 0.172$ and 0.463 respectively, Table 2), but for *K. ivorensis*, growth differences with relative *Khaya* density were observed for both diameter and height ($P = 0.000$, Table 3).

Generally, *Terminalia superba* had a greater growth rate than the other mixed species, with an average diameter of 7.2 cm and average height of 4.7 m. *Entandrophragma angolense* had an average diameter of 3.1 cm and average height of 3.1 m, while, *Heritiera utilis* had an average diameter of 2.0 cm and average height of 2.3 m. *Khaya grandifoliola* had an average diameter of 6.2 cm and height of 4.8 m and *Khaya ivorensis* had an average diameter of 4.5 cm and height of 3.9 m (Figure 2 and Figure 3).

In general *K. ivorensis* showed less forking than *K. grandifoliola*, except at 60% density (Figure 4) in the mixed plantings two years after planting in the field. There were significant differences among densities for both *K. grandifoliola* and *K. ivorensis* in mean height at first fork ($P = 0.010$ and $P = 0.018$, respectively, Table 2 and Table 3). The density which had the best height to first fork was 100% planting density at 2.16 m for *K. grandifoliola* and 60% planting density at 1.58 m for *K. ivorensis* (Figure 4).

3.2. *Hypsipyla robusta* Attacks on *Khaya* Species

The number of shoots with fresh attack recorded was very low for both species, with *K. grandifoliola* recording a range of 0.017 (40% density) to 0.098 (at 100% density) and a range of 0.00 (at 60% density) to 0.053 (at 100%

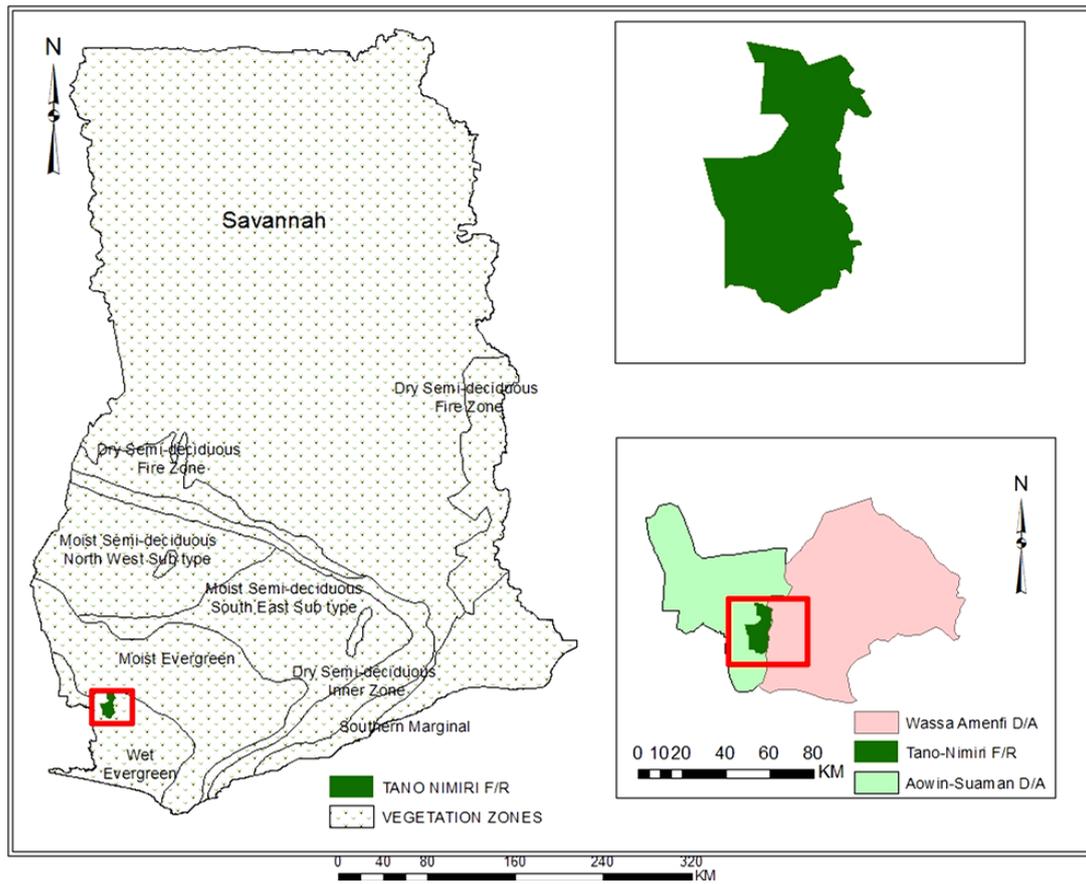


Figure 1. Vegetation map of Ghana showing the location of Tano-Numeri forest reserve.

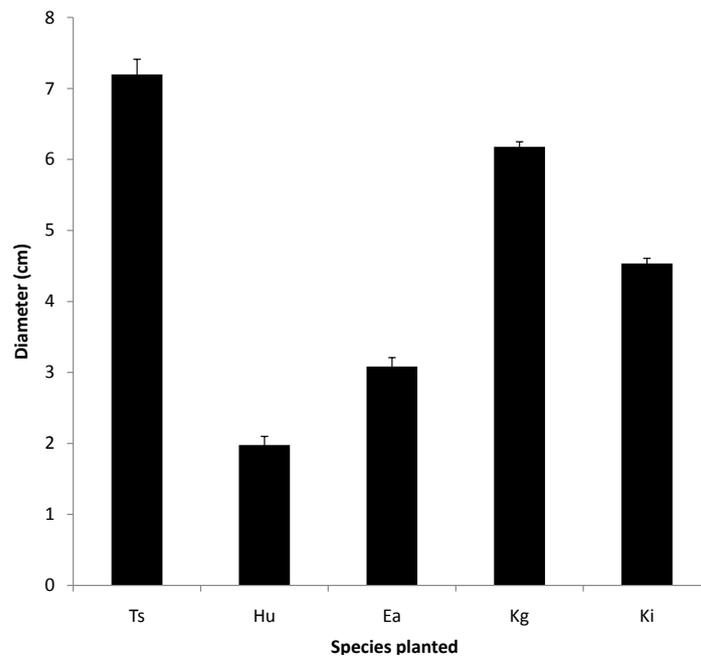


Figure 2. Mean diameter of *Terminalia superba* (Ts), *Heritiera utilis* (Hu), *Entandrophragma angolense* (Ea), *Khaya grandifoliola* (Kg) and *Khaya ivorensis* (Ki) imixed planting.

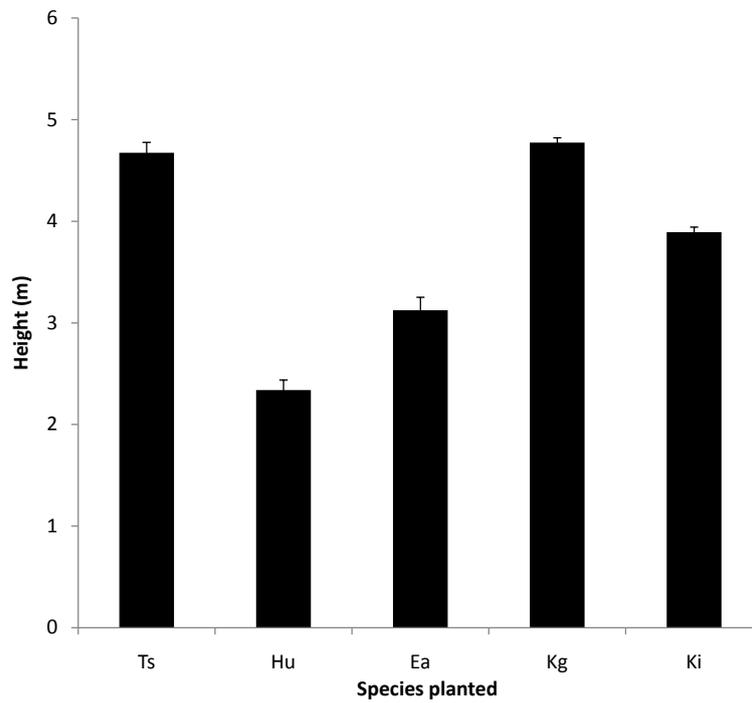


Figure 3. Mean height of *Terminalia superba* (Ts), *Heritiera utilis* (Hu), *Entandrophragma angolense* (Ea), *Khaya grandifoliola* (Kg) and *Khaya ivorensis* (Ki) in mixed planting.

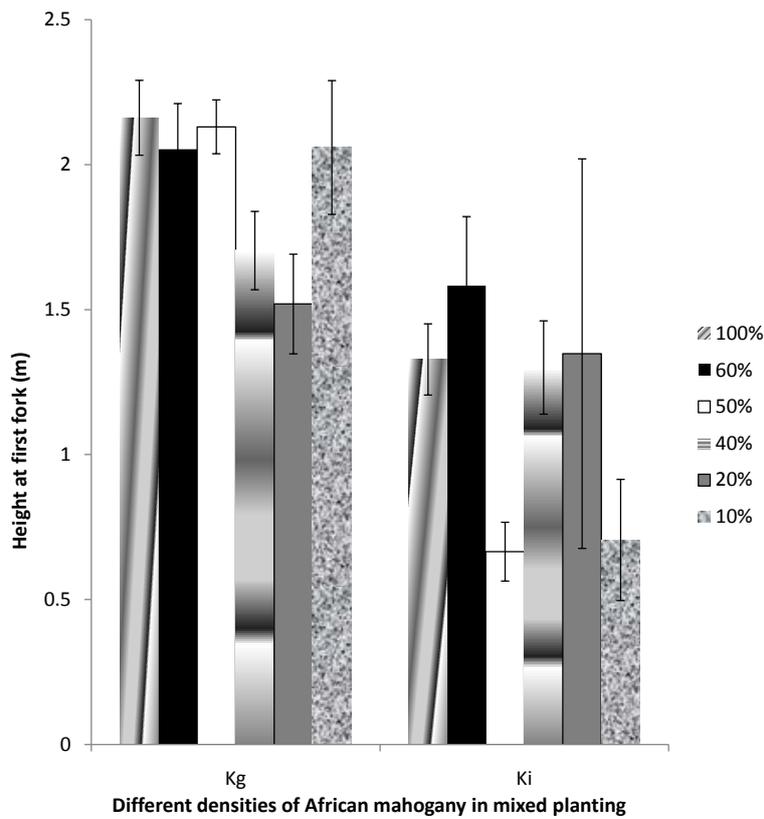


Figure 4. Mean height at first fork of *Khaya grandifoliola* (Kg) and *Khaya ivorensis* (Ki) in six different planting densities.

Table 1. Mean tree size of *Khaya grandifoliola* (Kg) and *Khaya ivorensis* (Ki) at age 2 in a wet evergreen forest.

Density	Kg			Ki		
	Height (m)	Diameter (cm)	Volume (m ³)	Height (m)	Diameter (cm)	Volume (m ³)
100%	4.93 (0.11)	6.39 (0.18)	0.0096 (0.0006)	3.77 (0.09)	4.46 (0.13)	0.0036 (0.0003)
60%	4.81 (0.13)	6.19 (0.19)	0.0092 (0.0007)	4.38 (0.19)	5.27 (0.23)	0.0057 (0.0006)
50%	4.73 (0.09)	6.13 (0.12)	0.0084 (0.0004)	3.67 (0.08)	4.20 (0.13)	0.0032 (0.0003)
40%	4.60 (0.11)	5.75 (0.19)	0.0075 (0.0006)	4.28 (0.12)	4.96 (0.17)	0.0049 (0.0004)
20%	4.76 (0.15)	6.24 (0.21)	0.0087 (0.0008)	3.76 (0.13)	4.41 (0.24)	0.0041 (0.0004)
10%	4.90 (0.20)	6.44 (0.31)	0.0105 (0.0013)	3.79 (0.17)	4.20 (0.27)	0.0035 (0.0005)

Note: Standard errors for means given in brackets.

Table 2. Analysis of variance results for growth and damage parameters for *Khaya grandifoliola* (Ki).

	Sum of Squares	Df	Mean Square	F	P-value
Diameter	30.734	5	6.147	1.550	0.172
Height	8.242	5	1.648	0.927	0.463
Height at first fork	35.390	5	7.078	3.044	0.010
Total shoots	80.007	5	16.001	3.161	0.008
No. of shoots attacked	16.576	5	3.315	1.788	0.113
No. of fresh attack	0.500	5	0.100	1.930	0.087
No. of dead shoots	27.814	5	5.563	7.142	0.000
Length of longest dead shoot	5660.187	5	1132.037	3.712	0.003

Table 3. Analysis of variance results for growth and damage parameters for *Khaya ivorensis* (Ki).

	Sum of Squares	Df	Mean Square	F	P-value
Diameter	58.444	5	11.689	5.023	0.000
Height	32.502	5	6.500	6.014	0.000
Height at first fork	52.211	5	10.442	2.775	0.018
Total shoots	30.419	5	6.084	4.293	0.001
No. of shoots attacked	23.967	5	4.793	6.682	0.000
No. of fresh attack	0.200	5	0.040	1.378	0.231
No. of dead shoots	6.061	5	1.212	3.860	0.002
Length of longest dead shoot	2184.452	5	436.890	3.080	0.010

density) for *K. ivorensis* (Table 4). Statistically, there were no significant differences among densities in fresh shoot attacks for either *Khaya* species (Table 2 and Table 3).

The results two years after planting in the field revealed that *K. grandifoliola* responded to *Hypsipyla robusta* attack with more branches than *K. ivorensis* (Figure 5). The number of shoots of *K. grandifoliola* and *K. ivorensis* attacked by *Hypsipyla robusta* was higher in *K. grandifoliola* than in *K. ivorensis*. The highest number of shoots attacked for *K. grandifoliola* was 1.39 obtained at 50% density for the mixed-species stands and lowest number of shoots attacked was 0.89 (at 10% density) (Figure 6). The highest number of shoots attacked for *K. ivorensis* was 0.89 (at 100% density) and lowest was 0.32 (at 20% density). For *K. ivorensis*, the number of total shoots ranged from 1.43 (at 20% planting density) to 2.16 (at 60% planting density) while for *K. grandifoliola* the number of total shoots ranged from 2.47 (at 10% density) to 3.38 (at 100% planting density).

K. grandifoliola recorded the lowest number of dead shoots at 0.15 (at 40% planting density) and the highest at 0.74 (at 60% planting density) and the length of the longest dead shoot at 10% planting density (Table 5). The number of dead shoots for *K. ivorensis* ranged from 0.085 (at 20% planting density) to 0.37 (at 100% planting density) (Table 5).

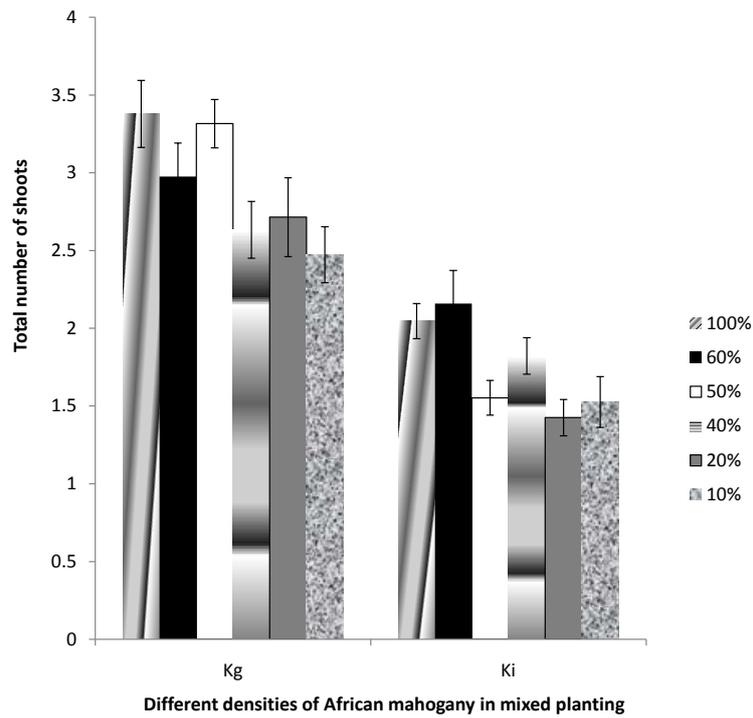


Figure 5. Mean total number of shoots of *Khaya grandifoliola* (Kg) and *Khaya ivorensis* (Ki) in six different planting densities.

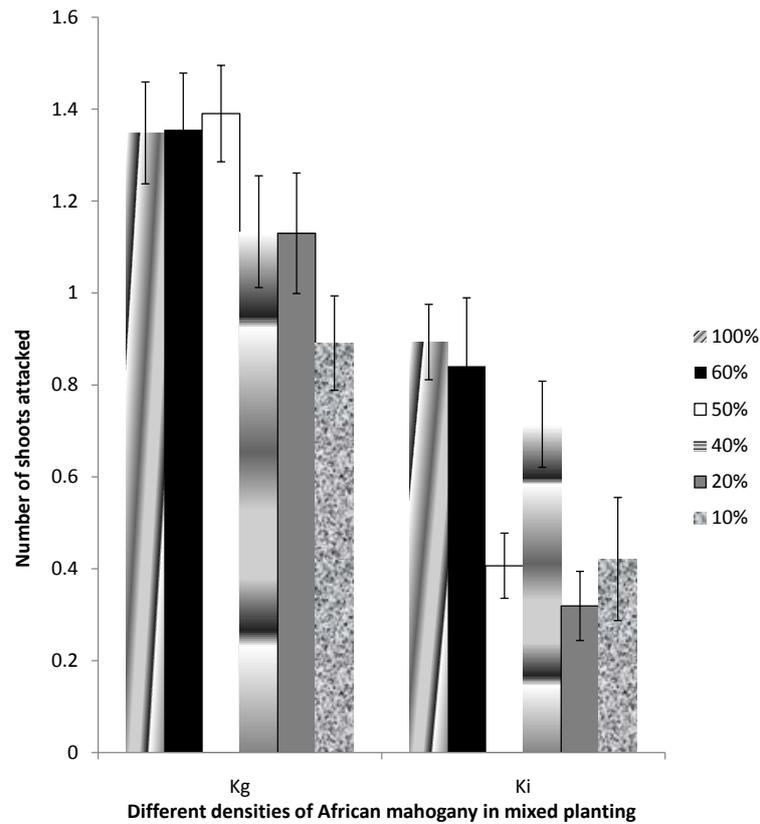


Figure 6. Mean total number of shoots attacked of *Khaya grandifoliola* (Kg) and *Khaya ivorensis* (Ki) in six different planting densities.

Table 4. Mean number of fresh attack \pm SE for different planting densities of *Khaya grandifoliola* (Kg) and *Khaya ivorensis* (Ki).

Density	Kg	Ki
100%	0.098 (0.028)	0.053 (0.019)
60%	0.049 (0.019)	0.000 (0.000)
50%	0.048 (0.015)	0.008 (0.008)
40%	0.017 (0.012)	0.048 (0.023)
20%	0.026 (0.018)	0.021 (0.021)
10%	0.036 (0.025)	0.027 (0.027)

Note: Standard errors for means given in brackets.

Table 5. Mean number of dead shoots and length of longest dead shoots \pm SE for different planting densities of *Khaya grandifoliola* (Kg) and *Khaya ivorensis* (Ki).

Density	Dead shoots	
	Kg	Ki
100%	0.447 (0.073)	0.374 (0.062)
60%	0.744 (0.101)	0.295 (0.101)
50%	0.539 (0.064)	0.098 (0.033)
40%	0.15 (0.044)	0.214 (0.054)
20%	0.675 (0.105)	0.081 (0.041)
10%	0.273 (0.074)	0.211 (0.120)

Note: Standard errors for means given in brackets.

4. Discussion

4.1. Growth of *Khaya* Species

Two years after planting *Khaya grandifoliola* and *Khaya ivorensis* in a mixed planting of different densities with *Terminalia superba*, *Entandrophragma angolense* and *Heritiera utilis* which are all important commercial timber trees in the tropics, differences were displayed for growth in diameter between the planting densities with the 10% density having the best increase in girth for *K. grandifoliola* and 60% for *K. ivorensis*. *K. grandifoliola*, however, did not demonstrate differences between mixed-planting densities for growth in height. This trend is similar to what is reported for monocultures and mixed plantations of Eucalyptus and Acacia (Khanna, 1997; Parrotta, 1999), Monocultures and mixed plantations of poplar species and *Alus glotinoso* (Hansen & Dawson, 1982). Also study conducted in the dry semideciduous forest in Ghana for mixed plantation of *K grandifoliola* with *Terminlia superba* and *Cedrela odorata* followed a similar trend (Opuni-Frimpong et al., 2013). The relative slow growth rate of the companion species might have given advantage to the faster growing *K. grandifoliola*, exposing it to more light and could photosynthesize more effectively than the other species, leading to quicker growth rate (Hawthorne, 1995; Poorter et al., 2004; Petit & Montagnini, 2006). On the other hand, there were significant differences between planting densities for growth in height and diameter of *K. ivorensis* trees, with the 60% *K. ivorensis* mixed stands having the best growth. This reveals that different species may require different treatments in mixed density planting. Even though the two species are of the same genus, they performed better under different mixed densities and thus each species requires some compatible level of mixtures to enhance the efficient use of resources in mixed-stands for productivity as observed by Forrester et al. (2006) and Kelty (2006). Height at first fork was recorded for both *Khaya* species to determine the harvestable bole length for the trees and again in this case each species performed better differently in density mixed planting.

The study conducted in the wet evergreen forest zone of Ghana, which is the natural range of *K. ivorensis* (Hall & Swaine, 1981; Oteng-Amoako, 2006), observed that *K. grandifoliola*, which naturally occurs in dry semideciduous forests (Poorter et al., 2004), showed a better growth performance than *K. ivorensis* in all of the

six mixed-densities planted. This could have been as a result of *K. grandifoliola*'s ability to adapt to more favourable environmental conditions in an ecological zone which has a better rainfall regime leading to its faster growth. Opuni-Frimpong et al. (2008a) also suggested that improved growth characteristics exhibited by *Khaya anthotheca* (genetically similar to *K. grandifoliola*) in a relatively moist forest as compared to its natural range of drier forests could have been as a result of better environmental conditions provided. This proves that species may have different use-efficiency for relevant resource like good rainfall pattern which could affect plants growth and species distribution (Grijpma, 1976; Swaine, 1996; Engelbrecht et al., 2007).

4.2. *Hypsipyla robusta* Attacks on *Khaya* Species

Silvicultural interventions to manage mahogany shoots borer (*Hypsipyla robusta*) problems and maximize growth of trees for timber in mahogany plantations, try to interfere with the mahogany shoot borer's ability to locate the host plant, reduce host suitability, encourage natural enemies and assist recovery of the trees after attack (Hauxwell et al., 2001). These measures include planting vigorous seedlings at good sites together with other plant species that may physically obstruct or may release chemicals that interfere with the chemical cues that help the shoot borer to locate the host plant (Opuni-Frimpong et al., 2005; Hauxwell et al., 2001; Griffiths, 2001).

Branching is one of the main features that expresses the effects of *H. robusta* attack. This occurrence has also been observed by Griffiths (2001); Nair (2001); Opuni-Frimpong et al. (2008b), whose work ascertained that frequent attacks on young plants generally lead to poor quality timber. The results of this study also showed that branching occurred in the mahogany trees in all six planting densities (pure and mixed-species stands) resulting in multiple shoots. The number of new shoots produced showed the mahogany's ability to recover from shoot borer attack. *K. grandifoliola* had more shoots than *K. ivorensis* which implied that *K. grandifoliola* had more *H. robusta* attack. For pure stands (100% planting density of each species) *K. grandifoliola* had 41% more shoots than *K. ivorensis*. This could possibly be because *K. grandifoliola* is more vulnerable to the mahogany shoot borer's attack than *K. ivorensis*. Similar findings were made by Opuni-Frimpong et al. (2008a), whose study on African mahogany species showed that *K. anthotheca* was more susceptible to *H. robusta* attack than *K. ivorensis*. Taller mahogany trees has been observed to attract higher *Hypsipyla* attacks in plantations (Cipiao et al., 2009; Perez-Salicrup & Esquivel, 2008; Opuni-Frimpong et al., 2008, 2013) and thus *K. grandifoliola* with its fast growth in the mixed plantation was more susceptible to *Hypsipyla* attack.

The lowest levels of *H. robusta* attack were observed in the 20% and lower planting densities for both *Khaya* species. This observation corroborates earlier reports that lower densities of mahogany in mixture stands tend to make it difficult for the mahogany shoot borer to locate the *Khaya* species, consequently reducing the host concentration of the pest (Opuni-Frimpong et al., 2005; Hauxwell et al., 2001; Griffiths, 2001; Kelty, et al., 2006).

Even though the effect of shade was not explicitly examined in this study, it was observed that low levels of attack by *H. robusta* were recorded in areas where *K. grandifoliola* and *K. ivorensis* were predominantly shaded by other plants in the mixture stands; this observation corresponds to a study conducted by Opuni-Frimpong et al. (2008b), which examined the effect of canopy shade on some mahogany species. The results of that study indicated that, canopy shade decreased *H. robusta* attack levels in the mahogany species studied; however, it also led to a reduction in growth of the species concerned as observed in this study for *K. ivorensis*. The number of dead shoots (die-back) for both *Khaya* species gives us an indication of the levels and extent of *H. robusta* attacks on the mahogany trees. It is also an indication of the mahogany's ability to recover from the incidence of shoot borer attack and produce new shoots. According to Hauxwell et al. (2001), Newton et al. (1999), and Opuni-Frimpong (2006), this observation may be as a result of the *Khaya* species mechanism of self-pruning which is attributed to the species.

Of the six densities studied, mixture stands with equal percentages of all species (20% density) and the 10% density had the lowest level of *H. robusta* attacks. Mixed species plantation according to Opuni-Frimpong et al. (2013), Kelty (2006), Hauxwell et al. (2001), Watt (1994), and Mayhew and Newton (1998), may help in reducing the incidence of *H. robusta* infestation in mahogany plantations. This expression of low levels of *H. robusta* infestation at lower densities of *Khaya* species may be attributed to stronger interference in chemical cues from companion species disrupting *Hypsipyla* ability to easily identifying host trees (Matsumoto & Kotulai, 2000). Again the companion species may have made available more diverse habitats to support greater population of natural enemies of *Hypsipyla* and potentially by providing a refuge for natural enemies leading to low at-

tacks (Watt, 1992; Parker et al., 2013).

5. Conclusion

The study demonstrated that mixture stands at different densities had effect on the growth and incidence of *H. robusta* infestation on the *Khaya* species. The two species were observed to behave differently under different density of mixed stands demonstrating that each species requires different treatment of mixture for better productivity in the field. The mixed density which had the most mitigating effect on the levels of *H. robusta* attacks for both *Khaya* species were 20% and lower density of the *Khaya* species in the mixture stand. Although the study was conducted in the wet evergreen forest zone of Ghana, which is not within the natural range of *K. grandifoliola*, it nonetheless showed better growth performance than *K. ivorensis* which naturally occurs within the forest type where the study was conducted. The relatively better performance of *K. grandifoliola* in the wet evergreen forest type makes it a favourable candidate for plantation establishment in this type of forest. The common assumption that mixed plantation reduces the attack in mahogany plantation to some extent was confirmed in this study. However, each species of mahogany may require detailed study to identify the most suitable density of mixture that will enhance growth as well as reduce the negative impacts of *Hypsipyla* attack in plantations.

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