KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

COLLEGE OF SCIENCE

DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY

CARBON SEQUESTRATION AND THE EFFECT OF DIFFERENT DENSITIES OF MIXTURE STANDS ON *HYPSIPYLA ROBUSTA* ATTACKS AND GROWTH OF AFRICAN MAHOGANY

BY

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BSc. (HONS.) NATURAL RESOURCES MANAGEMENT,

KNUST

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A THESIS SUBMITTED TO THE DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY IN PARTIAL FULFILMENT OF THE REQUIREMENTS OF THE MASTER OF SCIENCE DEGREE IN ENVIRONMENTAL SCIENCE

BY

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BSc. (HONS) NATURAL RESOURCES MANAGEMENT

DECLARATION

"I hereby declare that this submission is my own work towards the MSc. and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text".

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ABSTRACT

Establishment of tree plantations, like mahogany, in the tropics has been suggested as a way of reducing the rate of increase in atmospheric carbon providing valuable timber for commercial purposes by decreasing the dependence on natural forests for timber. The African mahogany in plantations is often assailed by a number of pests of which *Hypsipyla robusta* is the most destructive. Mixed species plantation is likely to be effective in managing *H. robusta* infestation by hindering the host finding ability of the pest and possible abundance in natural enemies in mixture stands. A ten hectare experimental plot at Sarmartex Timber and Plywood Company limited located in the wet evergreen forest zone of Ghana was planted with *Khaya grandifoliola* and *Khaya ivorensis* in mixture stands containing *Heritieria utilis*, *Terminalia superba*, and *Entandrophragma angolense* in densities of 100%, 60%, 50%, 40%, 20% and 10%. Growth measurements and damage by *H. robusta* was assessed for *Khaya grandifoliola* and *Khaya ivorensis* in pure and mixture stands. Amount of carbon which can be sequestrated was also assessed for all species in the mixture stands. Overall, the study showed that *Khaya grandifoliola* had a better growth performance than *Khaya ivorensis.* After two years of planting, there were not much difference shown between growths displayed for different planting densities for *K. grandifoliola*; however, the 10% density mixed stand had the best growth rate. Differences were shown between growths displayed for different planting densities for *K. ivorensis* trees, with the best growth exhibited by the mixed-species stands. The study also showed that forking occurred in all densities planted with multiply shoots with *K. ivorensis* having the least number of shoots. For *K. grandifoliola,* there were no significant difference between attack levels of different planting densities; however, the mixed species stands recorded the lowest level of *H. robusta* attack. On the other hand, there were clear differences between the attack levels of different planting densities with the pure stands having the highest levels of *H. robusta* attack for *K. ivorensis* trees. The presence of weaver ants (*Oecophylla longinoda*) affected the growth and damage by *H. robusta* attack for the African mahoganies. The presence of weaver ants on *K. grandifoliola* and *K. ivorensis* trees showed that the more weaver ants present, the lower the number of shoots attacked indicating that the presence of weaver ants can help decrease the intensity of *H. robusta* attack. The mixed species can serve as alternate hosts to the weaver ants which may impede *H. robusta* infestation with *Terminalia superba* having the most weaver ants as compared with the other species in the mixture stands. Carbon sequestration was projected for species planted using a forty year tree rotation. *K. grandifoliola* was shown to sequester more carbon and much earlier than the other species used, followed by *H. utilis*, *T. superba*, *E. angolense* and *K. ivorensis*. Due to the different species capability to sequester carbon at different rates and time, it indicated that mixed species plantations might have the ability to sequester more carbon than monocultures.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Over the past decade there has been a growing and serious concern regarding the status and use of global natural forests **(**Waggener, 2010). In spite of long-term forest management schemes and extensive protected area reserves, deforestation continues at alarming rates in much of the developing world **(**Waggener, 2010), including Ghana where designated forest reserves (e.g. Pamu-Berekum) have been degraded to grasslands (Hawthorne and Abu-Juan, 1995).

Forests have a role to play in reducing levels of carbon dioxide and other greenhouse gases (GHG) in the atmosphere. Increased establishment of tree plantations in the tropics has long been suggested as a way of reducing the rate of increase in atmospheric carbon dioxide (CO_2) (Dyson, 1977). As trees grow, they sequester carbon in their tissues, and as the amount of tree biomass increases the increase in atmospheric CO_2 is mitigated (Fearnside, 1999). The ability of plantations to sequester carbon has received renewed interest, since carbon sequestration projects in developing nations could receive investments from companies and governments wishing to offset their emissions of greenhouse gases through the Kyoto Protocol's Clean Development Mechanism (Fearnside, 1999).

According to FAO (2001b), demand for hardwood from tree plantations is predicted to intensify as increasing depletion of the limited forest resource base has resulted in worldwide commercial and political pressures restricting the traditional logging of natural forests. Sawn tropical hardwood (e.g. mahogany) is an important product both for structural and appearance type applications. Globally the important uses of mahogany are furniture (29 percent), mouldings (20 percent), structural housing (18 percent), flooring and panelling (8 percent), and decorative (8 percent) (FAO, 2001b). Production and export of tropical wood products from prime timbers like mahogany, for plywood and veneer, have grown two to threefold in the last 30 years (FAO, 2001b).

Mahogany has a generally straight grain and is usually free of voids and pockets. It has a reddish-brown colour, which darkens over time, and displays a reddish sheen when polished. It has excellent workability, and is very durable (Abbiw, 1990). Historically, the tree's girth allowed for wide boards from traditional mahogany species. These properties make it a favourable wood for crafting cabinets and furniture. In its natural habitat African mahogany is often found individually, dispersed in natural vegetation and secondary forests at about five trees per hectare in its natural range of distribution (Hall and Swaine, 1981). Mahogany (e.g. *Khaya ivorensis, K. anthotheca*), grows mainly in the riverine forests and can attain a height of more than 35m and a diameter of about 1½m. Deciduous savannah woodland mahogany such as *K. grandifoliola* and *K. senegalensis* can attain a height of about 24m and a diameter of about 1m (CAB International, 2000).

In plantations, the African mahogany is often assailed by a number of pests and diseases, some of which are the sapwood borer, *Apate monachus* which occurs especially in Nigeria and the shoot borer, *Hypsipyla robusta,* which is the most destructive. Fungal diseases include *Fomes noxius* (Basidiomycetes), which attacks the roots, and *Uredo tesoensis*, which afflicts the leaves (Griffiths, 2001). Injuries to the wood of live trees can provoke the formation of traumatic resin canals. *Hypsipyla robusta,* shoot borer larvae attack seed and fruit capsules and bore into the fresh, succulent shoots of the mahogany species, killing the first few centimeters of the shoots. The larvae destroy the terminal shoot causing the tree to form many side branches and frequently a deformed trunk thereby significantly reducing the economic value of the timber (Griffiths, 2001). Growth rate is thus reduced and heavy and repeated attacks can result in tree death.

According to Hauxwell *et al.* (2001a), mixed plantings containing non-Swietenioideae species may hinder the host-finding ability of adult moths. Cover crops or planting density may also affect the persistence and effectiveness of shoot borer regulation by natural enemies. Silvicultural techniques are recognised as having considerable potential for reducing the intensity of shoot borer damage.

When attacked by *H. robusta* the economic value of the tree goes down considerably since a relatively straight bole is most desired for commercial purposes (*H. robusta* attack leads to the tree forming many branches and stunted growth) (Watt, 1994; Mayhew and Newton, 1998). Several control measures which include biological, chemical and silvicultural measures have been undertaken to manage *H. robusta* (Hauxwell *et al*., 2001a; Opuni-Frimpong *et al.*, 2005). One silvicultural method is the use of mixed species plantation. Available literature indicates that mixed species plantation is likely to be effective in managing *H. robusta* for the following reasons: 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 less as a result of shading; natural enemies may be more abundant or effective in mixture stands (Watt, 1994; Mayhew and Newton, 1998; Hauxwell *et al*., 2001a; Opuni-Frimpong *et al.,* 2005).

To assess this, a collaboration between the Forest Research Institute of Ghana (FORIG) and Sarmartex Timber and Plywood Company limited has established an experimental plot at Tano-Nimire forest reserve in Samreboi, a town in the Western Region of Ghana. The experimental plot is a ten hectare land area planted with two species of African mahogany (*Khaya grandifoliola and Khaya ivorensis*), *Heritieria utilis* (Niangon), *Terminalia superba* (Ofram) *and Entandrophragma angolense* (Edinam) in different densities in a mixture stand.

1.2 Goal of the study

The main goal of this study is to assess the effect of mixture stands on the growth performance of two African mahogany (*Khaya ivorensis* and *Khaya grandifoliola*) under *Hypsipyla robusta* attacks in the ten hectare plot at the Tano-Numeri Forest Reserve in the wet evergreen forest zone of Ghana.

1.3 Specific objectives

- To evaluate the effect of different densities of mixed-species plantation on the growth of the African mahogany.

- To evaluate the effect of different densities of mixed-species plantation on *Hypsipyla robusta* attacks on mahoganies.
- To assess the effect of weaver ants (*Oecophylla longinoda*) on *Hypsipyla robusta*.
- To calculate the amount of carbon that can be sequestrated by the tree species planted.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Forest plantations

Forests are complex ecosystems that provide a variety of valuable products, such as timber, fuelwood, fibre and non-wood forest products, and contribute to the livelihoods of rural communities. They also provide vital ecosystem services, such as combating desertification, protecting watersheds, maintaining biodiversity, and enhancing carbon sequestration, and play an important role in preserving social and cultural values. It is critically important to protect these valuable resources from disturbances such as fire, pollution, invasive species, insects and diseases (FAO, 2009). There is growing recognition of the conservation value of plantations in reducing logging pressure on the natural forest, sequestrating carbon and restoring degraded lands (Seymour and Hunter, 1999).

According to FAO (2001a), forest plantations are being established at an increasing rate throughout the world and now accounts for five percent (5%) of global forest cover. These are for different purposes which include the economic benefits to be derived from the harvested wood such as furniture, pulp and paper. The Meliaceae or the 'mahogany family' are good examples of valuable tropical hardwoods. It includes the species of such genera as of *Khaya, Entandrophragma, Lovoa* in Africa and *Swietenia, Carapa, Cedrela* in Latin America (Hawthorne, 1990; Opuni-Frimpong *et al.,* 2008b).

Valuable hardwood plantations have the potential of satisfying an appreciable proportion of the demand for forest products in addition to reducing the need to exploit the natural forest (FAO, 2001b). However, when deforestation is being driven by demand to open new forest lands for farming, plantations will not help to reduce the pressure. It has been argued that if plantations supply large amounts of quality timber efficiently, they may undermine the value of natural forest stands and lead to their more rapid destruction (Grainger, 1993). Based on this, it has been suggested that a sensible balance be struck between production from natural forests and plantations where the former exist. Hence, where possible, natural forests and plantations should be managed on a complementary basis (Grainger, 1993).

2.1.1 Monoculture plantations

One advantage of monoculture plantation over mixed-species forest plantation is the ability to concentrate all site resources on the growth of a species with the most desirable characteristics, generally relating to growth rate and woody quality (Kelty, 2006). Evans and Turnbull (2004) stated that there were substantial economic benefits to be gained from using simple, standardized silvicultural and harvesting operations that is usually a characteristic of monoculture plantations. However, some risk associated with monoculture plantation includes damage by pest and diseases. This can lead to the abandonment of said plantations if the damage is very high (Cobbinah, 1997; Kelty, 2006). Operational scale native monoculture plantations of such valuable hardwoods as the African mahoganies and Afromosia have been unsuccessful due to the activities of insects that are largely unrecognised in the natural forests (Cobbinah, 1997).

2.1.2 Mixed-species plantations

Mixed-species plantations are usually promoted as being environmentally preferable to monocultures for theoretical reasons (Kelty, 2006). Mixed-species are normally used in ecological restoration of degraded lands in order to directly re-establish part of the native diversity of tree vegetation and to foster the establishment of additional native plants species in the plantation understory. Another advantage of mixed-species plantation is the reduction of market risk as a result of growing a variety of trees on the same piece of land (Kelty, 2006). Mixed-species plantation also aids in reducing the risk of pest and diseases damage to trees by diluting host concentration for pest organism and making it difficult for pest to find host plants (Hauxwell *et al*., 2001a). It also provide diverse habitat which may support higher populations of natural enemies (Watt, 1992, 1994; Mayhew and Newton, 1998; Hauxwell *et al*., 2001a).

2.1.3 Tree plantations and carbon sequestration

Forests have a role to play in reducing levels of carbon dioxide and other greenhouse gases (GHG) in the atmosphere. Trees reduce atmospheric carbon dioxide (CO_2) through sequestration and reducing GHG emissions by conserving energy used for space heating and cooling. Carbon sequestration is the process by which CO_2 is transformed into above- and belowground biomass and stored as carbon (McPherson *et al.*, 2008). During photosynthesis, atmospheric CO_2 enters the leaf through stomata, combines with water, and is converted into cellulose, sugars, and other materials in a chemical reaction catalyzed by sunlight. Most of these materials become fixed as wood, although some are respired back as CO_2 or used to make leaves that are eventually shed by the tree (McPherson *et al.*, 2008).

The IPCC Third Assessment Report (2001), presented new and stronger evidence that most of the warming observed in the last 50 years is due to human activities and warming is expected to continue this century and alter atmospheric composition. It was also predicted that by the year 2100, the average surface temperature will increase by between 1.4 to 5.8°C while sea level is expected to rise by 0.09 to 0.88cm, resulting in flooding of low-lying areas. CO_2 is the most abundant greenhouse gas and is responsible for more than half of the radiative forcing associated with the greenhouse effect (Dixon *et al.*, 1993; Moura-Costa, 1996).

Forest ecosystems play an important role in climate change because they can be both sources and sinks of CO_2 (Trexler and Haugen, 1994). At present, the world's tropical forests are found to be a net source of C due to anthropologic activities including deforestation with an emission of 1.6 x 10^9 tons, in the year 1990 alone (Trexler and Haugen, 1994).

2.2 Indigenous species

2.2.1 ***Heritieria utilis*** (Sprague) Sprague

Heritieria utilis is restricted to the West African forest zone, occurring from Sierra Leone to Ghana. However, it has been found in some localities in the savannah zone, in remnants of evergreen rain forest and in riparian forest in the savannah zone in Côte d'Ivoire (Adam, 2005). It is normally known by the local names Niangon, nyankom, red cedar, cola cedar. It belongs to the family Sterculiaceae (Abbiw, 1990).

Heritieria utilis is a medium-sized to large tree up to 35–45m tall. It has a cylindrical bole which is often crooked and remains branchless for up to 20–30m, up to 150–300cm in diameter, with high, thin and arched buttresses or with stilt-like buttresses (especially well developed in swamp forest) (Adam, 2005). The bark is pale brown, thin and smooth. The crown is compact and rounded, with a golden to bronze colour when viewed from below. Leaves are alternate, simple or digitately compound. The heartwood is pale pink to red-brown, usually distinctly demarcated from the whitish sapwood, which is 3–7.5cm thick (Abbiw, 1990; Adam, 2005). The grain is interlocked and a moderately coarse texture. The timber dries fairly easy and fairly rapidly, but often with a tendency to twist and occasional end surface checking. Once dry, it is moderately stable in service (Takahashi, 1978).

The wood blunts edged tools moderately rapidly due to the presence of interlocked grain, and there is a risk of tearing in machining and of clogging due to the presence of resin. It is moderately resistant to fungi and termites, but resistant to dry-wood borers; the sapwood is liable to powder-post beetle attack. The heartwood is extremely resistant to preservative treatment. The wood may cause dermatitis, although it is generally considered non-toxic and non-allergenic (Takahashi, 1978).

Heritieria utilis wood is widely used for exterior and interior joinery, panelling, flooring, moulding, carpentry, furniture, cabinet work, stairs (inside), shipbuilding (planks, deck), and sliced veneer for interior and exterior faces of plywood (Abbiw, 1990; Burkill, 2000). Locally, it is popular for making canoes, oars and planks for house building. It has been used for shingles.

The bark has been used for tanning leather (Abbiw, 1990; Burkill, 2000). In Côte d'Ivoire the wood is considered to have antidysenteric properties. The bark also has medicinal applications, a decoction being applied to skin affections caused by leprosy and taken internally as an aphrodisiac. The seeds are reportedly edible; the seed oil is used as an aphrodisiac, whereas ground seeds are applied to abscesses (Burkill, 2000).

2.2.2 *Terminalia superba* (Engl. and Diels)

Terminalia superba occurs in West and Central Africa, ranging from Guinea to Angola. It is usually known by the local name Ofram and has the trade names Limba, Afara and Fraké. It belongs to the family Combretaceae (Groulez and Wood, 1985). *T. superba* grows in deciduous moist forest and evergreen rain forest, where it colonises abandoned agricultural land. It prefers a climate with an annual rainfall of 1400-2000mm, a dry season and a mean annual temperature of 23-26°C. It favours fertile soils of alluvial origin but will grow on a variety of other soil types (Groulez and Wood, 1985).

According to FAO (1984), although the species is widespread, common and not generally threatened, it is becoming progressively impoverished by heavy exploitation. Supplies in the southern parts of its range have dwindled so that forest management and restocking are now needed in those areas where the best quality wood occurs (Groulez and Wood, 1985). *In situ* conservation is considered to be a priority for the species by FAO (1990). Heavy exploitation is threatening natural populations in West African countries such as Ghana and Nigeria (Groulez and Wood, 1985). Depending on where it is grown, *T. superba* is yellowish to brownish-black colour and of varying hardness and weight. The wood is not durable. It can be easily worked but has a tendency to split when nailed or screwed (Lamprecht, 1989). The timber is used for plywood, furniture, interior joinery and decorative veneers.

2.2.3 *Entandrophragma angolense* (Welw.) C. DC.

Entandrophragma angolense occurs throughout the high forest regions spreading from Guinea to Uganda and Angola. It usually grows to a maximum height of 50-60m and a diameter of about 5 m (at breast height). It is normally known by the trade names Edinam, Tiama and Gedu Nohor (Poorter *et al*., 2004; Hall and Swaine, 1981). It belongs to the family Meliaceae and genera *Entandrophragma* (Hawthorne, 1990; Hall and Swaine, 1981).

Entandrophragma angolense has a straight cylindrical bole with a grey bark which becomes whiter as the tree grows higher. It has a dark red slash and pink with white radial streaks with a faint 'cedar' smell (Hawthorne, 1990; Oteng-Amoako, 2006). The leaves of *E. angolense* are glossy and glaborous at seedling and sapling stages (Poorter *et al*., 2004; Oteng-Amoako, 2006). Seed germination rate is about 90%; however, seeds lose their viability very fast and should be sown within a few days after falling (Hall and Swaine, 1981). Seedlings grow about 1-1.2m per year (Hawthorne, 1995; Poorter *et al*., 2004).

The wood of *Entandrophragma angolense* is highly valued for furniture, veneer and plywood, ship building, interior trim, exterior and interior joinery and for flooring. The bark can be used as a brown dye (Abbiw, 1990). The bark is used in treatment of various ailments (for instance, bark decoction is taken for treatment of fever). External applications of the bark are also used as an antiseptic against stomach-ache and peptic ulcers, earache, kidney, rheumatic/arthritic pains. External applications are also used to treat ophthalmia, swellings and ulcers (Poorter *et al*., 2004). The stem-bark is used to treat cough and asthma, while the seeds are used to treat malaria (Oteng-Amoako, 2006).

2.2.4 *Khaya grandifoliola* (C. DC.)

Khaya grandifoliola occurs from Guinea to Sudan and Uganda and is found mostly in dry semi-deciduous forests and also in gallery forests (Poorter *et al*., 2004). It is normally known by the trade names African mahogany and acajou d'Afrique (local names, Odupon/ Dubini). It belongs to the family Meliaceae and the genera *Khaya* (Hawthorne, 1990; Hall and Swaine, 1981). *K. grandifoliola* is a red list species (IUCN, 2009).

Trees of *Khaya grandifoliola* can reach a maximum height of about 50m and diameter of about 120-200cm (Poorter *et al*., 2004; Hall and Swaine, 1981). The bole is branchless for up to 23m, is often twisted or leaning near the top; the tree is has a high buttresses up to 3m high. The bark is greyish brown and exfoliates in small circular scales (Poorter *et al*., 2004). The slash is red with white streaks, is bitter, with a smell between, rosewater and the 'cedar' of other Meliaceae (Hawthorne, 1990); wounds exude a clear gum. Natural regeneration by seed is good and seedling growth of this species is very rapid, attains 6.7cm dbh in 15 years.

Khaya grandifoliola trees are very vulnerable to the shoot borer, *Hypsipyla robusta* while seeds are usually attacked by seed-boring beetles (including while on the tree) and are also eaten by small rodents (Newton *et al*., 1993; Hall, 2008). Logs of *K. grandifoliola* are susceptible to attack by longhorn beetles while sapwood is attacked by the ambrosia beetles. *K. grandifoliola* wood is used for carpentry, joinery, furniture, cabinet work and decorative veneer; it is also used in light flooring and construction, ship building, novelties, carving, interior trim among others. According to Abbiw (1990), the bark is used for treatment of fevers caused by malaria. A decoction of the bark is also taken for treating stomach problems including gastric ulcers, pain after birth and skin diseases.

2.2.5 *Khaya ivorensis* (A. Chev)

Khaya ivorensis occurs in West and Central Africa from Cote d'Ivoire to Cameroon and Angola. It is mostly found in the wet and moist evergreen forests as well as in the south-east subtype of the moist semi-deciduous forests (Hall and Swaine, 1981; Oteng-Amoako, 2006). It is normally known as Dubini in Ghana, acajou rouge/red mahogany and has the trade name African mahogany (Oteng-Amoako, 2006). It belongs to the family Meliaceae and the genera *Khaya* (Hawthorne, 1990). It is a vulnerable species (IUCN, 2009).

Khaya ivorensis attains a maximum height of about 50 – 60m above buttress while the diameter can reach 150 – 210cm. The bole can be straight and branchless up to 30m (Hall and Swaine, 1981; Oteng-Amoako, 2006). *K. ivorensis* is unbuttressed in dry places. The bark is scaly and grey with deep pits forming where scales have fallen; slash is deep red, scented and extremely bitter (Hawthorne, 1990). The wood of *K. ivorensis* is highly valued for furniture, cabinet work, decorative boxes and cases, veneer; it is also used for panelling, window frames, doors, shipbuilding, vehicle bodies, and precision equipment among others (Oteng-Amoako, 2006). Bark decoctions are used to treat cough, fever and anemia; they are also applied externally to wounds, sores, ulcers and tumours and as an anodyne to treat rheumatic pains and lumbago. Root pulp is applied as an enema to treat dysentery (Abbiw, 1990).

2.3 *Hypsipyla* shoot borer

Hypsipyla shoot borers (Order: Lepidoptera, Family: Pyralidae) represents the main hindrance to the establishment of mahogany tree plantations in areas infested with the insect (Newton *et al*., 1993, 1999; Grijpma, 1973), of which the most important are *H. grandella* (Zeller), which occurs in South America, Central America and some parts of North America and a few of the Pacific islands and *H. robusta* (Moore) which occurs in areas of West and East Africa, Asia and Australia (Grijpma, 1973; Mayhew and Newton, 1998).

Adults are brown to greyish-brown in colour with a wingspan of approximately 23 to 45mm (Howard and Merida, 2005). The forewings are grey to brown with shades of rusty red on the lower portion and whitish scales with black dots toward the wing tips (Howard and Merida, 2005). Wing veins are distinctively overlaid with black. Hind wings are white to translucent with dark-coloured margins. Larvae are tan to white in colour, turning bluish in later instars, with a brown head capsule (Howard and Merida, 2005). Mature larvae are approximately 25mm long. Pupae are brownish-black and enclosed in a silken cocoon (Howard and Merida, 2005).

Eggs are oval, dorso-ventrally flattened, and measure 0.5 to 1.0mm by 0.5 to 0.98mm (Griffiths, 2001; Howard and Merida, 2005). When first laid they are white in colour and if fertilized, they develop distinct red and white banding within 24 hours. Females mate only once and lay 200 to 450 eggs over a period of five to eight days. On young trees, eggs are deposited singly or occasionally in clusters of three to five on the shoots, stems and leaves, particularly the upper leaf surface. Concentrated around the growing shoots, eggs may occur at all heights on the host tree and are often placed in concealed locations such as leaf axils, leaf scars, veins, lenticels and fissures in the bark (Griffiths, 2001).

Eggs laid on fruit are initially deposited singly on the fruit surface but are later laid in clumps of up to 12 among the frass and webbing associated with existing damage to the fruit (Griffiths, 2001). After three to five days, the eggs hatch and the larvae tunnel in the developing shoots of young trees and sometimes also feed upon the flowers, fruit and bark of host trees (Atuahene and Souto, 1983; Griffiths, 2001). They pupate either in the twigs, shoots or the soil. A generation usually takes 1 to 2 months but may extend to five months if larvae enter diapause, which has been reported from areas of low temperature or rainfall, and occurs immediately after fruit-feeding despite apparently suitable climatic conditions (Griffiths, 2001). Adults are typically nocturnal and mate within six days of emergence.

2.3.1 Nature of *Hypsipyla robusta* infestation

Hypsipyla robusta caterpillars attack seed and fruit capsules and bore into the tips, shoots and twigs of several high quality timber species killing the first few centimeters (Griffiths, 2001). The caterpillars destroy the terminal shoot causing the tree to form many side branches and frequently a deformed trunk thereby significantly reducing the economic value of the timber (Griffiths, 2001). Growth rate is reduced and heavy and repeated attacks can result in tree death.

Hypsipyla robusta mainly attacks trees in areas with high light, hence the biggest effects are observed in young planted forests, particularly those planted with a single species (Nair, 2001; Opuni-Frimpong *et. al*., 2008b). Young under storey trees in naturally regenerated forests suffer far less damage (Opuni-Frimpong, 2008b) but at the expense of vigorous growth associated with mahoganies. The borer is a problem to both nursery and planted stock; trees from three months to fourteen years in age and between 50cm and 15m in height are most severely affected by *H. robusta* attacks (Griffiths, 2001).

2.4 Control of *Hypsipyla robusta* shoot borers

Control of *Hypsipyla robusta* shoot borers has proven very difficult. Many biological, chemical and silvicultural methods have failed to reduce damage to economically acceptable levels (Mayhew and Newton, 1998; Opuni-Frimpong *et al.*, 2005). In spite of a great deal of research with chemical pesticides, no chemical control product has effectively and consistently provided economic control of these pests (Wylie, 2001). Evidence for silvicultural control of *Hypsipyla* is, unfortunately, conflicting and to a great extent anecdotal (Mayhem and Newton, 1998).

New attempts are now being made in West Africa and elsewhere, to get on top of the troublesome problem of shoot borer attack through an integrated pest management strategy (Floyd and Hauxwell, 2001; Speight and Cory, 2001; Opuni-Frimpong *et al.*, 2005, 2008b).

2.4.1 Silvicultural control of *Hypsipyla robusta*

Several silvicultural treatments have been used to reduce shoot borer damage. Much of the information available however, is unreliable. Trials are often unreplicated and results have been inconsistent (Floyd and Hauxwell, 2001). Consequently, guidelines that give effective, consistent results are not available, and an experimental analysis of the different silvicultural treatments is needed. Hauxwell *et al*. (2001a) reviewed the range of silvicultural treatments and discussed the relative importance of mechanisms by which they may contribute to shoot borer control. For example, mixed plantings containing non-Swietenioideae species may hinder the host-finding ability of adult moths, or cover crops or planting density may affect the persistence and effectiveness of shoot borer regulation by natural enemies. Silvicultural techniques are therefore recognized as having considerable potential for reducing the intensity of shoot borer damage (Floyd and Hauxwell, 2001; Opuni-Frimpong *et al.,* 2005).

Site manipulation can be used as a silvicultural tool to reduce the incidence of *Hypsipyla* attack by selecting favourable site such as fertile soil and adequate drainage of the soil. Tolerant and resistance varieties of mahogany species may be less vulnerable to *Hypsipyla* attack by possessing certain toxins which may serve as antifeedant. In addition, production of sturdy nursery stock, using timber nurse crops, pruning and the effect of shade are possible ways of reducing *Hypsipyla* attack (Mayhew and Newton, 1998; Opuni-Frimpong, 2006; Opuni-Frimpong *et al.,* 2008b).

2.4.2 Biological control of *Hypsipyla robusta*

Biological control of *Hypsipyla* involves several measures which include use of pathogens, parasitoids and predators (Mayhew and Newton, 1998). Some pathogens, including, fungi, viruses, bacteria, protozoa, and nematodes have successfully been used to control various insect pest including Lepidopteron pests (Hauxwell *et al.,* 2001b). Previous attempts at biological control of the shoot borers have not been successful (Sands and Murphy, 2001). The generalist egg parasitoid *Trichogram machilonis* (Ishii) failed to establish when released to control *H. robusta* in Madras, India. Most parasitoid species released against *H. grandella* in the Caribbean have also failed to establish (Sands and Murphy, 2001). Many natural enemies (such as *Apanteles*, *Cotesia*, *and*

Dolichogenidea), however, are related to species known to be effective biological control agents for other pests. Several other parasitoid groups contain potentially valuable agents for introduction if freed of their natural enemies. Inundative releases of native parasitoids, although the method may lead to control, are unlikely to be economically viable for the shoot borers (Sands and Murphy, 2001).

Extensive studies on the natural enemies of *H. robusta* in India and *H. grandella* in Latin America have provided a basis for selecting the most promising agents for biological control programs. Many attempts to control *H. grandella* by introducing parasitoids of *H. robusta* into Central America, the Caribbean, and Brazil, however, have been unsuccessful (Newton *et al*., 1993), possibly because of narrow host specificity or environmental differences. Native predators, however, might be encouraged or introduced locally to minimize the density of the immature stages of the shoot borers. Further work is needed to identify ants that have been used to control other pests and may be amenable to establishing in forest plantations (Khoo, 2001).

2.4.3 Chemical control of *Hypsipyla robusta*

In 2001, Wylie published a report reviewing research and operational experience with chemical control of shoot borers, a research that spans about eight decades and has involved at least 23 countries throughout the tropics. He concluded that the future role of chemical pesticides in shoot borer control would continue to be protecting nursery stock or as part of a program of integrated pest management. The use of chemical pesticides alone was generally believed unlikely to solve the shoot borer problem (Wylie, 2001).

This is because no chemical or application technology has yet been developed that will provide reliable, cost-effective, and environmentally sound protection for any of the high-value Meliaceae tree species for the period necessary to produce a marketable stem. Reasons for this relate mainly to the biology of the insects, the nature of the damage they cause, constraints imposed by climate, and the period of protection required, which may be up to 5 years from planting (Floyd and Hauxwell, 2001).

New compounds available commercially include imidocloprid (Bayer) and fipronil (Rhône-Poulenc) for combating the *Hypsipyla* shoot borer. These compounds however, need further testing to determine their effectiveness against the shoot borers as well as its environmental effects, particularly in controlled-release formulations (Floyd and Hauxwell, 2001; Wylie, 2001; Speight and Cory, 2001).

2.4.4 Use of pheromones

Although not much is known about the unpredictable components of the shoot borer sex pheromone glands, Bellas (2001), has identified three components secreted from *H. robusta* from a culture in France believed to have originated from West Africa. Preliminary studies on Australian populations have also shown the presence of the same compounds, among others, but in different ratios. Three different compounds have also been identified from the *H. grandella* ovipositor tip. Pheromones can be useful tools for monitoring shoot borer abundance, although further work is needed to determine their composition and develop suitable lures (Bellas, 2001). The remarkable ability of shoot borers to find isolated and distant host trees suggests that chemoreception is probably very well developed and important in the insect's behavior. Using the apparently well-developed chemoreceptive ability of these insects to attract and trap adults with volatiles from the shoot tips of host trees as attractants might be possible (Bellas, 2001).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study area

The study area is an experimental plot established at Tano-Nimire, a degraded forest reserve which is undergoing reforestation, two years ago. The area is a concession of SAMARTEX Timber and Plywood Company limited in Samreboi, a town in the Western Region of Ghana which is located in the wet evergreen forest zone of Ghana. It lies between altitudes of 60m and 180m with peaks rising to as high as 260m (Figure 1). The annual rainfall is between 1750mm and 2000mm (Asankragwa, 2006). The average temperature is 21^{o}C and 32^{o}C during the dry and wet seasons respectfully. Relative humidity is also between 70% and 85% per season (FMU 10, 2001).

3.2 Experimental design

The experimental plot is a ten (10) hectare area, laid out in a randomized complete block design, with four blocks. Each block was divided into ten plots with varying percentages of *Khaya grandifoliola* (Kg), *Khaya ivorensis* (Ki), *Heritieria utilis* (Hu), *Terminalia superba* (Ts) and *Entandrophragma angolense* (Ea) (Appendix A). Each plot had a dimension of nineteen meters by ninety meters (19m X 90m) with a spacing of three meters (3m) as planting distance. Each plot had a total of 220 individual trees. Data was collected in the second year of planting of the trees. Data collection was concentrated on the two *Khaya* species since that was the key species the experiment focused on.

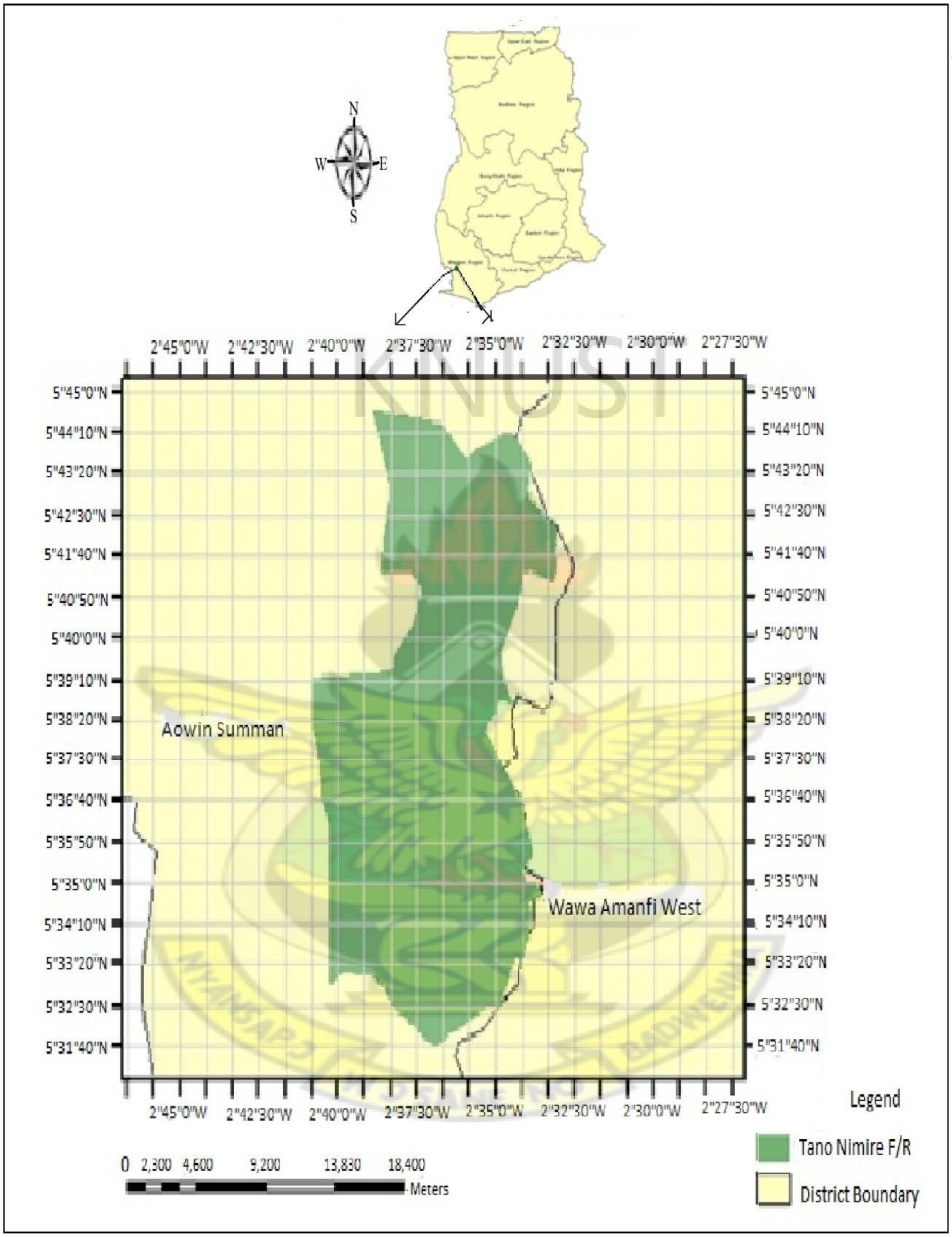

Figure 1. Map of Ghana showing the location of Tano-Nimire Forest Reserve

3.3 Data collection

3.3.1 *Khaya grandifoliola* and *Khaya ivorensis*

Khaya grandifoliola and *Khaya ivorensis* were planted in the densities of 100% (pure stand), 60%, 50%, 40%, 20% and 10% per plot for each of the species (Appendix A). 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 species. 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).

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) and the length of the longest dead shoot (LDS). For assessment of the effect of weaver ants (*Oecophylla longinoda*) on *Hypsipyla robusta*, the number of ant nests on mahogany trees was recorded. Site conditions for all plots were observed and noted.

3.3.2 *Terminalia superba, Entandrophragma angolense* and *Heritieria utilis*

Terminalia superba, *Entandrophragma angolense* and *Heritieria utilis* were planted as companion species in mixed densities with *Khaya grandifoliola* and *Khaya ivorensis*. *Terminalia superba and Entandrophragma angolense* were planted in densities of 10% and 20% for each species in allocated plots (Appendix A). *Heritieria utilis* was planted in densities of 10%, 20% and 50% in assigned plots (Appendix A). An average of ten (10) trees per plot were randomly selected and assessed for each species. Growth measurements taken were total tree height (Ht) and diameter at breast height (DBH) for each species. Site conditions for all plots were observed and noted.

3.4 Carbon sequestration by tree species

The amount of carbon to be removed was calculated by using the Clean Development Mechanism project design calculations for small-scale afforestation and reforestation project activities (CDM-SSC-AR-PDD) Version 01.

3.4.1 Baseline biomass assessment

The following equations to estimate the above and below ground biomass were used:

a) ***Total Baseline biomass***

$B(t)_i = \Sigma(BA(t)\ i + BB(t)\ i) * Ai$

where: $B(t)$ = carbon stocks in the living biomass pools within the project boundary at time t in the absence of the project activity (t C).

$BA(t)\ i$ = carbon stocks in above-ground biomass at time t of stratum i in the absence of the project activity (t C/ha).

$BB(t)\ i$ = carbon stocks in below-ground biomass at time t of stratum i in the absence of the project activity (t C/ha).

Ai = project activity area of stratum i (ha).

i = stratum i

b) *Above-ground biomass*

BA(t) is calculated per stratum *i* as follows:

$BA(t) = M(t) * 0.5$

where:

BA(t) = carbon stocks in above-ground biomass at time *t* in the absence of the project activity (t C/ha).

M(t) = above-ground biomass at time *t* that would have occurred in the absence of the project activity (t dry matter/ha).

0.5 = Carbon fraction of dry matter in tonnes of carbon per tonne of dry matter.

c) *Below-ground biomass*

BB(t) is calculated per stratum *i* as follows:

$BB(t) = M(t) * R * 0.5$

where:

BB(t) = carbon stocks in below-ground biomass at time *t* in the absence of the project activity (t C/ha).

M(t) = above-ground biomass at time *t* that would have occurred in the absence of the project activity (t dm/ha).

R = root to shoot ratio (t dm/t dm).

0.5 = carbon fraction of dry matter (t C/t dm).

3.4.2 Carbon stock assessment

Carbon stock was calculated as follows:

a) *Total Carbon stock*

$P(t)_i = \Sigma(PA(t)\ i + PB(t)\ i) * Ai$

where:

P(t) = carbon stocks within the project boundary at time *t* achieved by the project activity (t C).

PA(t) i = carbon stocks in above-ground biomass at time *t* of stratum *i* achieved by the project activity during the monitoring interval (t C/ha).

PB(t) i = carbon stocks in below-ground biomass at time *t* of stratum *i* achieved by the project activity during the monitoring interval (t C/ha).

Ai = project activity area of stratum *i* (ha).

i = stratum *i*.

b) *Above-ground biomass carbon stock*

PA(t) is calculated per stratum *i* as follows:

$PA(t) = E(t) * 0.5$

where:

PA(t) = carbon stocks in above-ground biomass at time *t* achieved by the project activity during the monitoring interval (t C/ha).

E(t) = estimate of above-ground biomass at time *t* achieved by the project activity (t dm/ha).

0.5 = carbon fraction of dry matter (t C/t dm).

E(t) is estimated through the following steps:

- The diameter at breast height (DBH) or and tree height.
- Estimate the above-ground biomass (AGB) using allometric equations.

Biomass expansion factors and stem volume as follows:

*E(t) = SV * BEF * WD*

where:

E (t) = estimate of above-ground biomass at time *t* achieved by the project activity (t dm/ha).

SV = stem volume (m^3/ha).

WD = basic wood density (t dm/m^3).

BEF = biomass expansion factor (over bark) from stem volume to total volume (dimensionless).

Default *BEF* proposed by the IPCC good practice guidance for LULUCF was used in order to obtain a conservative estimate of total biomass.

SV was estimated from on-site measurements using annual growth increment. Consistent application of BEF will be secured on the definition of stem volume (e.g. total stem volume or thick wood stem volume requires different BEFs). Values for *WD* obtained from table 3A.1.9 of the IPCC good practice guidance for LULUCF were used.

c) *Below-ground biomass carbon stock*

PB(t) shall be estimated for each stratum *i* as follows:

*PB(t) = E(t) * R * 0. 5*

where:

$PB(t)$ = carbon stocks in below-ground biomass at time t achieved by the project activity during the monitoring interval (t C/ha).

R = root to shoot ratio (dimensionless).

0.5 = carbon fraction of dry matter (t C/t dm).

Values for R were obtained from table 3A.1.8 of the IPCC good practice guidance for LULUCF.

$PB(t) = exp(.1.085 + 0.9256 * ln\ E(t)) * 0.5$

where:

$PB(t)$ = carbon stocks in below-ground biomass at time t achieved by the project activity during the monitoring interval (t C/ha).

$E(t)$ = estimate of above-ground biomass at time t achieved by the project activity (t dm/ha).

0.5 = carbon fraction of dry matter (t C/t dm).

3.4.3 Actual net GHG removals

Within the project boundary at time t ($N(t)$) shall be calculated as follows:

a) Total net GHG removals

$N(t)_i = \Sigma(NA(t)\ i + NB(t)\ i) * Ai$

where:

$N(t)$ = total carbon stocks in biomass at time t under the project scenario (t C/ha).

$NA(t)\ i$ = carbon stocks in above-ground biomass at time t of stratum i under the project scenario (t C/ha).

NB(t) i = carbon stocks in below-ground biomass at time *t* of stratum *i* under the project scenario (t C/ha).

Ai = project activity area of stratum *i* (ha).

i = stratum *i*.

b) *Above-ground biomass net GHG removals*

NA(t) is calculated per stratum *i* as follows:

NA(t) = T(t) * 0. 5

where:

NA(t) = carbon stocks in above-ground biomass at time *t* under the project scenario (t C/ha).

T(t) = Above-ground biomass at time .t. under the project scenario (t dry matter/ha).

0.5 = Carbon fraction of dry matter in tonnes of carbon per tonne of dry matter.

T(t) = SV(t) * BEF * WD

where:

T(t) = above-ground biomass at time *t* under the project scenario (t dm/ha).

SV(t) = Stem volume at time .t. for the project scenario (m^3 /ha), values used according to yield tables.

WD = Basic wood density (t dry matter/m^3).

BEF = Biomass expansion factor (over bark) from stem volume to total volume (dimensionless).

c) *Below-ground biomass net GHG removals*

NB(t) is calculated per stratum *i* as follows:

NB(t) = T(t) * R * 0.5

where:

NB(t) = carbon stocks in below-ground biomass at time *t* under the project scenario (t C/ha).

T(t) = above-ground biomass at time *t* under the project scenario (t dm/ha).

R = Root to shoot ratio (dimensionless).

0.5 = Carbon fraction of dry matter in tonnes of carbon per tonne of dry matter.

3.5 Data analysis

An analysis of variance (ANOVA) using a General Linear Model (GLM) of the SPSS statistical package (version 16) was used to test the significance at five percent ($P < 0.05$) level. The model chosen allows for pair-wise and multiple comparisons of the densities and block treatments. Analysis was performed to determine the degree of growth of the African mahogany and the degree of *H. robusta* infestation.

Cross-Tabulations were performed using the SPSS statistical package (version 16) to assess the relationship between the number of ant nests and the damage caused by *Hypsipyla robusta*. Correlation measures were then used to test the degree of the relationship between the ant nests and levels of *Hypsipyla robusta* attacked for *Khaya grandifoliola* and *Khaya ivorensis*. Data were analysed separately for *Khaya grandifoliola* and *Khaya ivorensis* due to the differences in the species. Calculations for the amount of carbon to be removed by trees planted were performed using Microsoft office excel (2007 edition). All graphs were drawn using the Microsoft Office Excel (2007 edition).

CHAPTER FOUR

4.0 RESULTS

4.1 Effect of different densities of mixed-species plantation on the growth of the African mahogany

4.1.1 Diameter and total height

On the whole, *Khaya grandifoliola* showed a better growth performance than *Khaya ivorensis* in all planting densities (Figures 2 and 3). The highest mean diameter and height for *K. grandifoliola* was obtained at 10% mixed-planting density with 6.56cm and 5.04m respectively while *K. ivorensis* obtained the highest mean diameter and height at 60% mixed-planting density with 5.13cm and 4.25m respectively (Figures 2 and 3).

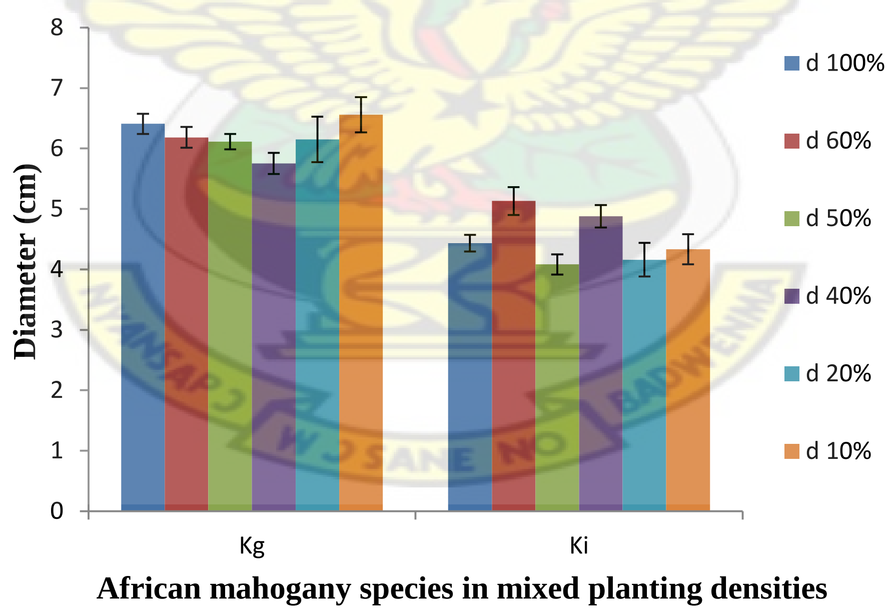

Figure 2. **Mean diameter of *Khaya grandifoliola* (Kg) and *Khaya ivorensis* (Ki) in six different planting densities**.

The mean diameter for the pure stands (100% planting density) of *K. grandifoliola* was 6.41cm while that of *K. ivorensis* was 30.8% lower (4.43cm). *K. grandifoliola* recorded a mean height of 4.94m in the pure stands while *K. ivorensis* recorded a mean height of 3.79m which was 23.3% lower (Figures 2 and 3).

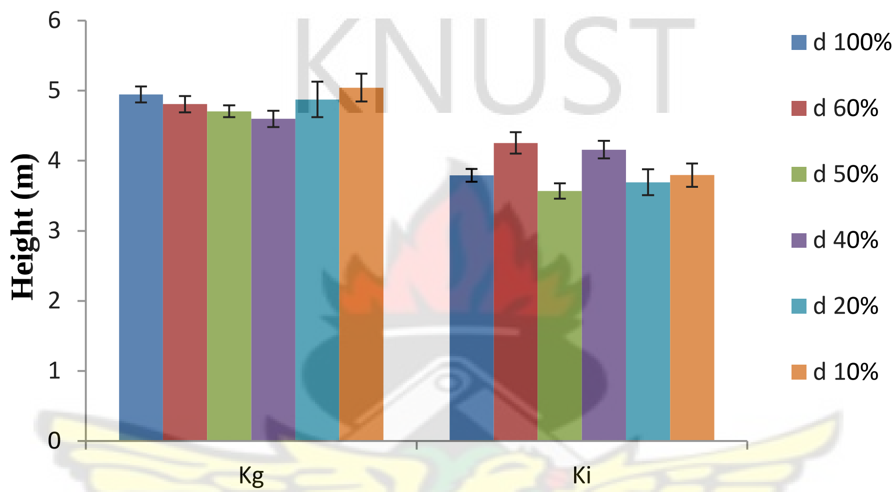

Figure 3. Mean height of *Khaya grandifoliola* (Kg) and *Khaya ivorensis* (Ki) in six different planting densities.

The different densities had a significant effect on the diameter of *K. grandifoliola* (P = 0.04), (Appendix B1) but showed no significant effect on the height of *K. grandifoliola* (P = 0.286) (Appendix B2). Similar to results obtained for *K. grandifoliola*, the different densities had significant effect on diameter of *K. ivorensis* (P = 0.000) (Appendix B3) but in contrast to results obtained for *K. grandifoliola*, the densities had significant effect on height *K. ivorensis* (P = 0.000) (Appendix B4).

The mean diameter for *K. grandifoliola* ranged from 5.75cm at 40% planting density to 6.56cm at 10% planting density. There were significant differences between 40% and 10% planting density (P = 0.005) and 100% and 40% planting density (P = 0.008) but not between 100% and 10% (Appendix B7). The mean height for *K. grandifoliola* ranged from 4.60cm at 40% planting density to 5.04cm at 10% planting density. There were no significant differences between densities (P > 0.05) in terms of height (Appendix B2).

For *K. ivorensis*, the mean diameter ranged from 4.08cm at 50% planting density to 5.13cm at 60% planting density. There were significant difference between 100% and 60% planting density (P = 0.002) and 100% and 40% planting density (P = 0.017); 60% and 50%planting density (P = 0.000) (Appendix B7). The mean height for *K. ivorensis* ranged from 3.57cm at 50% planting density to 4.25cm at 60% planting density. There were significant difference between 100% and 60% planting density (P = 0.000) and 100% and 40% planting density (P = 0.000); 60% and 50% planting density (P = 0.000) (Appendix B7).

In terms of growth in diameter, the performance of the two species of *Khaya* can be ranked in the following order: Kg 10% > Kg 100% > Kg 60% > Kg 20% > Kg 50% > Kg 40% > Ki 60% > Ki 40% > Ki 100% > Ki 10% > Ki 20% > Ki 50%. In terms of growth in height the performance of the two species of *Khaya* can be ranked in the following order: Kg 10% > Kg 100% > Kg 20% > Kg 60% > Kg 50% > Kg 40% > Ki 60% > Ki 40% > Ki 10% > Ki 100% > Ki 20% > Ki 50%.

4.1.2 Height at first fork (branch)

Figure 4 represents the mean height at first fork (branch) level for *K. ivorensis* and *K. grandifoliola* in mixed-planting densities. In general *K. ivorensis* showed early forking than *K. grandifoliola* except at 20% density. Density had a significant effect on the height at which *K. grandifoliola* branched. There were significantly differences between *K. grandifoliola* densities for mean height at first fork level (P = 0.002) (Appendix B6). The density which had the best height to first fork for the mixed stands was10% planting density at 2.15m for *K. grandifoliola* while 20% had the lowest height to first fork at 1.15m. In the pure stands (100% planting density) the harvestable length of bole was 2.15m for *K. grandifoliola* (Figure 4).

There were significantly differences between *K. ivorensis* densities for mean height at first fork (P = 0.017) (Appendix B5). 60% planting density for *K. ivorensis* showed the best harvestable length of bole at 1.52m whilst 50% had the lowest at 0.63m in the mixed stands. In the pure stands (100% planting density) the harvestable length of bole was 1.31m for *K. ivorensi* (Figure 4).

In terms of height at first fork, the performance of the two species of *Khaya* can be ranked in the following order: Kg 10% > Kg 100% > Kg 50% > Kg 60% > Kg 40% > Ki 60% > Ki 100% > Ki 20% > Kg 20% > Ki 40% > Ki 10% > Ki50.

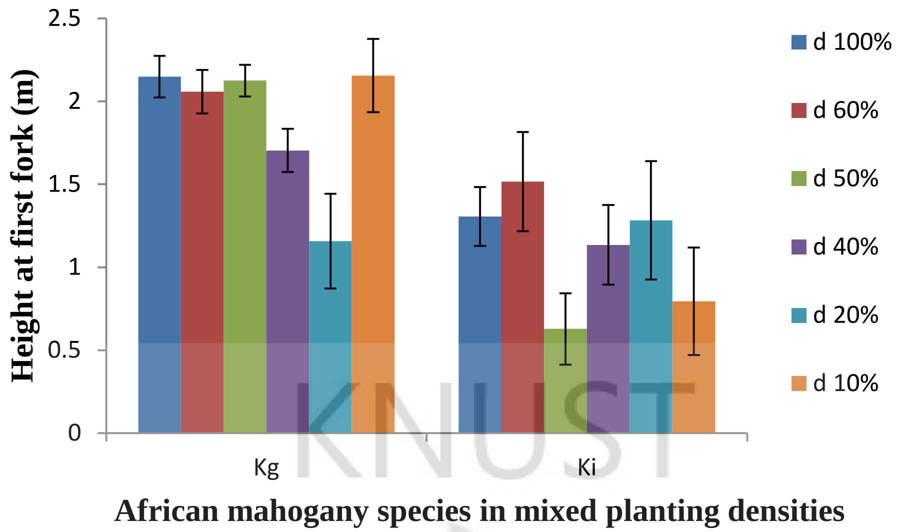

Figure 4. Mean height at first fork of *Khaya grandifoliola* (Kg) and *Khaya ivorensis* (Ki) in six different planting densities.

4.2 Effect of different densities of mixed-species plantation on *Hypsipyla robusta* attacks on African mahoganies

4.2.1 Number of shoots

Table 1 represents the total number of shoots for *K. grandifoliola* and *K. ivorensis* in the different planting densities. In general total number of shoots for *K. grandifoliola* were more in number than that for *K. ivorensis*. Except for 10% planting density for *K. grandifoliola and* 60% for *K. ivorensis* the number of total shoots in mixed-species stands was lower than that of the pure stands (100%). For *K.* ivorensis the number of total shoots ranged from 1.44 (at 20% planting density) to 2.21 (at 60% planting density) whilst for *K. grandifoliola* the number of total shoots ranged from 2.28 (at 20% density) to 3.56 (at 10% planting density) (Table 1). There were no significant differences between 100%, 60%, 50% and 10% densities ($P > 0.05$, Appendix B14) as well as no significant differences between 40% and 20% densities for *K. grandifoliola* (P > 0.05, Appendix B14). For *K. ivorensis*, there were no significant differences between 100% and 60% (P > 0.05, Appendix B15) as well as no significant differences between 50%, 20% and 10% densities (P > 0.05, Appendix B15). 40% density on the other hand showed no significant differences with all other densities (P > 0.05, Appendix B15).

In terms of total number of shoots, the performance of the two species of *Khaya* can be ranked in the following order: Kg 10% > Kg 100% > Kg 50% > Kg 60% > Kg 40% > Kg 20% > Ki 60% > Ki 100% > Ki 40% > Ki 10% > Ki 50% > Ki 20%.

Table 1. Different planting densities of *Khaya grandifoliola* (Kg) and *Khaya ivorensis* (Ki) showing the mean number of shoots ±SE.

Density	Mean number of shoots for	
	Kg	Ki
100%	3.43±0.20[a]	2.02±0.11[a, c]
60%	2.99±0.21[a]	2.21±0.18[a, c]
50%	3.33±0.15[a]	1.49±0.13[b, c]
40%	2.63±0.21[b]	1.70±0.15[c]
20%	2.28±0.45[b]	1.44±0.22[b, c]
10%	3.56±0.35[a]	1.67±0.20[b, c]

Means along the column with the same letter are not significantly different

4.2.2 Number of shoots attacked by *Hypsipyla robusta*

Table 2 represents the total number of shoots attacked for *K. grandifoliola* and *K. ivorensis* in the different planting densities. 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 1.41 obtained at 50% density (equal planting density) for the mixed-species stands and lowest number of shoots attacked was 0.88 (at 20% density). The highest number of shoots attacked for *K. ivorensis* was 0.85 (at 60% density) and lowest was 0.30 (at 20% density). The pure stands on the other hand had the mean number of shoots attacked to be 1.36 for *K. grandifoliola* and 0.90 for *K. ivorensis* (Table 2).

There was no significant difference between densities for the number of shoots attacked for *K. grandifoliola* (P = 0.490) (Appendix B8). In contrast, there was significant difference between densities for the number of shoots attacked for *K. ivorensis* (P = 0.000) (Appendix B9). For *K. ivorensis*, there were no significant differences shown between 100%, 60% and 40% (P > 0.05, Appendix B16) as well as no significant differences between 50%, 20% and 10% densities (P > 0.05, Appendix B16).

In terms of total number of shoots attacked, the performance of the two species of *Khaya* can be ranked in the following order: Kg 50% > Kg 60% > Kg 100% > Kg 10% > Kg 40% > Ki 100% > Kg 20% > Ki 60% > Ki 40% > Ki 10% > Ki 50% > Ki 20%.

Table 2. Different planting densities of *Khaya grandifoliola* (Kg) and *Khaya ivorensis* (Ki) showing the mean number of shoots attacked ±SE.

Density	Mean number of shoots attacked for	
	Kg	Ki
100%	1.36±0.12[a]	0.90±0.08[a]
60%	1.36±0.13[a]	0.85±0.13[a]
50%	1.41±0.09[a]	0.36±0.09[b]
40%	1.13±0.13[a]	0.61±0.10[a, c]
20%	0.88±0.28[a]	0.30±0.15[b]
10%	1.33±0.22[a]	0.54±0.14[b, c]

Means along the column with the same letter are not significantly different

There were no clear trend shown between tree height and the number of shoots attacked for both *Khaya* species. However, the densities which had the highest tree heights also had relatively high number of shoots attacked for both *K. grandifoliola* and *K. ivorensis* (Figures 5 and 6).

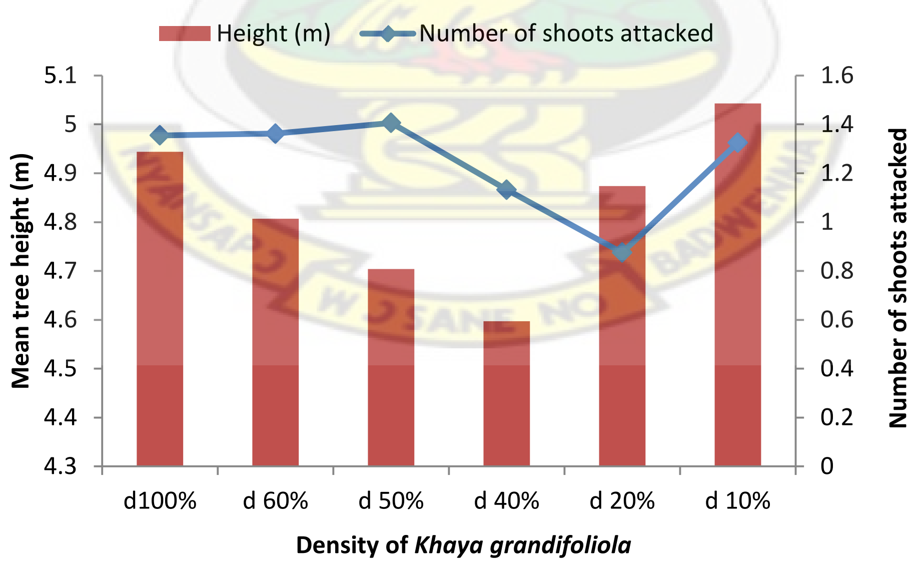

Figure 5. Mean tree height and mean number of shoots attacked for *Khaya grandifoliola* (Kg) in six different planting densities.

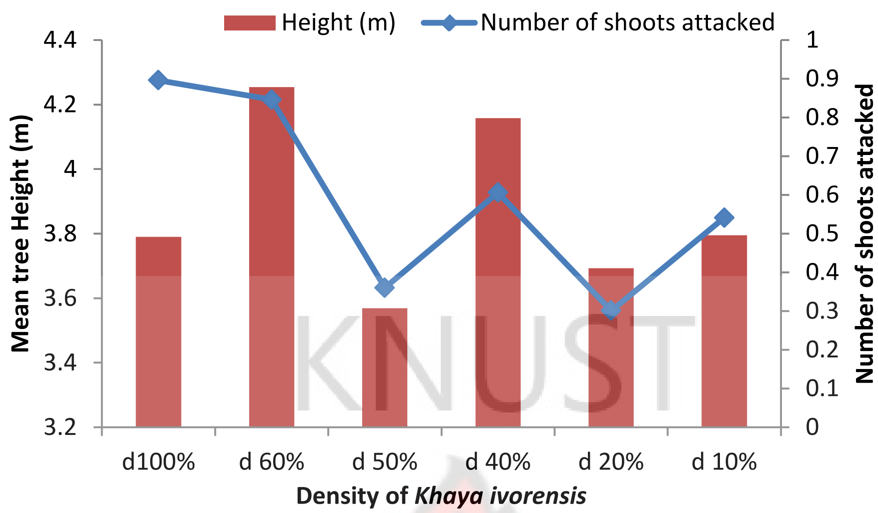

Figure 6. Mean tree height and mean number of shoots attacked for *Khaya ivorensis* (Ki) in six different planting densities.

4.2.3 Number of dead shoots

Table 3 represents the total number of dead shoots for *K. grandifoliola* and *K. ivorensis* in the different planting densities. *K. grandifoliola* recorded the lowest number of dead shoots at 4.50 (at 40% planting density) and the highest at 30.75 (at 50% planting density) with the pure stand recording 14.75 (at 100% planting density) The number of dead shoots for *K. ivorensis* ranged from 1.00 (at 20% planting density) to 4.50 (at 40% planting density) in the mixed stands, while the pure stands recorded an average number of dead shoots at 12.25. There were no significant differences between 100%, 60%, 40%, 20% and 10% densities ($P > 0.05$, Appendix B17) as well as no differences between 60% 50% and 20% densities ($P > 0.05$, Appendix B17) for *K. grandifoliola*. For *K. ivorensis*, there were no significant differences shown between 60%, 50%, 40%, 20% and 10% densities ($P > 0.05$, Appendix B18).

In terms of number of dead shoots, the performance of the two species of *Khaya* can be ranked in the following order: Kg 50% > Kg 60% > Kg 100% > Kg 20% > Ki 100% > Kg 10% > Kg 40% ≥ Ki 40% > Ki 60% > Ki 50% > Ki 10% > Ki 20%.

Table 3. Different planting densities of *Khaya grandifoliola* (Kg) and *Khaya ivorensis* (Ki) showing the mean number of dead shoots ±SE.

Density	Mean number of dead shoots for	
	Kg	Ki
100%	14.75±5.68[a, c]	12.25±3.52[a]
60%	22.5±7.26[c]	3.25±1.11[b]
50%	30.75±2.93[b, c]	3.00±1.22[b]
40%	4.50±2.33[a]	4.50±2.10[b]
20%	13.00±7.33[a, c]	1.00±1.00[b]
10%	6.75±2.56[a]	2.00±1.68[b]

Means along the column with the same letter are not significantly different

4.2.4 Length of longest dead shoot

Table 4 shows length of the longest dead shoots for both *K. grandifoliola* and *K. ivorensis.* The longest dead shoot for *K. grandifoliola* had a length of 13.58cm (at 10% planting density) and the shortest at 2.42cm (at 40% planting density) for the mixed stands, while, the pure stands (at 100% planting density) recorded an average of 4.92cm. *K. ivorensis* on the other hand, recorded 4.16cm (at 60% planting density) as the longest and 0.24cm (at 20% planting density) as the shortest in the mixed stands; the pure stands had an average of 6.05cm (at 100% planting density) (Table 4). There were no significant differences between 100%, 60%, 50%, 40% and 20% densities (P > 0.05, Appendix B19) for *K. grandifoliola*. For *K. ivorensis,* there were no significant differences shown between 100% and 40% (P > 0.05, Appendix B20) as well as no significant differences between 50%, 20% and 10% densities (P > 0.05, Appendix B20). 60% density on the other hand showed no significant differences with all other densities (P > 0.05, Appendix B20).

In terms of length of longest dead shoot, the performance of the two species of *Khaya* can be ranked in the following order: Kg 10% > Kg 60% > Kg 50% > Kg 20% > Ki 100% > Kg 100% > Ki 60% > Ki 40% > Kg 40% > Ki 10% > Ki 50% > Ki20.

Table 4. Different planting densities of *Khaya grandifoliola* (Kg) and *Khaya ivorensis* (Ki) showing the mean length of longest dead shoot±SE.

Density	Mean length of dead shoot for	
	Kg	Ki
100%	$4.92\pm1.51^{a, c}$	$6.05\pm1.09^{a, c}$
60%	8.64 ± 1.56^{a}	4.16 ± 1.83^{c}
50%	8.07 ± 1.14^{a}	$1.38\pm1.32^{b, c}$
40%	$2.42\pm1.57^{a, c}$	$4.11\pm1.48^{a, c}$
20%	6.70 ± 3.42^{a}	$0.24\pm0.22^{b, c}$
10%	13.58 ± 2.64^{b}	$1.67\pm0.20^{b, c}$

Means along the column with the same letter are not significantly different

4.2.5 Number of fresh *Hypsipyla robusta* attack on mahogany trees

In general the number of shoots with fresh attack recorded was very low for both species, with *K. grandifoliola* recording a range of 0.50 (at 10%, 20% and 40% density) to 3.25 (at 100% density) and a range of 0.00 (at 60% density) to 1.75 (at 100% density) for *K. ivorensis* (Table 5). There were no significant differences between densities for both *Khaya* species (Appendix B21)

Table 5. Different planting densities of *Khaya grandifoliola* (Kg) and *Khaya ivorensis* (Ki) showing the mean number of fresh attack ±SE.

Density	Mean number of fresh attack for	
	Kg	Ki
100%	3.25±2.93[a]	1.75±1.75[a]
60%	1.50±0.29[a]	0.00±0.00[a]
50%	2.75±0.85[a]	0.25±0.25[a]
40%	0.50±0.50[a]	1.00±1.00[a]
20%	0.50±0.29[a]	0.25±0.25[a]
10%	0.50±0.50[a]	0.25±0.25[a]

Means along the column with the same letter are not significantly different

4.3 Effect of weaver ants (*Oecophylla longinoda*) on *Hypsipyla robusta.*

The study area had weaver ants already endemic to the site (hosted by the mahogany trees) irrespective of the presence of *Hypsipyla robusta* attack. The number of shoots attacked by *H. robusta* on *K. grandifoliola* trees was influenced by the number of weaver ant nests recorded on the mahogany trees. Figures 7 and 8 represent cross-tabulation of the number of ant nests and the number of shoots with *H. robusta* attacks for *K. grandifoliola* and *K. ivorensis*. It was observed in *K. grandifoliola* and *K. ivorensis* that the number of shoots attacked by *H. robusta* decreased with increasing number of ant nests (Figures 7 and 8) with a measure of association value of -0.157 (Appendix 10) for *K. grandifoliola* and -0.061 (Appendix 12) for *K. ivorensis*. Correlation analysis to test the effect of the cross-tabulations and determine whether the number of ant nests influenced the number of shoots attacked for *K. grandifoliola* was significant (P = 0.000) (Appendix B10). On the contrary, correlation analysis to test the effect of the cross-tabulations and determine whether the number of ant nests influenced the number of shoots attacked for *K. ivorensis* was not significant (P = 0.186) (Appendix B12).

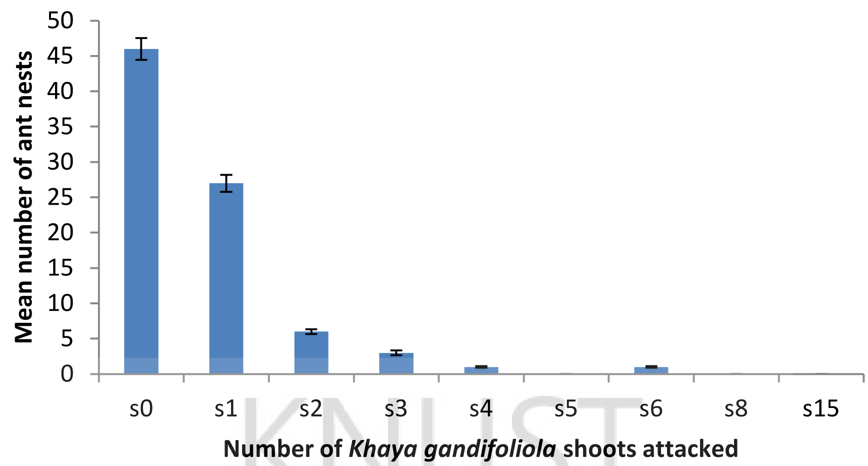

Figure 7. Mean number of ant nests and the number of shoots with *Hypsipyla robusta* attacks for *Khaya grandifoliola* (Kg) trees

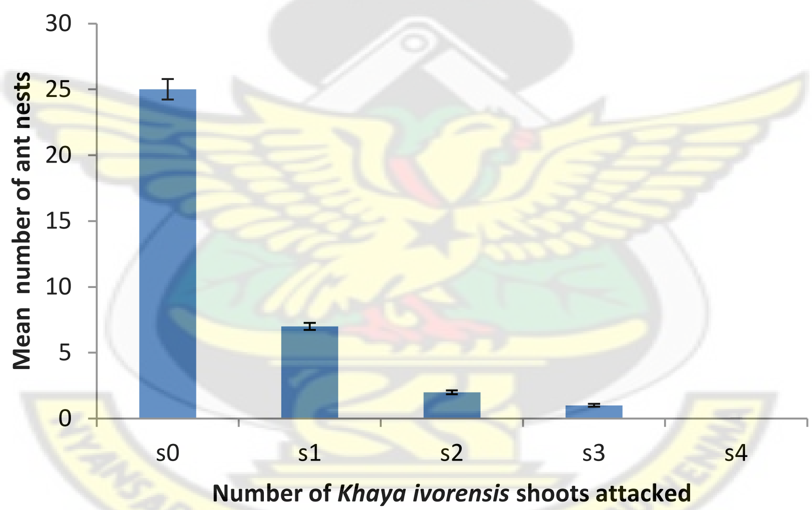

Figure 8. Mean number of ant nests and the number of shoots with *Hypsipyla robusta* attacks for *Khaya ivorensis* (Ki) trees

The number of ant nests found on *Khaya grandifoliola*, ranged from a mean value of 8 (at 20% density) to 21 (at 60% density) for the mixed stands, with the pure stand having a mean value of 17 (at 100% density) (Figure 9). For *Khaya ivorensis*, the number of ant nests ranged from a mean value of 0 (at 50% density) to 18 (at 40% density) for the mixed stands, with the pure stand having a mean value of five (at 100% density) (Figure 9). All planting densities for the two *Khaya* species had some quantity of ant nests with the exception of the 50% density of *K. ivorensis* which recorded no ant nests. Density was shown to significantly influence the distribution of ant nests for *K. grandifoliola* (P = 0.000) (Appendix B11), as well as significantly influence the distribution of ant nests for *K. ivorensis* (P = 0.000) (Appendix B13).

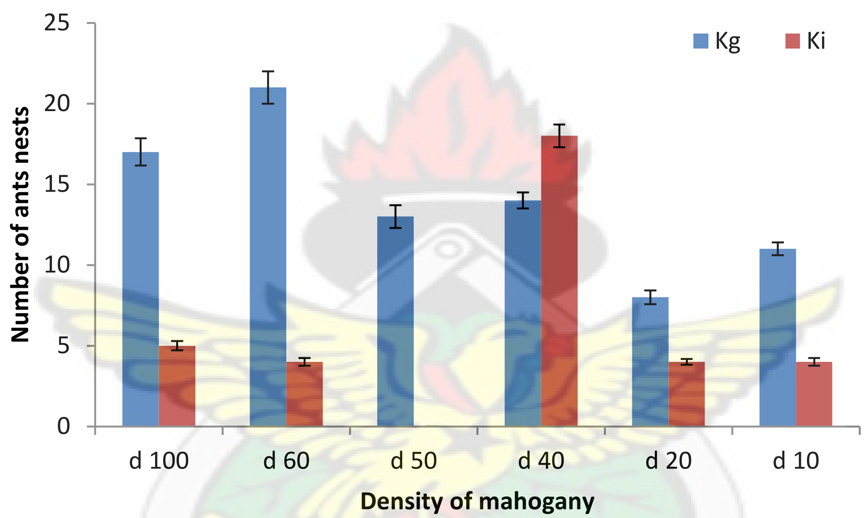

Figure 9. Mean number of ant nests in the different planting densities for *Khaya grandifoliola* (Kg) and *Khaya ivorensis* (Ki)

4.4 Growth performance of other species in the mixed stands in relation to *Khaya grandifoliola* and *Khaya ivorensis*

Figures 10 and 11 show the growth performance of all five species in the mixed stands. On the whole, *Terminalia superba* had a better growth performance than the other trees in the mixed stands with its highest growth performance displayed in the 20% density with a diameter of 7.80cm and a height of 5.26m. It was followed by *Khaya grandifoliola* which had its highest growth performance in the 10% density with a diameter of 6.56cm and height of 5.04m; then, *Khaya ivorensis* with the highest growth performance in the 60% density with a diameter of 5.13cm and height of 4.25m. *Entandrophragma angolense* followed after *K. ivorensis* with its highest growth performance in the 40% density with a diameter of 3.18cm and average height of 3.30m. *Heritieria utilis* demonstrated the slowest growth rate within the mixed planting densities. Its highest growth displayed was in the 60% and 10% densities with a diameter of 2.66cm and a height of 2.58m. (Figures 10 and 11).

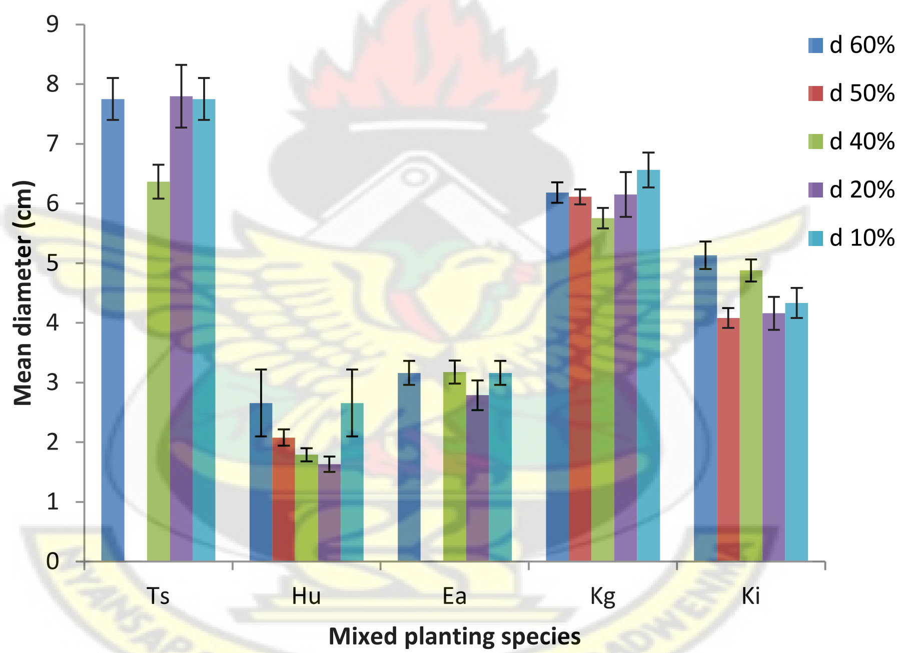

Figure 10. Mean diameter of *Terminalia superba* (Ts), *Heritieria utilis* (Hu), *Entandrophragma angolense* (Ea), *Khaya grandifoliola* (Kg) and *Khaya ivorensis* (Ki) in mixed planting.

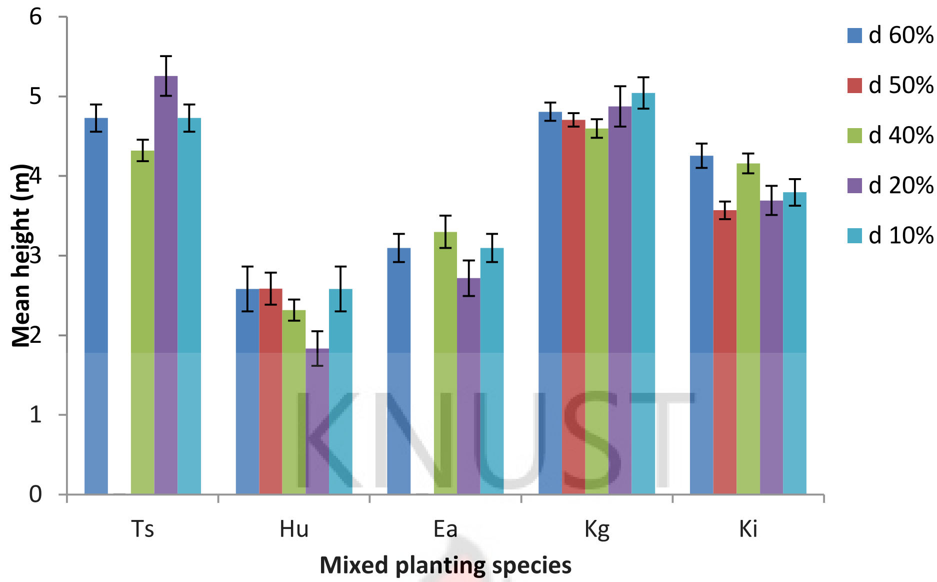

Figure 11. Mean height of *Terminalia superba* (Ts), *Heritieria utilis* (Hu), *Entandrophragma angolense* (Ea), *Khaya grandifoliola* (Kg) and *Khaya ivorensis* (Ki) in mixed planting.

4.5 Carbon sequestration by tree species in the mixed stands

The amount of carbon stored over the species' rotation age determined the carbon sequestration rate in metric tonnes of carbon dioxide (tco$_2$e) for above ground and below ground biomass of the tree species in a ten hectare area, predicted for a forty year rotation plan. It was projected that *K. grandifoliola* will have positive carbon stock storage from the ninth year of planting with an amount of 21.13 tco$_2$e (Figure 12); *K. ivorensis* from the twelve year of planting with an amount of 24.49 tco$_2$e (Figure 13); *E. angolense* form the twelve year of planting with an amount of 33.71 tco$_2$e (Figure 14); *H. utilis* form the tenth year of planting with an amount of 41.25 tco$_2$e (Figure 15); *T. superba* form the eleventh year of planting with an amount of 37.90 tco$_2$e (Figure 16).

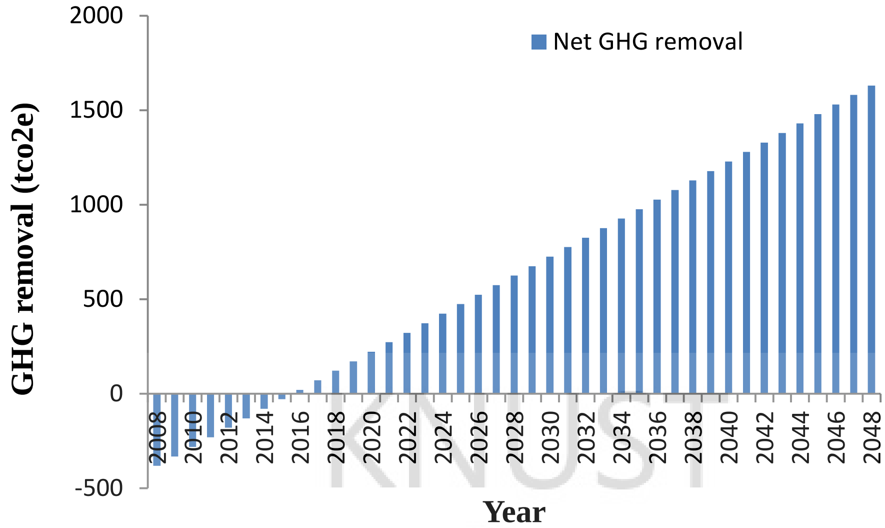

Figure 12. Net greenhouse gas removal for a forty year rotation by *Khaya grandifoliola* in mixed planting.

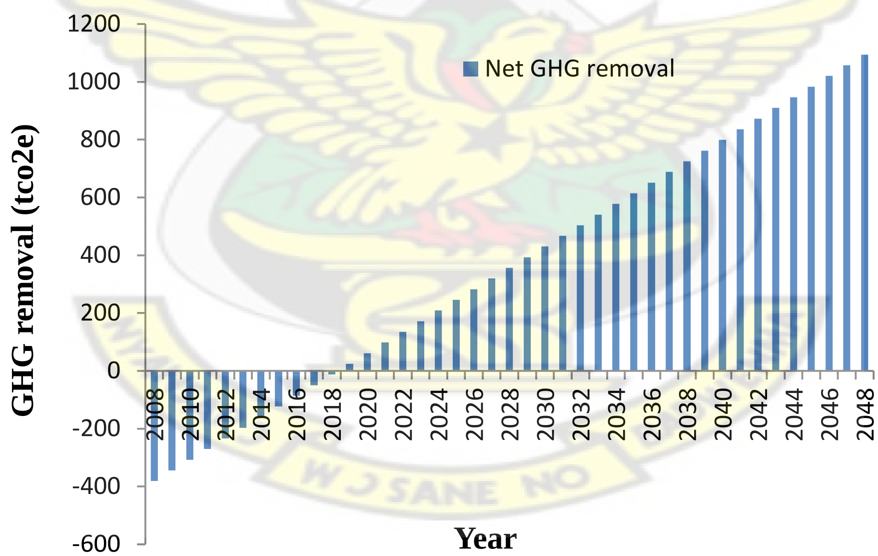

Figure 13. Net greenhouse gas removal for a forty year rotation by *Khaya ivorensis* in mixed planting.

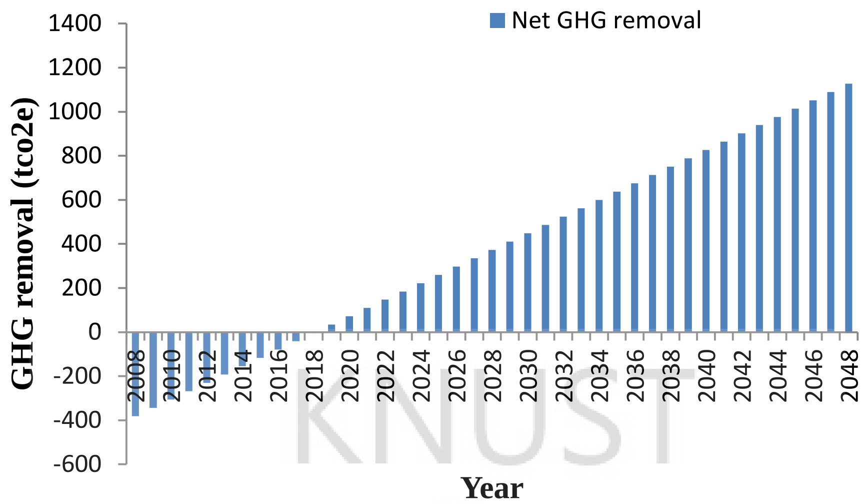

Figure 14. Net greenhouse gas removal for a forty year rotation by *Entandrophragma angolense* in mixed planting.

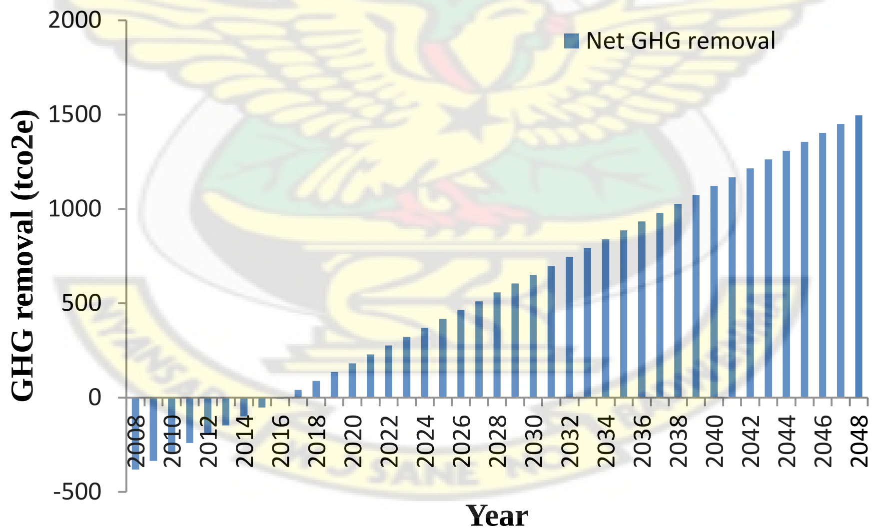

Figure 15. Net greenhouse gas removal for a forty year rotation by *Heritieria utilis* in mixed planting.

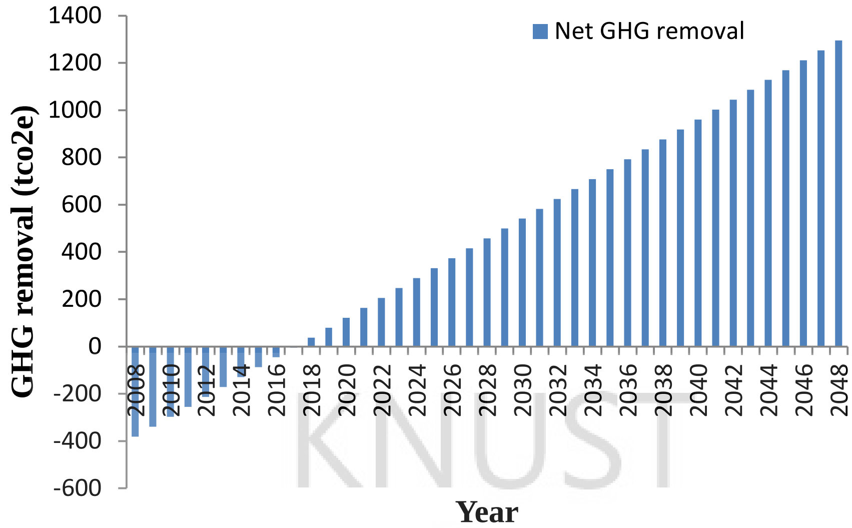

Figure 16. Net greenhouse gas removal for a forty year rotation by *Terminalia superba* in mixed planting.

Emission trade of carbon under the Kyoto protocol (1997; enforced 2005) was also determined for tree species planted. After thirty-seven years of planting projection, *K. grandifoliola* will have the highest carbon trade emission going up to 1429.43 tco_2e (Figure 17) followed by, *H. utilis* with an emission trade of up to 1308.72 tco_2e (Figure 18); then, *T. superba* with an emission trade of up to 1127.65 tco_2e (Figure 19); *E. angolense* with an emission trade of up to 976.76 tco_2e (Figure 20) and lastly, *K. ivorensis* with an emission trade of up to 946.59 tco_2e (Figure 21).

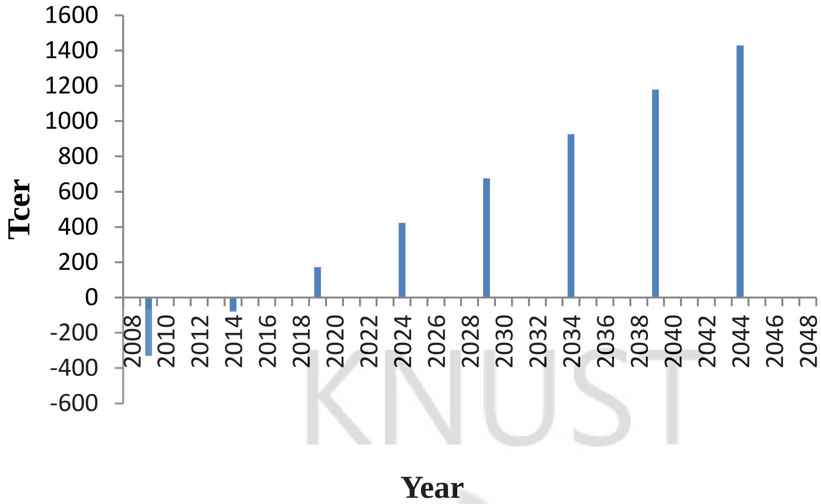

Figure 17. **Trade in certified emission reductions for a forty year rotation by *Khaya grandifoliola* in mixed planting.**

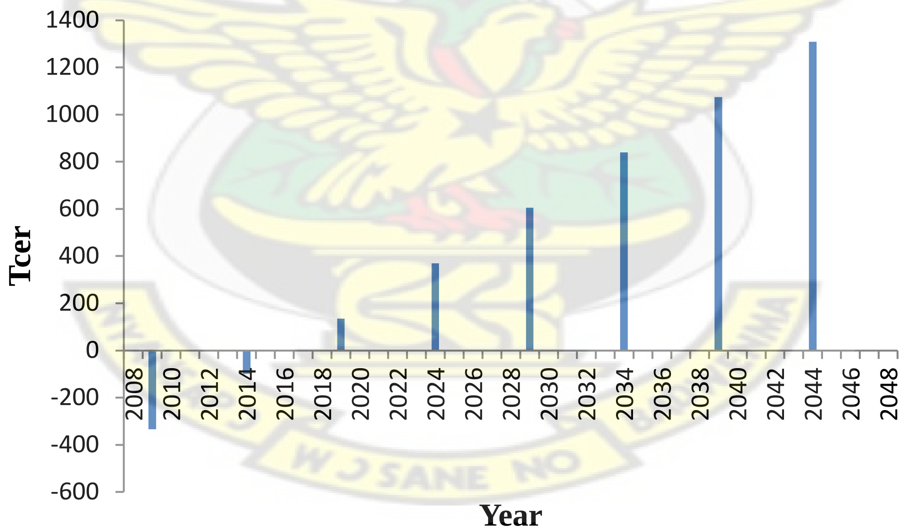

Figure 18. **Trade in certified emission reductions for a forty year rotation by *Heritieria utilis* in mixed planting.**

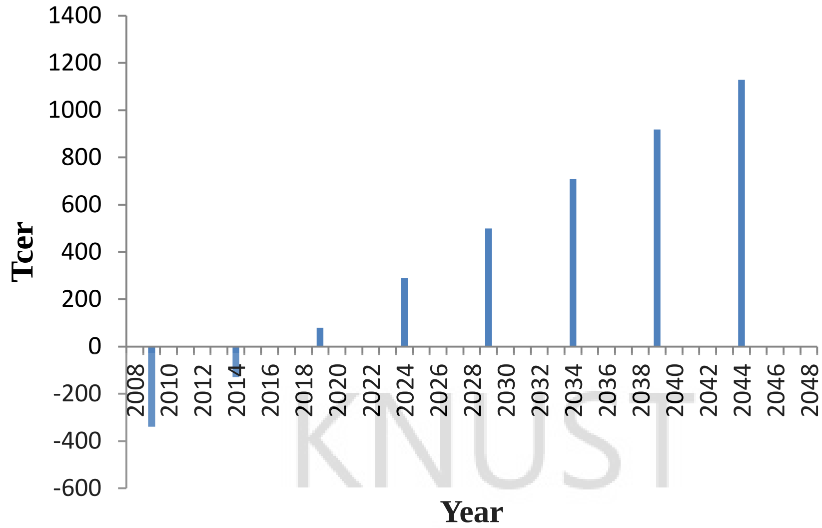

Figure 19. **Trade in certified emission reductions for a forty year rotation by *Terminalia superb* in mixed planting.**

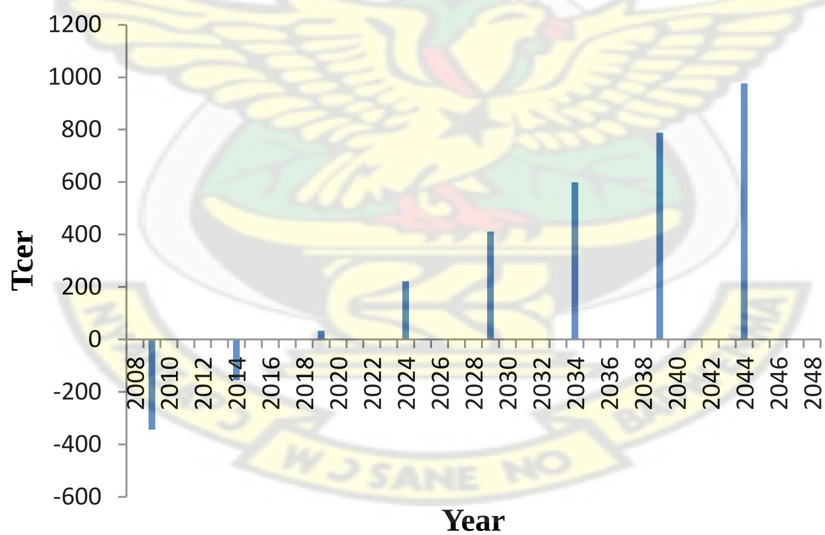

Figure 20. **Trade in certified emission reductions for a forty year rotation by *Entandrophragma angolense* in mixed planting.**

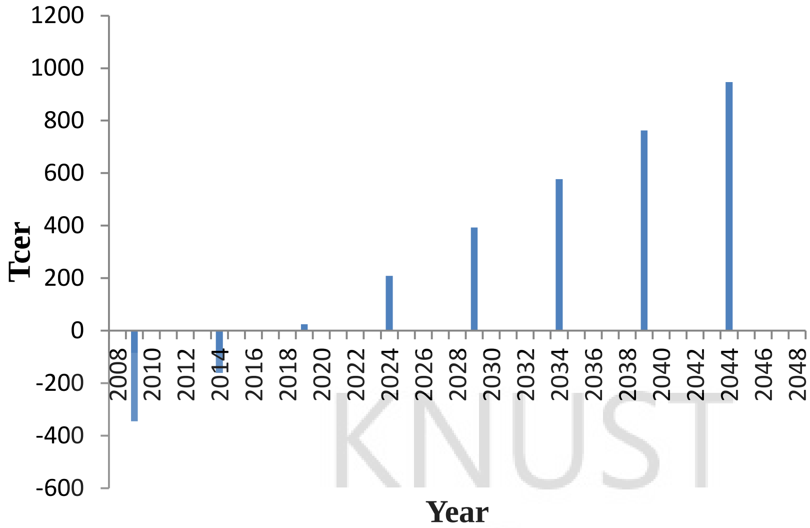

Figure 21. **Trade in certified emission reductions for a forty year rotation by *Khaya ivorensis* in mixed planting.**

CHAPTER FIVE

5.0 DISCUSSIONS

5.1 Effect of different densities of mixed-species plantation on the growth of the African mahogany

Establishment of plantations, such as mahogany trees, are being pursued to help mitigate the effects of deforestation as well as provide valuable timber for commercial purposes. Conservationist, however, are encouraging the establishment of mixed species plantations as a way of promoting species richness and closely mimicking the biodiversity functions of the natural forest (Kelty, 2006). Mixed species plantations according to some researchers (Forrester *et al.,* 2006b; Kelty, 2006; Binkley *et al.,* 2003) may improve growing conditions and lead to an increase in productivity of tree stand.

In this study, *Khaya grandifoliola* and *Khaya ivorensis* were cultivated in a mixed planting with *Terminalia superba, Entandrophragma angolense* and *Heritieria utilis* (Appendix A) which are all important commercial timber trees in the tropics. The focus of this study, however, was on the *Khaya* species and how the companion species (*Terminalia superba*, *Entandrophragma angolense* and *Heritieria utilis*) impacted on their growth and their ability tolerate the insect pest *Hypsipyla robusta*.

Growth indicators measured for *K. grandifoliola* and *K. ivorensis,* which included total tree height, diameter and height at first fork were assessed for pure *Khaya* stands (100% *Khaya*) and mixed-species stands (60%, 50%, 40%, 20% and 10% *Khaya*). After two years of planning, 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*. There were however, no differences between planting densities for growth in height for *K. grandifoliola*.

The fact that *K. grandifoliola* attained the highest height could be accounted for by the relatively slow growth rate of the companion species in the mixed-species stands (Hawthorne, 1995; Poorter *et al*., 2004). The faster growing *K. grandifoliola* trees would be exposed to more light and could photosynthesize more effectively than the other species, leading to quicker growth rate (Petit and Montagnini, 2006). On the other hand, there were significant differences between planting densities for growth in height and diameter *K. ivorensis* trees, with the 60% *K. ivorensis* mixed stands having the best growth. This may be because in the mixed-species stands interspecific competition between species leads to a more efficient use of resources and thus may have impacted positively on mixed-stands productivity as observed by Forrester *et al.* (2006b) and Kelty (2006). Height at first fork was recorded for both *Khaya* species to determine the harvestable bole length for the trees. The best height to first fork for both *Khaya* species were recorded in the 10% density for *K. grandifoliola* and 60% density for *K. ivorensis* with *K. grandifoliola* having a better harvestable bole than *K. ivorensis.* This could be attributed to the inherent ability of the *Khaya* species which allows the species to tolerate high levels of *H. robusta* attack without being extremely affected by it.

Although the study was conducted in the wet evergreen forest zone of Ghana, which is the natural range of *K. ivorensis* (Hall and Swaine, 1981; Oteng-Amoako, 2006), it was observed that *K. grandifoliola*, which naturally occurs in dry semi-deciduous forests (Poorter *et al*, 2004), showed a better growth performance than *K. ivorensis* in all the six densities planted. This could have been as a result of *K. grandifoliola* ability to adapt to more favourable environmental conditions in an ecological zone which have better rainfall regime leading to its faster growth. Opuni-Frimpong *et al.* (2008a) also observed 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 dry semi-deciduous forests, could have been as a result of better environmental conditions provided. Thus, good rainfall pattern is a contributing factor that affects plants growth and species distribution as observed by Grijpma (1976), Swaine (1996) and Engelbrecht *et al.* (2007).

The different growth patterns between the two *Khaya* species studied may also be attributed to genetic variation between the two species as was observed by Opuni-Frimpong (2006), Newton *et al.* (1999) and Hall and Swaine (1981). Their studies showed noticeable variations in growth between mahoganies of different species. Though, this study did not consider provenance (seed source) effect on the growth pattern of the *Khaya* species studied, it has been established by Opuni-Frimpong (2006), Newton *et al.* (1999), that seed source influences the growth of different mahogany species; this may in addition account for the variation between the growth pattern of *K. grandifoliola* and *K. ivorensis*.

5.2 Effect of different densities of mixed-species plantation on *Hypsipyla robusta* attacks on mahoganies

Silvicultural interventions to manage mahogany shoot 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*., 2001a). 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 cue that help the shoot borer to locate the host plant (Opuni-Frimpong *et al.,* 2005; Hauxwell *et al*., 2001a; Griffiths, 2001).

Khaya grandifoliola and *Khaya ivorensis* were planted with three companion species (*Terminalia superba, Entandrophragma angolense* and *Heritieria utilis*) (Appendix A) in mixture stands to assess the effect of *Hypsipyla robusta* attacks on the *Khaya* species. The number of branches/shoots, total shoots with attack, total number of dead shoots (die back) and the length of the longest dead shoot were identified as indicators resulting from *Hypsipyla robusta* attack. They were measured for both *K. grandifoliola* and *K. ivorensis* at all planting densities. *H. robusta* attack was observed in all densities (both pure stands and mixed-species stands) of the two *Khaya* species assessed.

Branching is one of the main features that express 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*.

The lowest levels of *H. robusta* attack were observed in the 20% planting densities for both *Khaya* species. This can be attributed to the fact that, the mixture stands had different genetic compositions which made it difficult for the mahogany shoot borer to locate the *Khaya* species by reducing the host concentration of the pest (Opuni-Frimpong *et al.*, 2005; Hauxwell *et al*., 2001a; Griffiths, 2001; Kelty, *et al.*, 2006).

Hypsipyla robusta attack for the *Khaya* species varied with plant height with no clear trend. However, it was observed that the highest trees had relatively high incidence of *H. robusta* attacks. This was also observed by Perez-Salicrup and Esquivel (2008), that plantations with taller *S. macrophylla* or *C. odorata* individuals had a higher probability of being infested with *H. grandella*. This can be attributed to the taller individuals having more time and space to be exposed to shoot borer attacked.

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 lead to a reduction in growth of the species concerned.

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 also gives us 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.* (2001a), Newton *et al.* (1999), Opuni-Frimpong (2006), this observation may be as a result of the *Khaya* species mechanism of self-pruning which is attributed to the species.

The results of this study have demonstrated that different densities of mixed-species stands of *K. ivorensis* had an effect on *H. robusta* attacks. The attack levels virtually changes with the densities for *K. ivorensis*. Both *K. grandifoliola* and *K. ivorensis* trees recorded the lowest levels of attacks at 20% density though *K. grandifoliola* showed no significant difference between densities for *H. robusta* attacks. Findings from a study conducted by Opuni-Frimpong *et al*. (2005) showed that there was no significant difference between mixed-planting densities of *K. anthotheca* on *Hypsipyla* attacks. Their study further stated that, low levels of *K. anthotheca* with other mixed-species at 25% density recorded the lowest *Hypsipyla* attacks. Of the six densities studied, mixture stands with equal percentages of all species (20% density) had the lowest level of *H. robusta* attacks. Mixed species plantation according to Kelty (2006), Hauxwell *et al.* (2001a), Watt (1994), 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 low densities of *Khaya* species can be attributed to semio-chemical effects of the companion species used in the mixed planting.

Hypsipyla species tends to infest smaller plants of class 2.0m to 3.0m in height and ascribed it to the relatively higher production of vigorous and succulent shoots, which serves as an appropriate substrate for egg deposition (Newton *et al.*, 1993). This apparent difference in the attack levels of the *Khaya* species used in this study which height are above 3m can be reconciled by the ages of the trees being assessed since according to Griffiths (2001), the shoot borer is a problem to both nursery and planted stock and usually attack trees from three months to fourteen years in age and between 50cm and 15m in height.

5.3 Effect of weaver ants (*Oecophylla longinoda*) on *Hypsipyla robusta.*

Sands and Murphy (2001), Lim and Kirton (2003) suggested that weaver ants could be used as biological control agents for reducing *H. robusta* infestation in mahogany species. This is because *Oecophylla smaragdina* has been successfully used as a biological control agent of insect pests in a number of fruit and cash crop species such as cashew and mango in Australia (Peng and Christian, 2006) as well as citrus in Vietnam (van Mele and Cuc, 2000). *O. longinoda* has also been used to control mango fruit fly in Africa (van Mele *et al*., 2007).

The results of this study showed that the presence of weaver ants (*Oecophylla longinoda*) reduces the damage caused by *H. robusta* attacked on *K. grandifoliola* and *K. ivorensis*, thus influencing their growth. The cross tabulation for the number of weaver ant nests on *K. grandifoliola* and *K. ivorensis* showed that the more weaver ants present, the lower the levels of *H. robusta* infestation leading to a reduction in the number of shoots attacked, which was divulged in the correlation measure value of negative for both *Khaya* species. This indicates that the presence of weaver ants can help decrease the intensity of *H. robusta* attack and the number of shoots on *Khaya* trees as observed by Peng *et al.* (2010), whose studies showed reductions in the number of shoots on *Khaya senegalensis* under the influence of weaver ants in Australia.

Weaver ants are territorial predators which attack insect pests and have the ability to adapt to any environment to suit their needs by constructing nests from the living foliage of numerous host plant species and this allows the ants to exploit a wide range of habitats (Holldobler 1983a in Lim, 2007). Planting African mahogany with suitable plants in mixture stands can aid in shoot borer control; the mixed species can serve as alternate hosts to the weaver ants which may impede *H. robusta* infestation. The mahogany species used in this study served as host to the weaver ants with ant nest which is in line with the observation of Khoo (2001) that *Khaya* species were host plants of *O. smaragdina* in Malaysia.

Lim (2007), identified host plants of weaver ants with potential for mixed-planting with *K. ivorensis* in Malaysia; several of the species identified as host plants to be mixed with mahogany were of the genera *Terminalia* and *Heritieria*. Of all the species in companion planting with the *Khaya* species for this study, only *Terminalia superba* trees were teemed with *O. longinoda*. This finding of *Terminalia superba* being a favourable alternate host plant to the weaver ants coupled with its ability as a fast growing species makes it a good candidate for companion planting with *Khaya* species. Also, the rapid lateral growth of *T. superba* branches comparable to the *Khaya* species could provide a link for the weaver ants to have access to the *Khaya* species. During of this research, no ants were however, observed to be on the *Heritieria utilis* trees. This might have been as a result of the slow growth of the *H. utilis* trees compared with the *Khaya* species in the mixture stands. Also, the percentages of the species planted in the mixture stands may not have been high enough to provide auspicious support for the weaver ants.

5.4 Carbon sequestration by tree species

Increased establishment of tree plantations in the tropics has long been suggested as a way of reducing the rate of atmospheric carbon. Carbon sequestration was projected for a ten hectare area using a forty year tree rotation for *Khaya grandifoliola, Khaya ivorensis, Heritieria utilis, Terminalia superba* and *Entandrophragma angolense* in a mixture stand using the Clean Development Mechanism project design calculation for small-scale afforestation and reforestation project activities (CDM-SSC-AR-PDD) Version 01. The quantity which can be used in emission trade with other countries under the Kyoto protocol was also calculated.

From the study, *K. grandifoliola* was shown to sequester more carbon, much earlier than the other species used, followed by *H. utilis*, *T. superba*, *E. angolense* and *K. ivorensis*. This trend can be attributed to the different wood density and wood biomass of the species under consideration, with *K. grandifoliola* having the highest biomass and wood density and *K. ivorensis* having the lowest. Furthermore *K. grandifoliola* had a faster growth rate compared to the other species, thereby having less competition for light, which affects productivity. Thus, *K. grandifoliola* is expected to have larger crowns which will lead to better photosynthesis and subsequently better carbon sequestration ability than the other species in the mixture stands. Petit and Montagnini, 2006 have also demonstrated that photosynthesis affects productivity in pure and mixed plantation of trees species. Contrary to this finding, Sales *et al.* (2010) observed that fast-growing species can sequester and store less carbon than the slow-growing species like *Swietenia macrophylla*, due to the differences in wood density and rotation age. Dyson (1977), however, stated that as the amount of tree biomass increases, the increase in atmospheric carbon is mitigated, as could be perceived by this study. Also, due to the different species capability to sequester carbon at different rates and time, the mixed species plantations may have the ability to sequester more carbon than monocultures (Forrester *et. al.*, 2006a).

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The study demonstrated that mixture stands at different densities had a significant effect on the growth and incidence of *H. robusta* infestation on *Khaya ivorensis.* There were no significant difference between attack levels of the different planting densities for *K. grandifoliola*; however, the mixed species stands recorded the lowest level of *H. robusta* attack for *K. grandifoliola*. It was also observed that despite the number of *H. robusta* attacks, the *Khaya* species had good recovery rates and relatively high growth rates as compared to the other species in the mixture stands. The density which had the most mitigating effect on the levels of *H. robusta* attacks for both *Khaya* species was 20%, which had equal percentages of all species in the mixture stand. This study demonstrated that mixture stands with equal percentage of species had relatively less *H. robusta* attack than the other densities.

Although the study was conducted in a 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* whose natural range falls within the study area. Thus, *K. grandifoliola* can be used as a fast growing species in mahogany plantations.

Mixed-species plantation can be effective in reducing *H. robusta* attack due to the different genetic compositions which makes it difficult for the mahogany shoot borer to locate the *Khaya* species by reducing the host concentration of the pest. They can also serve as host to the weaver ants, *Oecophylla longinoda,* which was observed to influence the incidence of *H. robusta* attack on the mahogany trees. Of all the species planted with the *Khaya* species for this study, only *Terminalia superba* trees were teemed with *O. longinoda*. The percentages of the species planted in the mixture stands may not have been high enough to provide auspicious support for the weaver ants and growth of the mahogany trees.

K. grandifoliola was shown to sequester more carbon, much earlier than the other species. It was followed by *H. utilis*, *T. superba*, *E. angolense* and *K. ivorensis*. It was also observed that due to the different species capability to sequester carbon at different rates and time, mixed species plantations may have the ability to sequester more carbon than monocultures.

6.2 Recommendations for further studies

It is recommended that:

- The effect of provenance (seed source) on the growth of African mahogany species in mixed-species plantations be examined.
- A mixed-species plantation design with higher percentage of *Terminalia superba* should be undertaken.
- Since this study was conducted after only two years of planting, more assessment should be undertaken at this study area after some years to evaluate the effect of mixed-species plantations on the African mahogany.
- Studies on carbon stock should be assessed for the study area based on actual carbon content of the species for this geographical region.

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APPENDICES

APPENDIX A

10-HECTARE MAHOGANY EXPERIMENTAL PLOT-SARMARTEX

Species: *Khaya grandifoliola (Kg), Khaya ivorensis (Ki), Heritieria utilis* (Hu), *Terminalia superba* (Ts) *and Entandrophragma angolense* (Ea)

Block 1 (10 plots)

PLOT Species %

1. Kg pure (100%)
2. Ki pure (100%)
3. Kg (60%), Ki (10%), Hu 10%, Ts 10%, Ea 10%
4. Ki (60%), Kg (10%), Hu 10%, Ts 10%, Ea 10%
5. Ki 50%, Kg 50%
6. 20% of each species
7. Ki 40%, Hu 20%, Ts 20%, Ea 20%
8. Kg 40%, Hu 20%, Ts 20%, Ea 20%
9. Kg 50%, Hu 50%
10. Ki 50% Hu 50%

Block 2 (10 plots)

PLOT Species %

1. Ki pure (100%)
2. Ki 50%, Kg 50%
3. Kg 50%, Hu 50%
4. Kg 40%, Hu 20%, Ts 20%, Ea 20%
5. Ki 50% Hu 50%
6. Kg pure (100%)
7. Kg (60%), Ki (10%), Hu 10%, Ts 10%, Ea 10%
8. Ki (60%), Kg (10%), Hu 10%, Ts 10%, Ea 10%
9. Ki 40%, Hu 20%, Ts 20%, Ea 20%
10. 20% of each species

Block 3 (10 plots)

PLOT	Species %
1.	20% of each species
2.	Kg (60%), Ki (10%), Hu 10%, Ts 10%, Ea 10%
3.	Ki (60%), Kg (10%), Hu 10%, Ts 10%, Ea 10%
4.	Ki 40%, Hu 20%, Ts 20%, Ea 20%
5.	Kg 40%, Hu 20%, Ts 20%, Ea 20%
6.	Kg pure (100%)
7.	Ki 50%, Kg 50%
8.	Ki 50% Hu 50%
9.	Ki pure (100%)
10.	Kg 50%, Hu 50%

Block 4 (10 plots)

PLOT	Species %
1.	Kg (60%), Ki (10%), Hu 10%, Ts 10%, Ea 10%
2.	Ki 50% Hu 50%
3.	Ki 50%, Kg 50%
4.	Kg pure (100%)
5.	Ki (60%), Kg (10%), Hu 10%, Ts 10%, Ea 10%
6.	Kg 50%, Hu 50%
7.	Ki pure (100%)
8.	Kg 40%, Hu 20%, Ts 20%, Ea 20%
9.	20% of each species
10.	Ki 40%, Hu 20%, Ts 20%, Ea 20%

APPENDIX B

B1. Analysis of variance for diameter in mixed planting density for *Khaya grandifoliola.*

Dependent Variable:Diameter (cm)

Source	Type I Sum of Squares	df	Mean Square	F	Sig.
Model	28784.563[a]	24	1199.357	334.820	.000
Block	28494.922	4	7123.730	1.989E3	.000
Density	42.048	5	8.410	2.348	.040
block * density	247.594	15	16.506	4.608	.000
Error	2582.688	721	3.582		
Total	31367.251	745			

a. R Squared = .918 (Adjusted R Squared = .915)

B2. Analysis of variance for height in mixed planting density for *Khaya grandifoliola.*

Dependent Variable: Height (m)

Source	Type I Sum of Squares	Df	Mean Square	F	Sig.
Model	17123.553[a]	24	713.481	434.703	.000
Block	17028.991	4	4257.248	2.594E3	.000
Density	10.225	5	2.045	1.246	.286
block * density	84.337	15	5.622	3.426	.000
Error	1185.023	722	1.641		
Total	18308.576	746			

a. R Squared = .935 (Adjusted R Squared = .933)

B3. Analysis of variance for diameter in mixed planting density for *Khaya ivorensis*

Dependent Variable:Diameter (cm)

Source	Type I Sum of Squares	df	Mean Square	F	Sig.
Model	9740.984[a]	23	423.521	189.746	.000
block	9623.556	4	2405.889	1.078E3	.000
density	52.925	5	10.585	4.742	.000
block * density	64.502	14	4.607	2.064	.013
Error	991.029	444	2.232		
Total	10732.013	467			

a. R Squared = .908 (Adjusted R Squared = .903)

B4. Analysis of variance for height in mixed planting density for *Khaya ivorensis*

Dependent Variable:Height (m)

Source	Type I Sum of Squares	df	Mean Square	F	Sig.
Model	7169.059[a]	23	311.698	316.256	.000
Block	7087.146	4	1771.787	1.798E3	.000
Density	30.810	5	6.162	6.252	.000
block * density	51.102	14	3.650	3.704	.000
Error	437.601	444	.986		
Total	7606.660	467			

a. R Squared = .942 (Adjusted R Squared = .939)

B5. Analysis of variance for height at first fork in mixed planting density for *Khaya ivorensis*

Dependent Variable:Height at first fork (m)

Source	Type I Sum of Squares	df	Mean Square	F	Sig.
Model	714.543[a]	23	31.067	8.299	.000
Block	603.744	4	150.936	40.319	.000
Density	52.024	5	10.405	2.779	.017
block * density	58.775	14	4.198	1.121	.336
Error	1662.130	444	3.744		
Total	2376.673	467			

a. R Squared = .301 (Adjusted R Squared = .264)

B6. Analysis of variance for height at first fork in mixed planting density for *Khaya grandifoliola*

Dependent Variable: Height at first fork (m)

Source	Type I Sum of Squares	df	Mean Square	F	Sig.
Model	3211.861[a]	24	133.828	64.785	.000
Block	3073.436	4	768.359	371.955	.000
Density	38.769	5	7.754	3.754	.002
block * density	99.655	15	6.644	3.216	.000
Error	1491.457	722	2.066		
Total	4703.317	746			

a. R Squared = .683 (Adjusted R Squared = .672)

B7. Multiple comparisons showing the differences in growth between significant densities on *Khaya grandifoliola* and *Khaya ivorensis*.

Growth indices	Density of Mahogany (%)	Density of Mahogany (%)	Std. Error	P-value
Diameter	***K. grandifoliola***			
	100%	40%	0.23872	0.008
	40%	10%	0.28864	0.005
Diameter	***K. ivorensis***			
	100%	60%	0.26032	0.002
		40%	0.20883	0.017
	60%	50%	0.26244	0.000
Height	***K. ivorensis***			
	100%	60%	0.17298	0.000
		40%	0.13877	0.000
	60%	50%	0.17439	0.000

B8. Analysis of variance for number of shoots attacked in mixed planting density for *Khaya grandifoliola*

Dependent Variable:No. of shoots attacked

Source	Type I Sum of Squares	df	Mean Square	F	Sig.
Model	1467.270[a]	24	61.136	31.446	.000
Block	1373.939	4	343.485	176.676	.000
Density	8.615	5	1.723	.886	.490
block * density	84.716	15	5.648	2.905	.000
Error	1401.730	721	1.944		
Total	2869.000	745			

a. R Squared = .511 (Adjusted R Squared = .495)

B9. Analysis of variance for number of shoots attacked in mixed planting density for *Khaya ivorensis*

Dependent Variable:No. of shoots attacked

Source	Type I Sum of Squares	df	Mean Square	F	Sig.
Model	232.116[a]	23	10.092	14.507	.000
Block	189.450	4	47.363	68.080	.000
Density	25.051	5	5.010	7.202	.000
block * density	17.614	14	1.258	1.808	.035
Error	308.884	444	.696		
Total	541.000	467			

B10. Correlation analysis for the number of ant nests and the total number of shoots attacked for *Khaya grandifoliola*

Symmetric Measures

		Value	Asymp. Std. Error	Approx. T	Approx. Sig.
Interval by Interval	Pearson's R	-.157	.020	-4.313	.000
N of Valid Cases		739			

B11. Analysis of variance for number of ant nests in different planting densities for *Khaya grandifoliola*

Dependent Variable:No. of ant nests present

Source	Type I Sum of Squares	df	Mean Square	F	Sig.
Model	108.117[a]	6	18.019	13.388	.000
density	108.117	6	18.019	13.388	.000
Error	987.883	734	1.346		
Total	1096.000	740			

a. R Squared = .099 (Adjusted R Squared = .091)

B12. Correlation analysis for the number of ant nests and the total number of shoots attacked for *Khaya ivorensis*

Symmetric Measures

		Value	Asymp. Std. Error	Approx. T	Approx. Sig.
Interval by Interval	Pearson's R	-.061	.035	-1.324	.186
N of Valid Cases		467			

B13. Analysis of variance for number of ant nests in different planting densities for *Khaya ivorensis*

Dependent Variable:No. of ant nests present

Source	Type I Sum of Squares	df	Mean Square	F	Sig.
Model	90.929[a]	6	15.155	11.740	.000
Density	90.929	6	15.155	11.740	.000
Error	595.071	461	1.291		
Total	686.000	467			

a. R Squared = .133 (Adjusted R Squared = .121)

B14. Multiple comparisons for total number of shoots for *Khaya grandifoliola*

Total shoots
LSD

(I) Density of Mahogany (%)	(J) Density of Mahogany (%)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
100%	60%	.40	.284	.156	-.15	.96
	50%	.07	.247	.780	-.42	.55
	40%	.75*	.285	.009	.19	1.30
	20%	.66*	.323	.040	.03	1.30
	10%	-.19	.338	.578	-.85	.48
60%	100%	-.40	.284	.156	-.96	.15
	50%	-.33	.254	.187	-.83	.16
	40%	.34	.291	.240	-.23	.91
	20%	.26	.329	.428	-.38	.91
	10%	-.59	.344	.085	-1.27	.08
50%	100%	-.07	.247	.780	-.55	.42
	60%	.33	.254	.187	-.16	.83
	40%	.68*	.254	.008	.18	1.18
	20%	.60*	.297	.045	.01	1.18
	10%	-.26	.313	.412	-.87	.36
40%	100%	-.75*	.285	.009	-1.30	-.19
	60%	-.34	.291	.240	-.91	.23
	50%	-.68*	.254	.008	-1.18	-.18
	20%	-.08	.329	.806	-.73	.57
	10%	-.93*	.344	.007	-1.61	-.26
20%	100%	-.66*	.323	.040	-1.30	-.03
	60%	-.26	.329	.428	-.91	.38
	50%	-.60*	.297	.045	-1.18	-.01
	40%	.08	.329	.806	-.57	.73
	10%	-.85*	.377	.024	-1.59	-.11
10%	100%	.19	.338	.578	-.48	.85
	60%	.59	.344	.085	-.08	1.27
	50%	.26	.313	.412	-.36	.87
	40%	.93*	.344	.007	.26	1.61
	20%	.85*	.377	.024	.11	1.59

B15. Multiple comparisons for total number of shoots for *Khaya ivorensis*

Total shoots
LSD

(I) Density of mahogany	(J) Density of mahogany	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
100%	60%	-.11	.206	.582	-.52	.29
	50%	.49*	.148	.001	.20	.78
	40%	.22	.165	.174	-.10	.55
	20%	.62*	.201	.002	.23	1.01
	10%	.52*	.217	.017	.09	.95
60%	100%	.11	.206	.582	-.29	.52
	50%	.61*	.207	.004	.20	1.01
	40%	.34	.220	.125	-.09	.77
	20%	.73*	.247	.003	.25	1.22
	10%	.63*	.261	.016	.12	1.15
50%	100%	-.49*	.148	.001	-.78	-.20
	60%	-.61*	.207	.004	-1.01	-.20
	40%	-.27	.167	.108	-.60	.06
	20%	.13	.202	.529	-.27	.52
	10%	.03	.219	.904	-.40	.46
40%	100%	-.22	.165	.174	-.55	.10
	60%	-.34	.220	.125	-.77	.09
	50%	.27	.167	.108	-.06	.60
	20%	.40	.215	.066	-.03	.82
	10%	.30	.231	.201	-.16	.75
20%	100%	-.62*	.201	.002	-1.01	-.23
	60%	-.73*	.247	.003	-1.22	-.25
	50%	-.13	.202	.529	-.52	.27
	40%	-.40	.215	.066	-.82	.03
	10%	-.10	.257	.696	-.61	.40
10%	100%	-.52*	.217	.017	-.95	-.09
	60%	-.63*	.261	.016	-1.15	-.12
	50%	-.03	.219	.904	-.46	.40
	40%	-.30	.231	.201	-.75	.16
	20%	.10	.257	.696	-.40	.61

B16. Multiple comparisons for total number of shoots attacked for *Khaya ivorensis*

No. of shoots attacked
LSD

(I) Density of mahogany	(J) Density of mahogany	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
100%	60%	.05	.145	.720	-.23	.34
	50%	.49*	.105	.000	.28	.69
	40%	.18	.117	.126	-.05	.41
	20%	.57*	.142	.000	.30	.85
	10%	.47*	.154	.002	.17	.77
60%	100%	-.05	.145	.720	-.34	.23
	50%	.43*	.147	.003	.15	.72
	40%	.13	.155	.415	-.18	.43
	20%	.52*	.175	.003	.18	.87
	10%	.42*	.185	.024	.06	.78
50%	100%	-.49*	.105	.000	-.69	-.28
	60%	-.43*	.147	.003	-.72	-.15
	40%	-.31*	.118	.009	-.54	-.08
	20%	.09	.143	.542	-.19	.37
	10%	-.01	.155	.925	-.32	.29
40%	100%	-.18	.117	.126	-.41	.05
	60%	-.13	.155	.415	-.43	.18
	50%	.31*	.118	.009	.08	.54
	20%	.40*	.152	.010	.10	.69
	10%	.29	.163	.073	-.03	.61
20%	100%	-.57*	.142	.000	-.85	-.30
	60%	-.52*	.175	.003	-.87	-.18
	50%	-.09	.143	.542	-.37	.19
	40%	-.40*	.152	.010	-.69	-.10
	10%	-.10	.182	.576	-.46	.26
10%	100%	-.47*	.154	.002	-.77	-.17
	60%	-.42*	.185	.024	-.78	-.06
	50%	.01	.155	.925	-.29	.32
	40%	-.29	.163	.073	-.61	.03
	20%	.10	.182	.576	-.26	.46

B17. Multiple comparisons for number of dead shoots for *Khaya grandifoliola*

dead1
LSD

(I) Density of mahogany	(J) Density of mahogany	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
100%	60%	-7.7500	7.28440	.301	-23.0540	7.5540
	50%	-16.0000*	7.28440	.041	-31.3040	-.6960
	40%	10.2500	7.28440	.176	-5.0540	25.5540
	20%	1.7500	7.28440	.813	-13.5540	17.0540
	10%	8.0000	7.28440	.287	-7.3040	23.3040
60%	100%	7.7500	7.28440	.301	-7.5540	23.0540
	50%	-8.2500	7.28440	.272	-23.5540	7.0540
	40%	18.0000*	7.28440	.024	2.6960	33.3040
	20%	9.5000	7.28440	.209	-5.8040	24.8040
	10%	15.7500*	7.28440	.044	.4460	31.0540
50%	100%	16.0000*	7.28440	.041	.6960	31.3040
	60%	8.2500	7.28440	.272	-7.0540	23.5540
	40%	26.2500*	7.28440	.002	10.9460	41.5540
	20%	17.7500*	7.28440	.025	2.4460	33.0540
	10%	24.0000*	7.28440	.004	8.6960	39.3040
40%	100%	-10.2500	7.28440	.176	-25.5540	5.0540
	60%	-18.0000*	7.28440	.024	-33.3040	-2.6960
	50%	-26.2500*	7.28440	.002	-41.5540	-10.9460
	20%	-8.5000	7.28440	.258	-23.8040	6.8040
	10%	-2.2500	7.28440	.761	-17.5540	13.0540
20%	100%	-1.7500	7.28440	.813	-17.0540	13.5540
	60%	-9.5000	7.28440	.209	-24.8040	5.8040
	50%	-17.7500*	7.28440	.025	-33.0540	-2.4460
	40%	8.5000	7.28440	.258	-6.8040	23.8040
	10%	6.2500	7.28440	.402	-9.0540	21.5540
10%	100%	-8.0000	7.28440	.287	-23.3040	7.3040
	60%	-15.7500*	7.28440	.044	-31.0540	-.4460
	50%	-24.0000*	7.28440	.004	-39.3040	-8.6960
	40%	2.2500	7.28440	.761	-13.0540	17.5540
	20%	-6.2500	7.28440	.402	-21.5540	9.0540

B18. Multiple comparisons for number of dead shoots for *Khaya ivorensis*

dead2
LSD

(I) Density of mahogany	(J) Density of mahogany	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
100%	60%	9.0000*	2.79136	.005	3.1356	14.8644
	50%	9.2500*	2.79136	.004	3.3856	15.1144
	40%	7.7500*	2.79136	.012	1.8856	13.6144
	20%	11.2500*	2.79136	.001	5.3856	17.1144
	10%	10.2500*	2.79136	.002	4.3856	16.1144
60%	100%	-9.0000*	2.79136	.005	-14.8644	-3.1356
	50%	.2500	2.79136	.930	-5.6144	6.1144
	40%	-1.2500	2.79136	.660	-7.1144	4.6144
	20%	2.2500	2.79136	.431	-3.6144	8.1144
	10%	1.2500	2.79136	.660	-4.6144	7.1144
50%	100%	-9.2500*	2.79136	.004	-15.1144	-3.3856
	60%	-.2500	2.79136	.930	-6.1144	5.6144
	40%	-1.5000	2.79136	.598	-7.3644	4.3644
	20%	2.0000	2.79136	.483	-3.8644	7.8644
	10%	1.0000	2.79136	.724	-4.8644	6.8644
40%	100%	-7.7500*	2.79136	.012	-13.6144	-1.8856
	60%	1.2500	2.79136	.660	-4.6144	7.1144
	50%	1.5000	2.79136	.598	-4.3644	7.3644
	20%	3.5000	2.79136	.226	-2.3644	9.3644
	10%	2.5000	2.79136	.382	-3.3644	8.3644
20%	100%	-11.2500*	2.79136	.001	-17.1144	-5.3856
	60%	-2.2500	2.79136	.431	-8.1144	3.6144
	50%	-2.0000	2.79136	.483	-7.8644	3.8644
	40%	-3.5000	2.79136	.226	-9.3644	2.3644
	10%	-1.0000	2.79136	.724	-6.8644	4.8644
10%	100%	-10.2500*	2.79136	.002	-16.1144	-4.3856
	60%	-1.2500	2.79136	.660	-7.1144	4.6144
	50%	-1.0000	2.79136	.724	-6.8644	4.8644
	40%	-2.5000	2.79136	.382	-8.3644	3.3644
	20%	1.0000	2.79136	.724	-4.8644	6.8644

B19. Multiple comparisons for length of longest dead shoot for *Khaya grandifoliola*

length of longest dead shoot
LSD

(I) Density of Mahogany (%)	(J) Density of Mahogany (%)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
100%	60%	-3.78	2.162	.081	-8.03	.46
	50%	-2.84	1.877	.131	-6.52	.85
	40%	2.39	2.167	.271	-1.87	6.64
	20%	-3.11	2.463	.208	-7.94	1.73
	10%	-9.63*	2.577	.000	-14.69	-4.57
60%	100%	3.78	2.162	.081	-.46	8.03
	50%	.95	1.931	.624	-2.84	4.74
	40%	6.17*	2.213	.005	1.83	10.51
	20%	.68	2.504	.787	-4.24	5.59
	10%	-5.85*	2.616	.026	-10.98	-.71
50%	100%	2.84	1.877	.131	-.85	6.52
	60%	-.95	1.931	.624	-4.74	2.84
	40%	5.22*	1.936	.007	1.42	9.02
	20%	-.27	2.263	.905	-4.71	4.17
	10%	-6.79*	2.386	.005	-11.48	-2.11
40%	100%	-2.39	2.167	.271	-6.64	1.87
	60%	-6.17*	2.213	.005	-10.51	-1.83
	50%	-5.22*	1.936	.007	-9.02	-1.42
	20%	-5.49*	2.508	.029	-10.42	-.57
	10%	-12.02*	2.620	.000	-17.16	-6.87
20%	100%	3.11	2.463	.208	-1.73	7.94
	60%	-.68	2.504	.787	-5.59	4.24
	50%	.27	2.263	.905	-4.17	4.71
	40%	5.49*	2.508	.029	.57	10.42
	10%	-6.52*	2.870	.023	-12.16	-.89
10%	100%	9.63*	2.577	.000	4.57	14.69
	60%	5.85*	2.616	.026	.71	10.98
	50%	6.79*	2.386	.005	2.11	11.48
	40%	12.02*	2.620	.000	6.87	17.16
	20%	6.52*	2.870	.023	.89	12.16

B20. Multiple comparisons for length of longest dead shoot for *Khaya ivorensis*

Length of longest dead shoot
LSD

(I) Density of mahogany	(J) Density of mahogany	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
100%	60%	2.02	2.064	.328	-2.03	6.08
	50%	4.46*	1.488	.003	1.53	7.38
	40%	1.00	1.656	.548	-2.26	4.25
	20%	5.71*	2.015	.005	1.75	9.67
	10%	4.85*	2.183	.027	.56	9.15
60%	100%	-2.02	2.064	.328	-6.08	2.03
	50%	2.43	2.081	.243	-1.66	6.52
	40%	-1.03	2.205	.642	-5.36	3.31
	20%	3.69	2.485	.139	-1.20	8.57
	10%	2.83	2.624	.281	-2.33	7.99
50%	100%	-4.46*	1.488	.003	-7.38	-1.53
	60%	-2.43	2.081	.243	-6.52	1.66
	40%	-3.46*	1.677	.040	-6.76	-.17
	20%	1.25	2.032	.538	-2.74	5.24
	10%	.40	2.199	.857	-3.92	4.72
40%	100%	-1.00	1.656	.548	-4.25	2.26
	60%	1.03	2.205	.642	-3.31	5.36
	50%	3.46*	1.677	.040	.17	6.76
	20%	4.71*	2.158	.030	.47	8.95
	10%	3.86	2.316	.096	-.69	8.41
20%	100%	-5.71*	2.015	.005	-9.67	-1.75
	60%	-3.69	2.485	.139	-8.57	1.20
	50%	-1.25	2.032	.538	-5.24	2.74
	40%	-4.71*	2.158	.030	-8.95	-.47
	10%	-.85	2.585	.741	-5.93	4.23
10%	100%	-4.85*	2.183	.027	-9.15	-.56
	60%	-2.83	2.624	.281	-7.99	2.33
	50%	-.40	2.199	.857	-4.72	3.92
	40%	-3.86	2.316	.096	-8.41	.69
	20%	.85	2.585	.741	-4.23	5.93

B21. Multiple comparisons for number of fresh attack for *Khaya grandifoliola* (Kg) and *Khaya ivorensis* (Ki)

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Fresh attack (Kg)	Between Groups	30.500	5	6.100	.919	.491
	Within Groups	119.500	18	6.639		
	Total	150.000	23			
Fresh attack (Ki)	Between Groups	8.833	5	1.767	.624	.684
	Within Groups	51.000	18	2.833		
	Total	59.833	23			

APPENDIX C

C1. Carbon sequestration calculation for *Khaya grandifoliola*

Kg																					
YR	Annual growth increment	Stock vol.	Biomass expansion factor	Wood density.	Tree biomass	Abovegrd Carbon stock	Root to shoot ratio	Belowgrd carbon	Area plted	Net carbon	Actual net GHG removal	Base line Biomass M	Base line Above grd C	R	Belowgrd C	Net C	Baseline actual net C	Net GHG removal	Year	Tcer	Net accumulation
		m³/ha	BEF	tdm/m³	tdm/ha	tc/ha	R	tc/ha	ha	tc	tco2e	tdm/ha	tc/ha		tc/ha	tc		tco2e		Tcer	tco2
0	2.3	0	1.4	0.6	0	0	0.42	0	10	0	0	6.2	3.1	1.58	4.898	103.974	381.238	-381.24	2008	0	-381.24
1	2.3	2.3	1.4	0.6	1.932	0.966	0.42	0.40572	10	13.7172	50.2964	6.2	3.1	1.58	4.898	103.974	381.238	-330.94	2009	-330.94	-712.18
2	2.3	4.6	1.4	0.6	3.864	1.932	0.42	0.81144	10	27.4344	100.593	6.2	3.1	1.58	4.898	103.974	381.238	-280.65	2010	0	-992.82
3	2.3	6.9	1.4	0.6	5.796	2.898	0.42	1.21716	10	41.1516	150.889	6.2	3.1	1.58	4.898	103.974	381.238	-230.35	2011	0	-1223.20
4	2.3	9.2	1.4	0.6	7.728	3.864	0.42	1.62288	10	54.8688	201.186	6.2	3.1	1.58	4.898	103.974	381.238	-180.05	2012	0	-1403.20
5	2.3	11.5	1.4	0.6	9.66	4.83	0.42	2.0286	10	68.586	251.482	6.2	3.1	1.58	4.898	103.974	381.238	-129.76	2013	0	-1533.00
6	2.3	13.8	1.4	0.6	11.592	5.796	0.42	2.43432	10	82.3032	301.778	6.2	3.1	1.58	4.898	103.974	381.238	-79.46	2014	-79.46	-1612.40
7	2.3	16.1	1.4	0.6	13.524	6.762	0.42	2.84004	10	96.0204	352.075	6.2	3.1	1.58	4.898	103.974	381.238	-29.163	2015	0	-1641.60
8	2.3	18.4	1.4	0.6	15.456	7.728	0.42	3.24576	10	109.738	402.371	6.2	3.1	1.58	4.898	103.974	381.238	21.1332	2016	0	-1620.50
9	2.3	20.7	1.4	0.6	17.388	8.694	0.42	3.65148	10	123.455	452.668	6.2	3.1	1.58	4.898	103.974	381.238	71.4296	2017	0	-1549.00
10	2.3	23	1.4	0.6	19.32	9.66	0.42	4.0572	10	137.172	502.964	6.2	3.1	1.58	4.898	103.974	381.238	121.726	2018	0	-1427.30
11	2.3	25.3	1.4	0.6	21.252	10.626	0.42	4.46292	10	150.889	553.26	6.2	3.1	1.58	4.898	103.974	381.238	172.022	2019	172.022	-1255.30
12	2.3	27.6	1.4	0.6	23.184	11.592	0.42	4.86864	10	164.606	603.557	6.2	3.1	1.58	4.898	103.974	381.238	222.319	2020	0	-1033.00
13	2.3	29.9	1.4	0.6	25.116	12.558	0.42	5.27436	10	178.324	653.853	6.2	3.1	1.58	4.898	103.974	381.238	272.615	2021	0	-760.36
14	2.3	32.2	1.4	0.6	27.048	13.524	0.42	5.68008	10	192.041	704.15	6.2	3.1	1.58	4.898	103.974	381.238	322.912	2022	0	-437.45
15	2.3	34.5	1.4	0.6	28.98	14.49	0.42	6.0858	10	205.758	754.446	6.2	3.1	1.58	4.898	103.974	381.238	373.208	2023	0	-64.24
16	2.3	36.8	1.4	0.6	30.912	15.456	0.42	6.49152	10	219.475	804.742	6.2	3.1	1.58	4.898	103.974	381.238	423.504	2024	423.504	359.264
17	2.3	39.1	1.4	0.6	32.844	16.422	0.42	6.89724	10	233.192	855.039	6.2	3.1	1.58	4.898	103.974	381.238	473.801	2025	0	833.06
18	2.3	41.4	1.4	0.6	34.776	17.388	0.42	7.30296	10	246.91	905.335	6.2	3.1	1.58	4.898	103.974	381.238	524.097	2026	0	1357.16
19	2.3	43.7	1.4	0.6	36.708	18.354	0.42	7.70868	10	260.627	955.632	6.2	3.1	1.58	4.898	103.974	381.238	574.394	2027	0	1931.56
20	2.3	46	1.4	0.6	38.64	19.32	0.42	8.1144	10	274.344	1005.93	6.2	3.1	1.58	4.898	103.974	381.238	624.69	2028	0	2556.25

21	2.3	48.3	1.4	0.6	40.572	20.286	0.42	8.52012	10	288.061	1056.22	6.2	3.1	1.58	4.898	103.974	381.238	674.986	2029	674.986	3231.23
22	2.3	50.6	1.4	0.6	42.504	21.252	0.42	8.92584	10	301.778	1106.52	6.2	3.1	1.58	4.898	103.974	381.238	725.283	2030	0	3956.52
23	2.3	52.9	1.4	0.6	44.436	22.218	0.42	9.33156	10	315.496	1156.82	6.2	3.1	1.58	4.898	103.974	381.238	775.579	2031	0	4732.09
24	2.3	55.2	1.4	0.6	46.368	23.184	0.42	9.73728	10	329.213	1207.11	6.2	3.1	1.58	4.898	103.974	381.238	825.876	2032	0	5557.97
25	2.3	57.5	1.4	0.6	48.3	24.15	0.42	10.143	10	342.93	1257.41	6.2	3.1	1.58	4.898	103.974	381.238	876.172	2033	0	6434.14
26	2.3	59.8	1.4	0.6	50.232	25.116	0.42	10.5487	10	356.647	1307.71	6.2	3.1	1.58	4.898	103.974	381.238	926.468	2034	926.468	7360.61
27	2.3	62.1	1.4	0.6	52.164	26.082	0.42	10.9544	10	370.364	1358	6.2	3.1	1.58	4.898	103.974	381.238	976.765	2035	0	8337.38
28	2.3	64.4	1.4	0.6	54.096	27.048	0.42	11.3602	10	384.082	1408.3	6.2	3.1	1.58	4.898	103.974	381.238	1027.06	2036	0	9364.44
29	2.3	66.7	1.4	0.6	56.028	28.014	0.42	11.7659	10	397.799	1458.6	6.2	3.1	1.58	4.898	103.974	381.238	1077.36	2037	0	10441.80
30	2.3	69	1.4	0.6	57.96	28.98	0.42	12.1716	10	411.516	1508.89	6.2	3.1	1.58	4.898	103.974	381.238	1127.65	2038	0	11569.40
31	2.3	71.3	1.4	0.6	59.892	29.946	0.42	12.5773	10	425.233	1559.19	6.2	3.1	1.58	4.898	103.974	381.238	1177.95	2039	1177.95	12747.40
32	2.3	73.6	1.4	0.6	61.824	30.912	0.42	12.983	10	438.95	1609.48	6.2	3.1	1.58	4.898	103.974	381.238	1228.25	2040	0	13975.60
33	2.3	75.9	1.4	0.6	63.756	31.878	0.42	13.3888	10	452.668	1659.78	6.2	3.1	1.58	4.898	103.974	381.238	1278.54	2041	0	15254.20
34	2.3	78.2	1.4	0.6	65.688	32.844	0.42	13.7945	10	466.385	1710.08	6.2	3.1	1.58	4.898	103.974	381.238	1328.84	2042	0	16583.00
35	2.3	80.5	1.4	0.6	67.62	33.81	0.42	14.2002	10	480.102	1760.37	6.2	3.1	1.58	4.898	103.974	381.238	1379.14	2043	0	17962.20
36	2.3	82.8	1.4	0.6	69.552	34.776	0.42	14.6059	10	493.819	1810.67	6.2	3.1	1.58	4.898	103.974	381.238	1429.43	2044	1429.43	19391.60
37	2.3	85.1	1.4	0.6	71.484	35.742	0.42	15.0116	10	507.536	1860.97	6.2	3.1	1.58	4.898	103.974	381.238	1479.73	2045	0	20871.30
38	2.3	87.4	1.4	0.6	73.416	36.708	0.42	15.4174	10	521.254	1911.26	6.2	3.1	1.58	4.898	103.974	381.238	1530.03	2046	0	22401.40
39	2.3	89.7	1.4	0.6	75.348	37.674	0.42	15.8231	10	534.971	1961.56	6.2	3.1	1.58	4.898	103.974	381.238	1580.32	2047	0	23981.70
40	2.3	92	1.4	0.6	77.28	38.64	0.42	16.2288	10	548.688	2011.86	6.2	3.1	1.58	4.898	103.974	381.238	1630.62	2048	0	25612.30

C2. Carbon sequestration calculation for *Khaya ivorensis*

Ki																					
YR	Annual growth increment	Stock vol.	Biomass expansion factor	Wood density.	Tree biomass	Abovegrd Carbon stock	Root to shoot ratio	Belowgrd carbon	Area plted	Net carbon	Actual net GHG removal	Baseline Biomass M	Baseline Above grd C	R	Belowgrd C	Net C	Baseline actual net C	Net GHG removal	Year	Tcer	Net accumulation
	m³/ha	m³/ha	BEF	tdm/m³	tdm/ha	tc/ha	R	tc/ha	ha	tc	tco2e	tdm/ha	tc/ha		tc/ha	tc		tco2e		Tcer	tco2
0	2.3	0	1.4	0.44	0	0	0.42	0	10	0	0	6.2	3.1	1.58	4.898	103.974	381.238	-381.24	2008	0	-381.24
1	2.3	2.3	1.4	0.44	1.4168	0.7084	0.42	0.29753	10	10.0593	36.884	6.2	3.1	1.58	4.898	103.974	381.238	-344.35	2009	-344.35	-725.59
2	2.3	4.6	1.4	0.44	2.8336	1.4168	0.42	0.59506	10	20.1186	73.7681	6.2	3.1	1.58	4.898	103.974	381.238	-307.47	2010	0	-1033.10
3	2.3	6.9	1.4	0.44	4.2504	2.1252	0.42	0.89258	10	30.1778	110.652	6.2	3.1	1.58	4.898	103.974	381.238	-270.59	2011	0	-1303.60
4	2.3	9.2	1.4	0.44	5.6672	2.8336	0.42	1.19011	10	40.2371	147.536	6.2	3.1	1.58	4.898	103.974	381.238	-233.7	2012	0	-1537.30
5	2.3	11.5	1.4	0.44	7.084	3.542	0.42	1.48764	10	50.2964	184.42	6.2	3.1	1.58	4.898	103.974	381.238	-196.82	2013	0	-1734.20
6	2.3	13.8	1.4	0.44	8.5008	4.2504	0.42	1.78517	10	60.3557	221.304	6.2	3.1	1.58	4.898	103.974	381.238	-159.93	2014	-159.93	-1894.10
7	2.3	16.1	1.4	0.44	9.9176	4.9588	0.42	2.0827	10	70.415	258.188	6.2	3.1	1.58	4.898	103.974	381.238	-123.05	2015	0	-2017.20
8	2.3	18.4	1.4	0.44	11.3344	5.6672	0.42	2.38022	10	80.4742	295.072	6.2	3.1	1.58	4.898	103.974	381.238	-86.166	2016	0	-2103.30
9	2.3	20.7	1.4	0.44	12.7512	6.3756	0.42	2.67775	10	90.5335	331.956	6.2	3.1	1.58	4.898	103.974	381.238	-49.282	2017	0	-2152.60
10	2.3	23	1.4	0.44	14.168	7.084	0.42	2.97528	10	100.593	368.84	6.2	3.1	1.58	4.898	103.974	381.238	-12.398	2018	0	-2165.00
11	2.3	25.3	1.4	0.44	15.5848	7.7924	0.42	3.27281	10	110.652	405.724	6.2	3.1	1.58	4.898	103.974	381.238	24.4863	2019	24.4863	-2140.50
12	2.3	27.6	1.4	0.44	17.0016	8.5008	0.42	3.57034	10	120.711	442.608	6.2	3.1	1.58	4.898	103.974	381.238	61.3703	2020	0	-2079.10
13	2.3	29.9	1.4	0.44	18.4184	9.2092	0.42	3.86786	10	130.771	479.492	6.2	3.1	1.58	4.898	103.974	381.238	98.2543	2021	0	-1980.90
14	2.3	32.2	1.4	0.44	19.8352	9.9176	0.42	4.16539	10	140.83	516.376	6.2	3.1	1.58	4.898	103.974	381.238	135.138	2022	0	-1845.70
15	2.3	34.5	1.4	0.44	21.252	10.626	0.42	4.46292	10	150.889	553.26	6.2	3.1	1.58	4.898	103.974	381.238	172.022	2023	0	-1673.70
16	2.3	36.8	1.4	0.44	22.6688	11.3344	0.42	4.76045	10	160.948	590.144	6.2	3.1	1.58	4.898	103.974	381.238	208.906	2024	208.906	-1464.80
17	2.3	39.1	1.4	0.44	24.0856	12.0428	0.42	5.05798	10	171.008	627.028	6.2	3.1	1.58	4.898	103.974	381.238	245.79	2025	0	-1219.00
18	2.3	41.4	1.4	0.44	25.5024	12.7512	0.42	5.3555	10	181.067	663.912	6.2	3.1	1.58	4.898	103.974	381.238	282.674	2026	0	-936.35
19	2.3	43.7	1.4	0.44	26.9192	13.4596	0.42	5.65303	10	191.126	700.797	6.2	3.1	1.58	4.898	103.974	381.238	319.559	2027	0	-616.79
20	2.3	46	1.4	0.44	28.336	14.168	0.42	5.95056	10	201.186	737.681	6.2	3.1	1.58	4.898	103.974	381.238	356.443	2028	0	-260.35

21	2.3	48.3	1.4	0.44	29.7528	14.8764	0.42	6.24809	10	211.245	774.565	6.2	3.1	1.58	4.898	103.974	381.238	393.327	2029	393.327	132.97
22	2.3	50.6	1.4	0.44	31.1696	15.5848	0.42	6.54562	10	221.304	811.449	6.2	3.1	1.58	4.898	103.974	381.238	430.211	2030	0	563.18
23	2.3	52.9	1.4	0.44	32.5864	16.2932	0.42	6.84314	10	231.363	848.333	6.2	3.1	1.58	4.898	103.974	381.238	467.095	2031	0	1030.28
24	2.3	55.2	1.4	0.44	34.0032	17.0016	0.42	7.14067	10	241.423	885.217	6.2	3.1	1.58	4.898	103.974	381.238	503.979	2032	0	1534.26
25	2.3	57.5	1.4	0.44	35.42	17.71	0.42	7.4382	10	251.482	922.101	6.2	3.1	1.58	4.898	103.974	381.238	540.863	2033	0	2075.12
26	2.3	59.8	1.4	0.44	36.8368	18.4184	0.42	7.73573	10	261.541	958.985	6.2	3.1	1.58	4.898	103.974	381.238	577.747	2034	577.747	2652.87
27	2.3	62.1	1.4	0.44	38.2536	19.1268	0.42	8.03326	10	271.601	995.869	6.2	3.1	1.58	4.898	103.974	381.238	614.631	2035	0	3267.50
28	2.3	64.4	1.4	0.44	39.6704	19.8352	0.42	8.33078	10	281.66	1032.75	6.2	3.1	1.58	4.898	103.974	381.238	651.515	2036	0	3919.01
29	2.3	66.7	1.4	0.44	41.0872	20.5436	0.42	8.62831	10	291.719	1069.64	6.2	3.1	1.58	4.898	103.974	381.238	688.399	2037	0	4607.41
30	2.3	69	1.4	0.44	42.504	21.252	0.42	8.92584	10	301.778	1106.52	6.2	3.1	1.58	4.898	103.974	381.238	725.283	2038	0	5332.69
31	2.3	71.3	1.4	0.44	43.9208	21.9604	0.42	9.22337	10	311.838	1143.4	6.2	3.1	1.58	4.898	103.974	381.238	762.167	2039	762.167	6094.86
32	2.3	73.6	1.4	0.44	45.3376	22.6688	0.42	9.5209	10	321.897	1180.29	6.2	3.1	1.58	4.898	103.974	381.238	799.051	2040	0	6893.91
33	2.3	75.9	1.4	0.44	46.7544	23.3772	0.42	9.81842	10	331.956	1217.17	6.2	3.1	1.58	4.898	103.974	381.238	835.935	2041	0	7729.85
34	2.3	78.2	1.4	0.44	48.1712	24.0856	0.42	10.116	10	342.016	1254.06	6.2	3.1	1.58	4.898	103.974	381.238	872.819	2042	0	8602.67
35	2.3	80.5	1.4	0.44	49.588	24.794	0.42	10.4135	10	352.075	1290.94	6.2	3.1	1.58	4.898	103.974	381.238	909.703	2043	0	9512.37
36	2.3	82.8	1.4	0.44	51.0048	25.5024	0.42	10.711	10	362.134	1327.82	6.2	3.1	1.58	4.898	103.974	381.238	946.587	2044	946.587	10459.00
37	2.3	85.1	1.4	0.44	52.4216	26.2108	0.42	11.0085	10	372.193	1364.71	6.2	3.1	1.58	4.898	103.974	381.238	983.471	2045	0	11442.40
38	2.3	87.4	1.4	0.44	53.8384	26.9192	0.42	11.3061	10	382.253	1401.59	6.2	3.1	1.58	4.898	103.974	381.238	1020.36	2046	0	12462.80
39	2.3	89.7	1.4	0.44	55.2552	27.6276	0.42	11.6036	10	392.312	1438.48	6.2	3.1	1.58	4.898	103.974	381.238	1057.24	2047	0	13520.00
40	2.3	92	1.4	0.44	56.672	28.336	0.42	11.9011	10	402.371	1475.36	6.2	3.1	1.58	4.898	103.974	381.238	1094.12	2048	0	14614.10

C3. Carbon sequestration calculation for *Entandrophragma angolense*

Ea																					
YR	**Annual growth increment**	**Stock vol.**	**Biomass expansion factor**	**Wood density.**	**Tree biomass**	**AbovegrdCarbon stock**	**Root to shoot ratio**	**Belowgrd carbon**	**Area plted**	**Net carbon**	**Actual net GHG removal**	**Baseline Biomass M**	**Baseline Above grd C**	**R**	**Below grd C**	**Net C**	**Baseline actual net C**	**Net GHG removal**	**Year**	**Tcer**	**Net accumulation**
	m³/ha	m³/ha	BEF	tdm/m³	tdm/ha	tc/ha	R	tc/ha	ha	tc	tco2e	tdm/ha	tc/ha		tc/ha	tc		tco2e		Tcer	tco2
0	2.3	0	1.4	0.45	0	0	0.42	0	10	0	0	6.2	3.1	1.58	4.898	103.974	381.238	-381.238	2008	0	-381.24
1	2.3	2.3	1.4	0.45	1.449	0.7245	0.42	0.30429	10	10.2879	37.7223	6.2	3.1	1.58	4.898	103.974	381.238	-343.516	2009	-343.516	-724.75
2	2.3	4.6	1.4	0.45	2.898	1.449	0.42	0.60858	10	20.5758	75.4446	6.2	3.1	1.58	4.898	103.974	381.238	-305.793	2010	0	-1030.55
3	2.3	6.9	1.4	0.45	4.347	2.1735	0.42	0.91287	10	30.8637	113.1669	6.2	3.1	1.58	4.898	103.974	381.238	-268.071	2011	0	-1298.62
4	2.3	9.2	1.4	0.45	5.796	2.898	0.42	1.21716	10	41.1516	150.8892	6.2	3.1	1.58	4.898	103.974	381.238	-230.349	2012	0	-1528.97
5	2.3	11.5	1.4	0.45	7.245	3.6225	0.42	1.52145	10	51.4395	188.6115	6.2	3.1	1.58	4.898	103.974	381.238	-192.627	2013	0	-1721.59
6	2.3	13.8	1.4	0.45	8.694	4.347	0.42	1.82574	10	61.7274	226.3338	6.2	3.1	1.58	4.898	103.974	381.238	-154.904	2014	-154.904	-1876.50
7	2.3	16.1	1.4	0.45	10.143	5.0715	0.42	2.13003	10	72.0153	264.0561	6.2	3.1	1.58	4.898	103.974	381.238	-117.182	2015	0	-1993.68
8	2.3	18.4	1.4	0.45	11.592	5.796	0.42	2.43432	10	82.3032	301.7784	6.2	3.1	1.58	4.898	103.974	381.238	-79.4596	2016	0	-2073.14
9	2.3	20.7	1.4	0.45	13.041	6.5205	0.42	2.73861	10	92.5911	339.5007	6.2	3.1	1.58	4.898	103.974	381.238	-41.7373	2017	0	-2114.88
10	2.3	23	1.4	0.45	14.49	7.245	0.42	3.0429	10	102.879	377.223	6.2	3.1	1.58	4.898	103.974	381.238	-4.015	2018	0	-2118.89
11	2.3	25.3	1.4	0.45	15.939	7.9695	0.42	3.34719	10	113.1669	414.9453	6.2	3.1	1.58	4.898	103.974	381.238	33.7073	2019	33.7073	-2085.18
12	2.3	27.6	1.4	0.45	17.388	8.694	0.42	3.65148	10	123.4548	452.6676	6.2	3.1	1.58	4.898	103.974	381.238	71.4296	2020	0	-2013.75
13	2.3	29.9	1.4	0.45	18.837	9.4185	0.42	3.95577	10	133.7427	490.3899	6.2	3.1	1.58	4.898	103.974	381.238	109.1519	2021	0	-1904.60
14	2.3	32.2	1.4	0.45	20.286	10.143	0.42	4.26006	10	144.0306	528.1122	6.2	3.1	1.58	4.898	103.974	381.238	146.8742	2022	0	-1757.73
15	2.3	34.5	1.4	0.45	21.735	10.8675	0.42	4.56435	10	154.3185	565.8345	6.2	3.1	1.58	4.898	103.974	381.238	184.5965	2023	0	-1573.13
16	2.3	36.8	1.4	0.45	23.184	11.592	0.42	4.86864	10	164.6064	603.5568	6.2	3.1	1.58	4.898	103.974	381.238	222.3188	2024	222.3188	-1350.81
17	2.3	39.1	1.4	0.45	24.633	12.3165	0.42	5.17293	10	174.8943	641.2791	6.2	3.1	1.58	4.898	103.974	381.238	260.0411	2025	0	-1090.77
18	2.3	41.4	1.4	0.45	26.082	13.041	0.42	5.47722	10	185.1822	679.0014	6.2	3.1	1.58	4.898	103.974	381.238	297.7634	2026	0	-793.01
19	2.3	43.7	1.4	0.45	27.531	13.7655	0.42	5.78151	10	195.4701	716.7237	6.2	3.1	1.58	4.898	103.974	381.238	335.4857	2027	0	-457.52
20	2.3	46	1.4	0.45	28.98	14.49	0.42	6.0858	10	205.758	754.446	6.2	3.1	1.58	4.898	103.974	381.238	373.208	2028	0	-84.31

21	2.3	48.3	1.4	0.45	30.429	15.2145	0.42	6.39009	10	216.0459	792.1683	6.2	3.1	1.58	4.898	103.974	381.238	410.9303	2029	410.9303	326.61
22	2.3	50.6	1.4	0.45	31.878	15.939	0.42	6.69438	10	226.3338	829.8906	6.2	3.1	1.58	4.898	103.974	381.238	448.6526	2030	0	775.27
23	2.3	52.9	1.4	0.45	33.327	16.6635	0.42	6.99867	10	236.6217	867.6129	6.2	3.1	1.58	4.898	103.974	381.238	486.3749	2031	0	1261.64
24	2.3	55.2	1.4	0.45	34.776	17.388	0.42	7.30296	10	246.9096	905.3352	6.2	3.1	1.58	4.898	103.974	381.238	524.0972	2032	0	1785.74
25	2.3	57.5	1.4	0.45	36.225	18.1125	0.42	7.60725	10	257.1975	943.0575	6.2	3.1	1.58	4.898	103.974	381.238	561.8195	2033	0	2347.56
26	2.3	59.8	1.4	0.45	37.674	18.837	0.42	7.91154	10	267.4854	980.7798	6.2	3.1	1.58	4.898	103.974	381.238	599.5418	2034	599.5418	2947.10
27	2.3	62.1	1.4	0.45	39.123	19.5615	0.42	8.21583	10	277.7733	1018.502	6.2	3.1	1.58	4.898	103.974	381.238	637.2641	2035	0	3584.37
28	2.3	64.4	1.4	0.45	40.572	20.286	0.42	8.52012	10	288.0612	1056.224	6.2	3.1	1.58	4.898	103.974	381.238	674.9864	2036	0	4259.35
29	2.3	66.7	1.4	0.45	42.021	21.0105	0.42	8.82441	10	298.3491	1093.947	6.2	3.1	1.58	4.898	103.974	381.238	712.7087	2037	0	4972.06
30	2.3	69	1.4	0.45	43.47	21.735	0.42	9.1287	10	308.637	1131.669	6.2	3.1	1.58	4.898	103.974	381.238	750.431	2038	0	5722.49
31	2.3	71.3	1.4	0.45	44.919	22.4595	0.42	9.43299	10	318.9249	1169.391	6.2	3.1	1.58	4.898	103.974	381.238	788.1533	2039	788.1533	6510.65
32	2.3	73.6	1.4	0.45	46.368	23.184	0.42	9.73728	10	329.2128	1207.114	6.2	3.1	1.58	4.898	103.974	381.238	825.8756	2040	0	7336.52
33	2.3	75.9	1.4	0.45	47.817	23.9085	0.42	10.04157	10	339.5007	1244.836	6.2	3.1	1.58	4.898	103.974	381.238	863.5979	2041	0	8200.12
34	2.3	78.2	1.4	0.45	49.266	24.633	0.42	10.34586	10	349.7886	1282.558	6.2	3.1	1.58	4.898	103.974	381.238	901.3202	2042	0	9101.44
35	2.3	80.5	1.4	0.45	50.715	25.3575	0.42	10.65015	10	360.0765	1320.281	6.2	3.1	1.58	4.898	103.974	381.238	939.0425	2043	0	10040.48
36	2.3	82.8	1.4	0.45	52.164	26.082	0.42	10.95444	10	370.3644	1358.003	6.2	3.1	1.58	4.898	103.974	381.238	976.7648	2044	976.7648	11017.25
37	2.3	85.1	1.4	0.45	53.613	26.8065	0.42	11.25873	10	380.6523	1395.725	6.2	3.1	1.58	4.898	103.974	381.238	1014.487	2045	0	12031.73
38	2.3	87.4	1.4	0.45	55.062	27.531	0.42	11.56302	10	390.9402	1433.447	6.2	3.1	1.58	4.898	103.974	381.238	1052.209	2046	0	13083.94
39	2.3	89.7	1.4	0.45	56.511	28.2555	0.42	11.86731	10	401.2281	1471.17	6.2	3.1	1.58	4.898	103.974	381.238	1089.932	2047	0	14173.87
40	2.3	92	1.4	0.45	57.96	28.98	0.42	12.1716	10	411.516	1508.892	6.2	3.1	1.58	4.898	103.974	381.238	1127.654	2048	0	15301.53

C4. Carbon sequestration calculation for *Heritieria utilis*

Hu YR	Annual growth increment	Stock vol.	Biomass expansion factor	Wood density.	Tree biomass	Abovegrd Carbon stock	Root to shoot ratio	Belowgrd carbon	Area plted	Net carbon	Actual net GHG removal	Baseline Biomass M	Baseline Above grd C	R	Belowgrd C	Net C	Baseline actual net C	Net GHG removal	Year	Tcer	Net accumulation
	m³/ha	m³/ha	BEF	tdm/m³	tdm/ha	tc/ha	R	tc/ha	ha	tc	tco2e	tdm/ha	tc/ha		tc/ha	tc		tco2e		Tcer	tco2
0	2.3	0	1.4	0.56	0	0	0.42	0	10	0	0	6.2	3.1	1.58	4.898	103.974	381.238	-381.238	2008	0	-381.24
1	2.3	2.3	1.4	0.56	1.8032	0.9016	0.42	0.378672	10	12.80272	46.94331	6.2	3.1	1.58	4.898	103.974	381.238	-334.295	2009	-334.295	-715.53
2	2.3	4.6	1.4	0.56	3.6064	1.8032	0.42	0.757344	10	25.60544	93.88661	6.2	3.1	1.58	4.898	103.974	381.238	-287.351	2010	0	-1002.88
3	2.3	6.9	1.4	0.56	5.4096	2.7048	0.42	1.136016	10	38.40816	140.8299	6.2	3.1	1.58	4.898	103.974	381.238	-240.408	2011	0	-1243.29
4	2.3	9.2	1.4	0.56	7.2128	3.6064	0.42	1.514688	10	51.21088	187.7732	6.2	3.1	1.58	4.898	103.974	381.238	-193.465	2012	0	-1436.76
5	2.3	11.5	1.4	0.56	9.016	4.508	0.42	1.89336	10	64.0136	234.7165	6.2	3.1	1.58	4.898	103.974	381.238	-146.521	2013	0	-1583.28
6	2.3	13.8	1.4	0.56	10.8192	5.4096	0.42	2.272032	10	76.81632	281.6598	6.2	3.1	1.58	4.898	103.974	381.238	-99.5782	2014	-99.5782	-1682.86
7	2.3	16.1	1.4	0.56	12.6224	6.3112	0.42	2.650704	10	89.61904	328.6031	6.2	3.1	1.58	4.898	103.974	381.238	-52.6349	2015	0	-1735.49
8	2.3	18.4	1.4	0.56	14.4256	7.2128	0.42	3.029376	10	102.4218	375.5465	6.2	3.1	1.58	4.898	103.974	381.238	-5.69155	2016	0	-1741.18
9	2.3	20.7	1.4	0.56	16.2288	8.1144	0.42	3.408048	10	115.2245	422.4898	6.2	3.1	1.58	4.898	103.974	381.238	41.25176	2017	0	-1699.93
10	2.3	23	1.4	0.56	18.032	9.016	0.42	3.78672	10	128.0272	469.4331	6.2	3.1	1.58	4.898	103.974	381.238	88.19507	2018	0	-1611.74
11	2.3	25.3	1.4	0.56	19.8352	9.9176	0.42	4.165392	10	140.8299	516.3764	6.2	3.1	1.58	4.898	103.974	381.238	135.1384	2019	135.1384	-1476.60
12	2.3	27.6	1.4	0.56	21.6384	10.8192	0.42	4.544064	10	153.6326	563.3197	6.2	3.1	1.58	4.898	103.974	381.238	182.0817	2020	0	-1294.52
13	2.3	29.9	1.4	0.56	23.4416	11.7208	0.42	4.922736	10	166.4354	610.263	6.2	3.1	1.58	4.898	103.974	381.238	229.025	2021	0	-1065.49
14	2.3	32.2	1.4	0.56	25.2448	12.6224	0.42	5.301408	10	179.2381	657.2063	6.2	3.1	1.58	4.898	103.974	381.238	275.9683	2022	0	-789.52
15	2.3	34.5	1.4	0.56	27.048	13.524	0.42	5.68008	10	192.0408	704.1496	6.2	3.1	1.58	4.898	103.974	381.238	322.9116	2023	0	-466.61
16	2.3	36.8	1.4	0.56	28.8512	14.4256	0.42	6.058752	10	204.8435	751.0929	6.2	3.1	1.58	4.898	103.974	381.238	369.8549	2024	369.8549	-96.756
17	2.3	39.1	1.4	0.56	30.6544	15.3272	0.42	6.437424	10	217.6462	798.0362	6.2	3.1	1.58	4.898	103.974	381.238	416.7982	2025	0	320.04
18	2.3	41.4	1.4	0.56	32.4576	16.2288	0.42	6.816096	10	230.449	844.9795	6.2	3.1	1.58	4.898	103.974	381.238	463.7415	2026	0	783.78
19	2.3	43.7	1.4	0.56	34.2608	17.1304	0.42	7.194768	10	243.2517	891.9228	6.2	3.1	1.58	4.898	103.974	381.238	510.6848	2027	0	1294.47
20	2.3	46	1.4	0.56	36.064	18.032	0.42	7.57344	10	256.0544	938.8661	6.2	3.1	1.58	4.898	103.974	381.238	557.6281	2028	0	1852.09
21	2.3	48.3	1.4	0.56	37.8672	18.9336	0.42	7.952112	10	268.8571	985.8094	6.2	3.1	1.58	4.898	103.974	381.238	604.5714	2029	604.5714	2456.67

22	2.3	50.6	1.4	0.56	39.6704	19.8352	0.42	8.330784	10	281.6598	1032.753	6.2	3.1	1.58	4.898	103.974	381.238	651.5147	2030	0	3108.18
23	2.3	52.9	1.4	0.56	41.4736	20.7368	0.42	8.709456	10	294.4626	1079.696	6.2	3.1	1.58	4.898	103.974	381.238	698.4581	2031	0	3806.64
24	2.3	55.2	1.4	0.56	43.2768	21.6384	0.42	9.088128	10	307.2653	1126.639	6.2	3.1	1.58	4.898	103.974	381.238	745.4014	2032	0	4552.04
25	2.3	57.5	1.4	0.56	45.08	22.54	0.42	9.4668	10	320.068	1173.583	6.2	3.1	1.58	4.898	103.974	381.238	792.3447	2033	0	5344.39
26	2.3	59.8	1.4	0.56	46.8832	23.4416	0.42	9.845472	10	332.8707	1220.526	6.2	3.1	1.58	4.898	103.974	381.238	839.288	2034	839.288	6183.68
27	2.3	62.1	1.4	0.56	48.6864	24.3432	0.42	10.22414	10	345.6734	1267.469	6.2	3.1	1.58	4.898	103.974	381.238	886.2313	2035	0	7069.91
28	2.3	64.4	1.4	0.56	50.4896	25.2448	0.42	10.60282	10	358.4762	1314.413	6.2	3.1	1.58	4.898	103.974	381.238	933.1746	2036	0	8003.08
29	2.3	66.7	1.4	0.56	52.2928	26.1464	0.42	10.98149	10	371.2789	1361.356	6.2	3.1	1.58	4.898	103.974	381.238	980.1179	2037	0	8983.19
30	2.3	69	1.4	0.56	54.096	27.048	0.42	11.36016	10	384.0816	1408.299	6.2	3.1	1.58	4.898	103.974	381.238	1027.061	2038	0	10010.26
31	2.3	71.3	1.4	0.56	55.8992	27.9496	0.42	11.73883	10	396.8843	1455.243	6.2	3.1	1.58	4.898	103.974	381.238	1074.005	2039	1074.005	11084.26
32	2.3	73.6	1.4	0.56	57.7024	28.8512	0.42	12.1175	10	409.687	1502.186	6.2	3.1	1.58	4.898	103.974	381.238	1120.948	2040	0	12205.21
33	2.3	75.9	1.4	0.56	59.5056	29.7528	0.42	12.49618	10	422.4898	1549.129	6.2	3.1	1.58	4.898	103.974	381.238	1167.891	2041	0	13373.10
34	2.3	78.2	1.4	0.56	61.3088	30.6544	0.42	12.87485	10	435.2925	1596.072	6.2	3.1	1.58	4.898	103.974	381.238	1214.834	2042	0	14587.94
35	2.3	80.5	1.4	0.56	63.112	31.556	0.42	13.25352	10	448.0952	1643.016	6.2	3.1	1.58	4.898	103.974	381.238	1261.778	2043	0	15849.72
36	2.3	82.8	1.4	0.56	64.9152	32.4576	0.42	13.63219	10	460.8979	1689.959	6.2	3.1	1.58	4.898	103.974	381.238	1308.721	2044	1308.721	17158.44
37	2.3	85.1	1.4	0.56	66.7184	33.3592	0.42	14.01086	10	473.7006	1736.902	6.2	3.1	1.58	4.898	103.974	381.238	1355.664	2045	0	18514.10
38	2.3	87.4	1.4	0.56	68.5216	34.2608	0.42	14.38954	10	486.5034	1783.846	6.2	3.1	1.58	4.898	103.974	381.238	1402.608	2046	0	19916.71
39	2.3	89.7	1.4	0.56	70.3248	35.1624	0.42	14.76821	10	499.3061	1830.789	6.2	3.1	1.58	4.898	103.974	381.238	1449.551	2047	0	21366.26
40	2.3	92	1.4	0.56	72.128	36.064	0.42	15.14688	10	512.1088	1877.732	6.2	3.1	1.58	4.898	103.974	381.238	1496.494	2048	0	22862.75

C5. Carbon sequestration calculation for *Terminalia superba*

Ts																					
YR	**Annual growth increment**	**Stock vol.**	**Biomass expansion factor**	**Wood density.**	**Tree biomass**	**AbovegrdCarbon stock**	**Root to shoot ratio**	**Below grd carbon**	**Area plted**	**Net carbon**	**Actual net GHG removal**	**Baseline Biomass M**	**Baseline Above grd C**	**R**	**Belowgrd C**	**Net C**	**Baseline actual net C**	**Net GHG removal**	**Year**	**Tcer**	**Net accumulation**
	m³/ha	m³/ha	BEF	tdm/m³	tdm/ha	tc/ha	R	tc/ha	ha	tc	tco2e	tdm/ha	tc/ha		tc/ha	tc		tco2e		Tcer	tco2
0	2.3	0	1.4	0.5	0	0	0.42	0	10	0	0	6.2	3.1	1.58	4.898	103.974	381.238	-381.238	2008	0	-381.24
1	2.3	2.3	1.4	0.5	1.61	0.805	0.42	0.3381	10	11.431	41.91367	6.2	3.1	1.58	4.898	103.974	381.238	-339.324	2009	-339.324	-720.56
2	2.3	4.6	1.4	0.5	3.22	1.61	0.42	0.6762	10	22.862	83.82733	6.2	3.1	1.58	4.898	103.974	381.238	-297.411	2010	0	-1017.97
3	2.3	6.9	1.4	0.5	4.83	2.415	0.42	1.0143	10	34.293	125.741	6.2	3.1	1.58	4.898	103.974	381.238	-255.497	2011	0	-1273.47
4	2.3	9.2	1.4	0.5	6.44	3.22	0.42	1.3524	10	45.724	167.6547	6.2	3.1	1.58	4.898	103.974	381.238	-213.583	2012	0	-1487.05
5	2.3	11.5	1.4	0.5	8.05	4.025	0.42	1.6905	10	57.155	209.5683	6.2	3.1	1.58	4.898	103.974	381.238	-171.67	2013	0	-1658.72
6	2.3	13.8	1.4	0.5	9.66	4.83	0.42	2.0286	10	68.586	251.482	6.2	3.1	1.58	4.898	103.974	381.238	-129.756	2014	-129.756	-1788.48
7	2.3	16.1	1.4	0.5	11.27	5.635	0.42	2.3667	10	80.017	293.3957	6.2	3.1	1.58	4.898	103.974	381.238	-87.8423	2015	0	-1876.32
8	2.3	18.4	1.4	0.5	12.88	6.44	0.42	2.7048	10	91.448	335.3093	6.2	3.1	1.58	4.898	103.974	381.238	-45.9287	2016	0	-1922.25
9	2.3	20.7	1.4	0.5	14.49	7.245	0.42	3.0429	10	102.879	377.223	6.2	3.1	1.58	4.898	103.974	381.238	-4.015	2017	0	-1926.27
10	2.3	23	1.4	0.5	16.1	8.05	0.42	3.381	10	114.31	419.1367	6.2	3.1	1.58	4.898	103.974	381.238	37.89867	2018	0	-1888.37
11	2.3	25.3	1.4	0.5	17.71	8.855	0.42	3.7191	10	125.741	461.0503	6.2	3.1	1.58	4.898	103.974	381.238	79.81233	2019	79.81233	-1808.55
12	2.3	27.6	1.4	0.5	19.32	9.66	0.42	4.0572	10	137.172	502.964	6.2	3.1	1.58	4.898	103.974	381.238	121.726	2020	0	-1686.83
13	2.3	29.9	1.4	0.5	20.93	10.465	0.42	4.3953	10	148.603	544.8777	6.2	3.1	1.58	4.898	103.974	381.238	163.6397	2021	0	-1523.19
14	2.3	32.2	1.4	0.5	22.54	11.27	0.42	4.7334	10	160.034	586.7913	6.2	3.1	1.58	4.898	103.974	381.238	205.5533	2022	0	-1317.64
15	2.3	34.5	1.4	0.5	24.15	12.075	0.42	5.0715	10	171.465	628.705	6.2	3.1	1.58	4.898	103.974	381.238	247.467	2023	0	-1070.17
16	2.3	36.8	1.4	0.5	25.76	12.88	0.42	5.4096	10	182.896	670.6187	6.2	3.1	1.58	4.898	103.974	381.238	289.3807	2024	289.3807	-780.79
17	2.3	39.1	1.4	0.5	27.37	13.685	0.42	5.7477	10	194.327	712.5323	6.2	3.1	1.58	4.898	103.974	381.238	331.2943	2025	0	-449.49
18	2.3	41.4	1.4	0.5	28.98	14.49	0.42	6.0858	10	205.758	754.446	6.2	3.1	1.58	4.898	103.974	381.238	373.208	2026	0	-76.28
19	2.3	43.7	1.4	0.5	30.59	15.295	0.42	6.4239	10	217.189	796.3597	6.2	3.1	1.58	4.898	103.974	381.238	415.1217	2027	0	338.84
20	2.3	46	1.4	0.5	32.2	16.1	0.42	6.762	10	228.62	838.2733	6.2	3.1	1.58	4.898	103.974	381.238	457.0353	2028	0	795.87
21	2.3	48.3	1.4	0.5	33.81	16.905	0.42	7.1001	10	240.051	880.187	6.2	3.1	1.58	4.898	103.974	381.238	498.949	2029	498.949	1294.82

22	2.3	50.6	1.4	0.5	35.42	17.71	0.42	7.4382	10	251.482	922.1007	6.2	3.1	1.58	4.898	103.974	381.238	540.8627	2030	0	1835.68
23	2.3	52.9	1.4	0.5	37.03	18.515	0.42	7.7763	10	262.913	964.0143	6.2	3.1	1.58	4.898	103.974	381.238	582.7763	2031	0	2418.46
24	2.3	55.2	1.4	0.5	38.64	19.32	0.42	8.1144	10	274.344	1005.928	6.2	3.1	1.58	4.898	103.974	381.238	624.69	2032	0	3043.15
25	2.3	57.5	1.4	0.5	40.25	20.125	0.42	8.4525	10	285.775	1047.842	6.2	3.1	1.58	4.898	103.974	381.238	666.6037	2033	0	3709.75
26	2.3	59.8	1.4	0.5	41.86	20.93	0.42	8.7906	10	297.206	1089.755	6.2	3.1	1.58	4.898	103.974	381.238	708.5173	2034	708.5173	4418.27
27	2.3	62.1	1.4	0.5	43.47	21.735	0.42	9.1287	10	308.637	1131.669	6.2	3.1	1.58	4.898	103.974	381.238	750.431	2035	0	5168.70
28	2.3	64.4	1.4	0.5	45.08	22.54	0.42	9.4668	10	320.068	1173.583	6.2	3.1	1.58	4.898	103.974	381.238	792.3447	2036	0	5961.05
29	2.3	66.7	1.4	0.5	46.69	23.345	0.42	9.8049	10	331.499	1215.496	6.2	3.1	1.58	4.898	103.974	381.238	834.2583	2037	0	6795.31
30	2.3	69	1.4	0.5	48.3	24.15	0.42	10.143	10	342.93	1257.41	6.2	3.1	1.58	4.898	103.974	381.238	876.172	2038	0	7671.48
31	2.3	71.3	1.4	0.5	49.91	24.955	0.42	10.4811	10	354.361	1299.324	6.2	3.1	1.58	4.898	103.974	381.238	918.0857	2039	918.0857	8589.56
32	2.3	73.6	1.4	0.5	51.52	25.76	0.42	10.8192	10	365.792	1341.237	6.2	3.1	1.58	4.898	103.974	381.238	959.9993	2040	0	9549.56
33	2.3	75.9	1.4	0.5	53.13	26.565	0.42	11.1573	10	377.223	1383.151	6.2	3.1	1.58	4.898	103.974	381.238	1001.913	2041	0	10551.48
34	2.3	78.2	1.4	0.5	54.74	27.37	0.42	11.4954	10	388.654	1425.065	6.2	3.1	1.58	4.898	103.974	381.238	1043.827	2042	0	11595.30
35	2.3	80.5	1.4	0.5	56.35	28.175	0.42	11.8335	10	400.085	1466.978	6.2	3.1	1.58	4.898	103.974	381.238	1085.74	2043	0	12681.04
36	2.3	82.8	1.4	0.5	57.96	28.98	0.42	12.1716	10	411.516	1508.892	6.2	3.1	1.58	4.898	103.974	381.238	1127.654	2044	1127.654	13808.70
37	2.3	85.1	1.4	0.5	59.57	29.785	0.42	12.5097	10	422.947	1550.806	6.2	3.1	1.58	4.898	103.974	381.238	1169.568	2045	0	14978.26
38	2.3	87.4	1.4	0.5	61.18	30.59	0.42	12.8478	10	434.378	1592.719	6.2	3.1	1.58	4.898	103.974	381.238	1211.481	2046	0	16189.75
39	2.3	89.7	1.4	0.5	62.79	31.395	0.42	13.1859	10	445.809	1634.633	6.2	3.1	1.58	4.898	103.974	381.238	1253.395	2047	0	17443.14
40	2.3	92	1.4	0.5	64.4	32.2	0.42	13.524	10	457.24	1676.547	6.2	3.1	1.58	4.898	103.974	381.238	1295.309	2048	0	18738.45