KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

KUMASI, GHANA

ASSESSMENT OF THE ROOTING ABILITIES OF FOUR AFRICAN MAHOGANY SPECIES USING LEAFY STEM CUTTINGS

A THESIS

SUBMITTED TO THE DEPARTMENT OF SILVICULTURE AND FOREST MANAGEMENT OF THE FACULTY OF RENEWABLE NATURAL RESOURCES IN FULFILMENT OF THE REQUIREMENTS OF THE DEGREE OF MASTER OF PHILOSOPHY

BY

SANDRA ACHEAMPONG OWUSU

JULY, 2011

DECLARATION

I hereby declare that this submission is my own work towards the Master of Philosophy and to the best of my knowledge. It contains no material previously published by another person or 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.

Sandra Acheampong Owusu …… ……

Student Signature Date

Dr. C. Antwi-Boasiako ……. ……

Supervisor Signature Date

Dr. E. Opuni-Frimpong …….. …….....

Co-Supervisor Signature Date

Dr. Kyere Boateng ……. …….....

Head of Department Signature Date

ABSTRACT

Efforts to restore degraded forest lands using indigenous and important timber species including those of the Meliaceae family exist. Success of this exercise will, however, be dependent on the availability of quality planting material as African mahoganies are attacked by the shoot borer moth, *Hypsipyla robusta*. Existence of genotypes tolerant to the shootborer, therefore necessitates propagation using vegetative propagation in raising seedlings. This study was to develop vegetative propagation techniques using leafy stem cuttings and simple non-mist propagators to assess the effects of African mahogany species *(Khaya grandifoliola, Khaya ivorensis, Entandrophragma angolense,* and *Entandrophragma utile).* It also assessed rooting-media (river-sand, top soil and a mixture of the two (50:50 v/v) and age of stock-plant (1, 4, 7 and 12 years) of *K. grandifoliola* on the rooting ability. Anatomical properties of the shoots were studied through tissue (vessel, fibre and parenchyma) counts from transverse sections and measurements of vessel and fibre dimensions from macerated samples to determine the variability between species and ages and their relationship to the rooting ability of the stem cuttings. Rooting ability ranked as follows among the species: *K. grandifoliola* (73%) > *K. ivorensis* > *E. angolense* > *E.utile* (30%). Rooting percentage was highest for cuttings placed in the mixed medium for the *Khaya* species. This was 73% in *K. grandifoliola* and 65% in *K. ivorensis*. The *Entandrophragma* species recorded their highest rooting in top soil 46% in *E. angolense* and 40% in *E. utile* and lowest for both in river-sand: 37 % and 30 % respectively. Age of stock-plant influenced rooting ability in stem cuttings of *K. grandifoliola*: 77% (age 1) > 70% (age 4) > 68% (age 7) > 60% (age 12). Stem cuttings taken from the middle portions of shoots recorded the highest rooting

ability in all the four species (73% (*K. grandifoliola*), 65% (*K. ivorensis*), 54% (*E. angolense*) and 45% (*E. utile*) and also in 4 years (70%), 7 years (60%) and 12 years for (55%) *K. grandifoliola* stem cuttings. Sections from the four species showed similarities in vessel, parenchyma and fibre proportions with parenchyma ranking as follows: *K. grandifoliola* (35.96%) > *E. utile* (39.92%) > *K. ivorensis* (34.92%) > *E. angolense* (34.25%) and fibre ranking as follows: *E. angolense* (38.79%) > *K. ivorensis* (38.33%) > *E. utile* (37.83%) > *K. grandifoliola* (37.75%). Fibre and vessel proportions increased with increasing age of stock-plant from age 1year to12 years, while parenchyma proportion decreased with increasing age of stock-plant of *K. grandifoliola*. The high proportion of parenchyma (39.96%) corresponded with high rooting ability (73%) in *K. grandifoliola*, while high proportion of fibre (38.79%) in *E. angolense* corresponded with low rooting ability (30%). Fibre diameter, fibre lumen diameter and double fibre wall thickness ranked as follows in the species: *E. utile* > *E. angolense* > *K. grandifoliola* > *K. ivorensis*. Aside the vessel diameter, fibre and vessel dimensions ranked as follows in the four different aged stock-plants of *K. grandifoliola*: 1 < 4 < 7 < 12. The study strongly supports the idea that the four African mahogany species can be propagated vegetatively using stem cuttings which are important for *ex-situ* conservation and restoration of the mahogany species in Ghana's forest estate, especially older trees (4, 7 and 12 years) that have shown tolerance to the mahogany shootborer.

Table of Contents

TITLE PAGE NUMBER

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

APPENDICES

ACKNOWLEDGEMENTS

I am greatly indebted to the following institutions and people:

The ITTO Fellowship Programme (ITTO Fellowship Ref. 019/09A) and Dr. E. Opuni-Frimpong for financing my research work.

Dr. C. Antwi – Boasiako (FRNR) and Dr. E. Opuni – Frimpong (FORIG) for their advice, support and guidance throughout my study period.

Dr. A. A. Oteng – Amoako, Dr. S. A. Coke and Mr. E. Ebanyenle for their invaluable contributions to my studies.

The staff of FORIG especially staff of Anatomy and Entomology laboratories that were very accommodating and helped in various ways towards completing my research work.

Lord, Maureen, Nana Yaa, Joseph, Gyebi and Collins who all helped and encouraged me throughout my study period.

Kofi Amosah for his support and encouragement during my studies.

Mr. and Mrs. Owusu for the good training and education they offered me and for their help and support. To my brother, Dennis and my sisters, Nancy, Mary and Vera, I couldn't have done this without all your support and encouragement.

I wish to dedicate this thesis to my parents, Mr. and Mrs. Owusu.

CHAPTER 1

1.0 INTRODUCTION

1.1 Introduction

The Meliaceae, high-value mahoganies, have supplied international markets since the exploitation of *Swietenia* by the Spanish began in the 1500s in the Central Americas (Lamb, 1966). African mahogany species of *Entandrophragm*a and *Khaya* are considered among the most valuable commercial tropical hardwood species worldwide, contributing on average 15-30% of the timber exports of Ghana (Atuahene, 2001). Commercial exploitation of the African mahogany species has intensified over the past decades with increasing exploitation pressure across their natural ranges. FAO (1993) stated that valuable Meliaceae in Ghana (*Entandrophragma angolense*, *E. cylindricum*, *E. utile*, *Khaya anthotheca*, *K. grandifoliola* and *K. ivorensis*) are likely to become commercially extinct at their current exploitation rates mainly due to lower diameter felling limits, improved logging technology and expanding transportation networks which also enhance exploitation of timber from very long distances.

The highly selective ‘‘high grade’’ logging of the mahoganies often leads to regeneration and/or recruitment failure where natural regeneration is insufficient to replace harvested stems on a time scale required for sustainable timber production (Hall *et al*., 2003; Grogan and Galvão, 2006). Even when seed production and germination are sufficient, significant loss of seeds and seedlings may occur from predation by small mammals as reported for *Entandrophragma* species seeds in the Central African Republic, when other

food sources were in short supply (Hall, 2008). Lower regeneration of mahoganies are also attributed to insect and fungal attacks killing the majority of seedlings in more mature, humid forests, with small mammals being the most important mortality agents in young secondary forests (Negreros-Castillo *et al*., 2003; Grogan and Galvão, 2006). Thus, the reliance on natural regeneration of these important species for continuous supply of timber and conservation of genetic resources is seriously threatened.

Diminishing stocks of the natural resource base of the African mahogany species, due to over-exploitation and the poor natural regeneration has necessitated their cultivation in plantations (Alder, 1989; Hawthorne, 1993; Opuni-Frimpong, 2000). This is to ensure a sustainable resource base, which is important in maintaining the global supply of these species. Most African mahogany species have relatively fast growth rate and their high light requirement for establishment makes them especially suitable for plantations. Establishment of mahogany plantations, however, has been hampered by attacks of the larvae of the mahogany shootborer moth, *Hypsipyla robusta* (Newton *et al*., 1993; Atuahene, 2001), which destroy the apical meristem of their seedlings and saplings, resulting in excessive branching, poor form, and reduced commercial value.

There is an increased demand for genetic selection from the scarce mahogany populations still existing in the wild for genetic resistance to *Hypsipyla* for incorporation into an integrated pest management programme for their control (Newton *et al*., 1993; Opuni-Frimpong *et al*., 2008a). Studies by Opuni-Frimpong *et al*. (2008a) have indicated that some resistance/tolerance to the pest exists within natural populations of the African

mahogany species in Ghana. They recommended the need to propagate African mahogany plants that are tolerant to the shoot borer on a large scale, and develop silvicultural systems for their planting in plantations. To be successful in plantation establishment that exploit the genetically superior *Hypsipyla*-tolerant varieties and develop pest-resistant cultivars, the development of vegetative propagation techniques for the mahogany cultivars is paramount. This will produce propagules that will be genetically identical to the tolerant trees.

However, mass propagation of the African mahogany species in West Africa, where high-tech facilities, well-trained personnel and funds are difficult to come by, propagation, using stem cuttings, is the best option since it is relatively cheap and easy to adopt by local people (Hartmann *et al*., 1997).

Successful propagation of tropical tree species by rooting leafy stem cuttings depends on many interacting factors including the plant species (Maynard and Bassuk, 1996), rooting medium (Tchoundjeu *et al*., 2002), leaf area of the cutting (Leakey and Coutts, 1989; Newton *et al*., 1992a; Opuni-Frimpong, 2008b), the physiological state of the cuttings (Newton *et al*., 1996; Ofori *et al*., 1997) and the propagation environment (Ofori *et al*., 1996; Tchoundjeu and Leakey, 2001). A variety of mahogany species have been successfully propagated by rooting stem cuttings such as *K. anthotheca* (Opuni-Frimpong *et al*., 2008), *K. senegalensis* and *K. ivorensis* (Tchoundjeu and Leakey, 1996; 2000; Opuni-Frimpong *et al*., 2008b). Some of these experiments investigated rooting by testing the auxin concentration, the stock-plant age, the leaf area and cutting lengths.

Maturation is an integral part of the life cycle of all vascular plants and has important practical significance since the length of the juvenile period is inversely related to the breeding efficiency of woody perennials and to the selection of improved cultivars (Hartmann *et al*., 1997; Ofori *et al*., 1997; Husen and Pal, 2006). There have been several reasons to explain the decrease in rooting ability as stock plants mature. These include accumulation of rooting inhibitors, decrease in the endogenous content of auxins and/or root promoters and decreased sensitivity of tissues to auxins with physiological aging of the stock plant (Hartmann *et al*., 1997; Husen and Pal, 2006). However, desirable phenotypic characteristics of plants are not expressed until they reach some level of maturity (Opuni-Frimpong *et al*., 2008), making age of stock-plants a significant consideration in the rooting of leafy stem cuttings. As cuttings from coppice shoots root more readily than those from mature trees, the loss of rooting ability with age may be overcome by coppicing (Leakey *et al*., 1982b; Leakey, 1983). The transition from the juvenile to matured phase is accompanied by anatomical, morphological, physiological and biochemical changes, any of which could be used as indicators of maturity in selecting stock plants for vegetative propagation (Husen and Pal, 2006).

The type of rooting medium used in rooting cuttings is a significant factor in the rooting process (Hartmann *et al*., 1997). Even though many species are known to root successfully in various rooting media (Leakey *et al*., 1990), their rooting performance, in terms of both number of roots and rooting percentage, may largely be influenced by the type of rooting medium used (Leakey *et al*., 1990; Ofori *et al*., 1996; Tchoundjeu *et al*.,

2002). Adventitious root formation in stem cuttings of woody perennials usually originate from living parenchyma cells in the young, secondary phloem, but sometimes in vascular rays, cambium, phloem, callus, or lenticels (Hartmann *et al*., 1997; Kozlowski and Pallardy, 1997). One of the prerequisites for development of roots on cuttings, according to Kozlowski and Pallardy (1997), is availability and receptivity of parenchyma cells for regeneration of meristematic regions, as occurs in the process of wound-induced root formation.

1.2 Aim and objectives

The aim of the study was to develop a vegetative propagation techniques for African mahoganies based on the species, rooting media, age of stock plant and shoot anatomy.

The objectives of this study were to:

1. To assess the rooting ability of leafy stem cuttings of four species of African mahogany (i.e. *E. angolense, E. utile, K. grandifoliola and K. ivorensis*) in different rooting media (i.e. river sand, top soil and mixture of river sand and top soil (50:50 by volume)).
2. To assess the effect of age of stock-plants (i.e. 1-, 4-, 7- and 12-years) on the rooting ability of *K. grandifoliola* leafy stem cuttings.
3. To determine the effect of cutting position on shoot on the rooting ability of the four African mahogany species as well as from the four different ages of *K. grandifoliola*.

4. To determine the anatomical properties of shoots based on the position on shoot, type of African mahogany species and age of stock-plant of *K. grandifoliola* and their relationship to rooting ability of leafy stem cuttings.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Vegetative propagation

Vegetative propagation is the reproduction of plant material so that the progeny will contain the exact characteristics of the parent material with regard to genotype and health status (Macdonald, 1993). It can occur naturally by special vegetative structures (e.g. bulbs, tip layers, rhizomes, and runners) and can also occur as an artificial process (Leakey, 1985). The artificial process dates back about 1,000 years in both China and Japan where Chinese fir (*Cunninghamia lanceolata* (Lamb.) Hook) and sugi (*Cryptomeria japonica* (L.f.) D. Don) have been vegetatively propagated (Hartmann *et al.*, 1997). Its importance is primarily due to its ability to produce uniform planting stock and also to capture major genetic gains in a single step (Hartmann *et al.*, 1997).

Establishment of plantations of most West African timber species has been difficult and largely unsuccessful due to pest and disease attacks as well as seed availability and viability. Important hardwoods like the African mahogany species and *Milicia excelsa* are known to have severe insect pest attacks by the mahogany shootborer, *Hypsipyla robusta* and *Phytolyma* respectively. Diseases such as the die-back in *Terminalia ivorensis* and *Ceiba pentandra* also deter the establishment of these species in plantations. Some of these important species also have erratic flowering of about between 5-10 year periods as in *Triplochiton scleroxylon* (Taylor, 1960; Leakey *et al.*, 1982a), which makes seed

availability very unpredictable. Some seeds also suffer serious predation by small animals, while others have short viability periods (Grogan and Galvao, 2006).

Reduced economic value of the timbers due to pest and disease attacks, coupled with the slow returns realized from capital invested in plantation establishment, makes indigenous tree cultivation very unattractive to growers. There has, however, been growing interest in producing some of these species commercially, especially by means of vegetative propagation (Leakey *et al.*, 1982b). Vegetative reproduction of superior individuals of such species will give a more rapid method for their multiplication. In forestry, vegetative propagation can be used to reproduce fast growing trees that can produce high quality timber (Opuni-Frimpong *et al*., 2008b). A vegetative reproduction approach to plantation improvement, through the use of stem cuttings of elite trees, plays an essential role in enhancing uniformity, productivity and quality in forest plantations (Hartmann *et al*., 1997). Several methods have been applied in the vegetative propagation of these plants including grafting (budding), layering, cuttings and tissue culture (micro-propagation) (Leakey, 1985; Macdonald, 1993; Hartmann *et al.*, 1997). The use of stem cuttings, according to Leakey (1990), has become a common propagation method in forestry and agroforestry. Root initiation in stem cuttings requires that there is an appropriate environment that would reduce post-severance and physiological stress in the cutting (Hartmann *et al.*, 1997). Propagation systems used in cultivation of stem cuttings are based on spraying mist, fogging or enclosing cuttings in polythene. The design for non-mist propagators has been improved for use in most tropical environmental conditions (Leakey and Longman, 1988). However, the use of stem cuttings in most

tropical countries can be very costly due to the cost of electricity and continuous supply of water, as is needed in mist propagation systems for research and commercial scale projects (Opuni-Frimpong *et al*., 2008b).

2.2 Use of stem cuttings in vegetative propagation

Propagation by cuttings makes use of a portion of stem, root or leaf from a parent plant and then inducing the portion to develop roots and shoots by chemical, mechanical, and/or environmental manipulation (Hartmann *et al.*, 1997). Stem cuttings can be categorized mainly into leafy softwood cuttings from young shoots and leafless hardwood cuttings from older shoots (Hartmann *et al.*, 1997; Leakey, 2004). Leafy stem cuttings have the ability to photosynthesize in the propagation bed once the favourable factors are met (Mesen *et al.*, 1997b; Leakey, 2004). Propagation by cuttings requires only that a new adventitious root system or both an adventitious root and shoot systems develop (Hartmann *et al*., 1997).

2.2.1 Anatomical features and processes involved in adventitious root formation in stem cuttings

The formation of adventitious roots is dependent on the ability of plant cells to dedifferentiate and develop into a root system. Adventitious roots are of two main types, preformed roots and wound-induced roots. Preformed or latent roots generally lie dormant until cuttings are made from the stems and placed under favourable environmental conditions for further development and emergence of the primordia as adventitious roots (Hartmann *et al.*, 1997). Wound-induced roots, however, are formed

only after the cutting has been made, in response to the wounding in preparing the cutting. When the surfaces of living cells are cut and exposed, a response to wounding begins with root regeneration. The wound response and root regeneration process involve the following three processes:

- Death of the injured outer cells, formation of a necrotic plate, sealing of the wound with a corky material (suberin) and the plugging of the xylem with gum.
- Living cells behind this plate begin to divide after a few days and a layer of parenchyma cells (callus) forms a wound periderm.
- Certain cells within the vicinity of the vascular cambium and the phloem begin to divide and initiate de novo adventitious roots (Hartmann *et al.*, 1997).

Adventitious roots are usually initiated in the vicinity of differentiating vascular tissues of the organ, which gives rise to them. In young organs, the adventitious primordium is initiated by a group of cells near the periphery of the vascular system (Esau, 1965). In young stems, the cells forming the root primordium are commonly derived from the interfascicular parenchyma and from a vascular ray in older stems. Roots may also appear to be initiated in the cambial zone. Origin of adventitious roots in the interfascicular region, in the vascular ray or in the cambium, places the young root close to both xylem and phloem of the parent axis and facilitates the establishment of vascular connection between the two organs (Esau, 1965). The primordia of adventitious roots are initiated by divisions of phloem ray parenchyma cells (Hartmann *et al*., 1997). In dicotyledonous plants and gymnosperms, these may be parenchyma cells of the phloem region or they may be callus cells (Esau, 1965) which are an irregular mass of parenchyma cells (Hartmann *et al*., 1997).

2.2.1.1 Callus

Callus is an irregular mass of parenchyma cells in various stages of lignifications that commonly develop at the basal end of a cutting placed under environmental conditions suitable for rooting (Hartmann *et al.*, 1997). Formation of callus and adventitious root formation in cuttings both depend upon similar internal and environmental factors. The belief that callus formation is essential for rooting in cuttings is held mostly because roots frequently emerge through the callus (Hartmann *et al.*, 1997). However, Ayoub and Qrunfleh (2006) observed in two olive cultivars that no root primordia were initiated from the callus formed in the stem cuttings and root formation sometimes also occurred without callus formation. Even though not essential, callus formation was mostly observed in one cultivar, 'Nabali', which these authors described as a difficult-to-root species; the other cultivar, 'Raseei' which they described as easy-to-root had most of its cuttings rooting with very few forming callus. Thus, Hartmann *et al*. (1997) and Ayoub and Qrunfleh (2006) described callus formation as a characteristic of adventitious root formation in most difficult-to-root species but not a prerequisite for adventitious root formation. According to Liu *et al.* (1996), the formation and development of cuttings rather play a strong inhibitory effect on the development of adventitious roots, as the cuttings use the resources required for the formation of the adventitious roots on callus formation. Some studied species such as *Feijoa sellowiana* (Zhang *et al*., 2009) and in 'Raseei' an olive cultivar (Ayoub and Qrunfleh, 2006) indicate callus formation and adventitious root formation as two processes independent of each other.

2.2.2 Anatomy of shoots and rooting behaviour of stem cuttings

The presence of a continuous sclerenchyma ring in the cortex of stem cuttings has been related to poor rooting. In *E. maidenii* (Liu *et al*., 1997), *Feijoa sellowiana* (Zhang *et al*., 2009) and dove trees (Yi *et al*., 2000), the presence of a sclerenchyma ring in the cortex of the stem was related to poor rooting ability in their stem cuttings. These studies including those of Beakbane (1961) and Amissah *et al*. (2008) stated that this sclernchyma ring acts as a mechanical barrier to the emergence of adventitious roots. According to Esau (1977), sclerenchyma cells are made up of sclereids and fibres which are not sharply distinguished from each other. Thus, a high proportion of fibres in sections of shoots may be related to rooting ability of its cuttings. In branches of grape, however, the presence of a thin cortex and large pith which is made up primarily of parenchyma cells, enable stem cuttings show a higher ease of rooting (Wang *et al*., 1980). Amissah *et al.* (2008) indicated a relationship between the percentage of parenchymatous gaps within the ring of pericyclic fibres (sclerenchyma ring) observed in transverse sections and the relative success of adventitious root formation. Higher parenchymatous gaps correlated well with higher rooting percentage in *Quercus bicolor*, while *Q. macrocarpa*, which had lower parenchymatous gaps coincided with lower percentage rooting. Thus, rooting ability of stem cuttings may be related to proportions of parenchyma and fibres in the stems of the shoots (Amissah *et al*., 2008). However, studies by Ayoub and Qrunfleh (2006) on two olive cultivars 'Nabali' and 'Raseei' indicated that there was a gradual dissolution of the sclerenchyma ring, thus, suggesting that the belief that this sclerenchyma ring may not actually form a mechanical barrier in adventitious root formation.

2.3 Factors which affect adventitious root formation in stem cuttings

Adventitious root formation in cuttings is dependent on the complex interaction of physiological, stock-plant and environmental factors (Leakey *et al*., 1992; Hartmann *et al*., 1997). These include the growth environment of the stock-plant, the propagation environment, post-severance factors and cutting origin. The rooting capacity of stem cuttings varies with plant species (Maynard and Bassuk, 1996; Hartmann *et al*., 2002), thus, their treatment and management will have to be varied to achieve the best rooting. Methods used in creating favorable conditions to enhance rooting in cuttings include the use of propagation boxes and fogging systems in greenhouses (Leakey, 1985; Leakey *et al*., 1990, Hartmann *et al*., 1997). Some of the factors that influence rooting in stem cuttings, which are important in the raising of plants from stem cuttings, are discussed below.

2.3.1 Stock-plant factors which affect adventitious root formation of stem cuttings

2.3.1.1 Water

The physiological status of stock-plants for cutting propagation depends on the stock-plant genotype and its environmental conditions, which chiefly includes water (Hartmann *et al*., 1997; 2002). Presence of water in plants is important for cell processes (e.g. photosynthesis, respiration and growth); translocation of substances and for the activities of enzymes. Stomatal closure in plants with high water deficits leads to reduction in exchange of gases and subsequently to a reduced photosynthetic rate; thus cuttings from such stock-plants are likely to have limited carbohydrate initiation and growth of adventitious roots (Hartmann *et al*., 1997). It is important therefore to avoid water stress

as cuttings taken from stock-plants with water deficits show reduced root initiation (Hartmann *et al*., 1997; 2002). Water stress in cuttings can be avoided by watering stock-plants regularly especially in the dry season; stock-plants can also be watered a day before collection of cuttings; and also by taking cuttings early in the morning when the plants are in a turgid condition (Leakey *et al*., 1992; Hartmann *et al*., 1997; 2002).

2.3.1.2 Light

Light duration (photoperiod), irradiance and spectral quality influence the stock-plant condition and subsequent rooting of cuttings (Leakey and Storeton-West, 1992; Mesen, 1993; Hartmann *et al*., 1997). Light is important as it is the main source of energy for the process of photosynthesis. Its effects can either be on the stock-plant or the cutting itself and affects both the production of cuttings by stock-plants and their rooting capability. There is no optimum irradiance level for all species and varies from species to species. A certain level of irradiance to stock plants is needed to maintain some minimal endogenous auxin for rooting in cuttings of plants like chrysanthemum (Hartmann *et al*., 1997). A very high irradiance, however, may cause the photo-destruction of the auxin or negatively affect stock-plant water relations. It also reduces significantly internode length which affects the length of a single node cutting (which is important in the rooting success) (Leakey, 1986). Studies by Tchoundjeu (1989) on *K. ivorensis* and Leakey and Storeton–West (1992) on *Triplochiton scleroxylon* showed higher rooting percentages of cuttings from stock-plant managed under high artificial irradiance. High far-red content of light is important for rooting success of cuttings: red:far-red ratio of 6:3 had longer

internode length with higher rooting than a red:far-red ratio of 6:1 in *T. scleroxylon* (Leakey and Storeton-West, 1992).

2.3.1.3 Type of species

According to Leakey (1985), Maynard and Bassuk (1996) and Hartmann *et al*. (1997; 2002), the rooting capacity of cuttings varies between species, between clones of a species and also plants within a clone. Leakey (1985) suggested that genetic causes of this variability in the capacity of stem cuttings might be attributed to a lack of endogenous auxins; or auxins for synthesis of auxin-phenol complexes and presence of rooting inhibitors, and enzymes that degrade auxins. Other factors including the physiological condition of the plant (which is in turn influenced by the environment, the season, age and size of trees, position of harvested shoots and the presence of pathogens) and the treatment of cuttings also influence the rooting capacity of stem cuttings (Leakey, 1985). Reports on studies of species from the same genera show differences in rooting capacity of the stem cuttings when they were subjected to the same conditions with some showing preferences for different conditions. For instance, studies by Alegre *et al*. (1998) on two species of the same genus (*Dorycnium pentaphyllum* and *D. hirsutum*) showed different rooting abilities when the same factors (temperature of rooting environment, auxin and cutting position on shoot) were applied to them. While *D. pentaphyllum* preferred a warm environment for rooting, unaffected by the cutting position on shoot and improved rooting ability whatever dose of auxin was applied to the cuttings, *D. hirsutum* preferred the cold environment, was unaffected by application of indole-butyric-acid (IBA) but had higher rooting in cuttings from the apical portions of the

shoots. Opuni-Frimpong *et al*. (2008b) investigated the rooting ability and efficiency of two *Khaya* species (i.e. *K. anthotheca* and *K. ivorensis*). *K. anthotheca* stem cuttings exhibited higher rooting ability than *K. ivorensis* stem cuttings of the same age of stock-plant in the same propagation environment. *Quercus bicolor* cuttings exhibited higher rooting ability than in *Q. macrocarpa* cuttings under the same propagation conditions even though they are from the same genus (Amissah *et al*., 2008).

2.3.1.4 Age of stock-plant

Studies have shown that age of stock-plants affects rooting of stem cuttings and that adventitious root formation in the cuttings also declines with increasing age of the stock-plant (Hartmann *et al*., 1997; 2002; Stenvall *et al*., 2004; Husen and Pal, 2006; Opuni-Frimpong *et al*., 2008). There have been several explanations for the decrease in rooting ability of cuttings as the age of stock-plants increase. These include accumulation of rooting inhibitors, decrease in endogenous content of auxin and/or root promoters, and decreased sensitivity of aging tissues to auxins with physiological aging of stock-plants (Hartmann *et al*., 1997; Ofori *et al*., 1997; Husen and Pal, 2006; 2007a). Husen and Pal (2006) found that aging of stock-plants suppresses rooting and sprouting in teak (*Tectona grandis* Linn.f.). Their studies also found that requirement for auxin to promote rooting in the teak cuttings also seemed to increase with increasing age of the stock-plants.

However, Leakey (2004) stated that a good understanding of the reasons for the difficulty in rooting cuttings from mature stock-plants has never been achieved. He, however, emphasized the importance of physiological aging in softwood cuttings from mature

stock-plants of *Prunus avium*; attributing the rooting difficulty to availability of stored reserves.

2.3.1.5 Mineral nutrition

The carbon/nitrogen ratio (C/N ratio), which denotes the carbohydrate and nitrogen levels has been found to be significant to the rooting of cuttings. Macdonald (1993) and Hartmann *et al.* (1997) suggested that rooting could be increased by controlling the nitrogen fertility of stock-plants as nitrogen has been negatively correlated to rooting. This negative correlation between rooting and nitrogen is due to the use of the nitrogen for the development of the shoot, which will compete with the adventitious root for carbohydrates, mineral nutrients and hormones (Hartmann *et al*., 1997). This implies that even though some nutrients may be necessary for development of shoots, in excess, they may inhibit the rooting of cuttings.

Cuttings taken from *T. scleroxylon* stock-plants treated with fertilizer under high irradiance rooted better than those under the same irradiance but with no fertilizer application (Leakey and Storeton-West, 1992). However, cuttings from *T. scleroxylon* at a lower irradiance without fertilizer application rooted better than those from cuttings with the same irradiance level but with fertilizer, which suggests that the rooting of the cuttings might be due to the interaction between the level of irradiance and the fertilizer more than to just the fertilizer.

2.3.2 Physiological factors that affect rooting of cuttings

2.3.2.1 Plant hormones

Plant hormones are normally applied to cuttings to increase the number of cuttings that root, hasten the initiation of roots and also increase the number of roots formed per rooted cutting (Leakey *et al*., 1982a; Longman, 1993; Mesen, 1993). However, some plant species such as *Vochysia hoondurensis* (Leakey *et al*., 1990), *Shorea macrophylla* (Lo, 1985) and *Nauclea diderrichii* (Matin, 1989; Leakey, 1990) are able to root without the exogenous application of auxins. Scientists have attributed this to endogenous supply of auxins for root initiation (Leakey, 1990; Ofori *et al*., 1996; Hartmann *et al*., 1997; Opuni-Frimpong *et al*., 2008). Thus, with these easy rooting species, there may not be the need for the cost of applying exogenous auxins. Various studies have proven that different species require different auxin concentrations to stimulate rooting of cuttings. Optimum rooting was achieved with 0.8% IBA in *K. anthotheca* (Opuni-Frimpong *et al*., 2008b), 0.2-0.4% IBA in *M. excelsa* (Ofori *et al*., 1996), 200µg of IBA in *K. ivorensis* (Tchoundjeu, 1989) and 0.4% IBA in *T. scleroxylon* (Leakey *et al*., 1982a).

2.3.2.2 Cutting length

Longer cuttings produce higher rooting percentage due likely to higher content of nutrients to sustain cuttings until they become self sustaining (Hartmann *et al*., 1997). There is, however, no generalized optimum length due to the different requirements for different species. Cutting length plays a major role in rooting of cuttings (Leakey and Mohammed, 1985); which might be due to the need for storage capacity for current assimilates until the new roots form a sink for these carbohydrates. Tchoundjeu and

Leakey (1996) proved this importance further by finding a negative relationship between leaf area and cutting length, which suggested that short cuttings cannot provide the storage capacity for assimilates coming from a large leaf. Leakey and Mohammed (1985) also found a positive correlation between increasing cutting length and rooting percentage of *T. scleroxylon*. In *M. excelsa*, cutting length had no significant effect on rooting percentage (Ofori *et al*., 1997). Leakey (2004) stated, however, that as a practical measure to reduce variation in the seedlings produced from the stem cuttings, the best option would be to use cuttings of uniform length.

2.3.2.3 Position of cutting on shoot

Marked differences are known to exist in the chemical and structural composition of shoots from base to tip. Differences in rooting from these portions have been attributed to age differences (Leakey, 1986), internode length (Leakey, 1986; Leakey and Storeton-West, 1992), extent of secondary thickening (Hartman *et al*.,1990; Hartmann and Kester, 1983), carbohydrate content (Leakey and Coutts, 1989), rate of photosynthesis (Leakey and Storeton-West, 1992), and the content of plant growth inhibitors. The position of cutting on a stock-plant, on different shoots as well as in different species, significantly affects rooting ability (Ofori, 1994). Cuttings taken from the apices of *T. scleroxylon* (Leakey, 1983; Leakey and Coutts, 1989; Leakey and Storeton-West, 1992) and *Lovoa trichiliodes* (Tchoundjeu, 1989) rooted better than those from the base. Ofori *et al.* (1997) also found that rooting percentage decreased basipetally in *M. excelsa* and attributed this to increased leaf abscission and lower values of relative water content. Tchoundjeu

(1989) and Amri *et al.* (2010), however, indentified cuttings from the basal portions of the shoots of *K. ivorensis* and *Dalbergia melanoxylon* had better rooting.

2.3.2.4 Application of auxins

Auxins are the most thoroughly studied group of plant hormones and play very important roles including stimulation of cell division, cell enlargement, cell elongation, continued growth of callus, differentiation of tissues in callus, root formation on cuttings, among others (Tchoundjeu *et al*., 2002; Husen and Pal, 2007a and b; Husen, 2008). Even though auxins are known to promote the production of adventitious roots in stem cuttings, some difficult-to-root species still do not root appreciably even after being treated with auxin (Hartmann *et al*., 1997). Various studies have observed that most of these difficult-to-root have different requirements in terms of type and concentration of the auxin to be used under a given set of conditions (Hartmann *et al*., 1997)

2.3.2.5 Presence of Leaves

Leaf area has been reported severally to affect root initiation in various species (Leakey *et al*., 1982a; Ofori *et al*., 1996; Tchoundjeu and Leakey, 1996; Tchoundjeu *et al*., 2006; Opuni-Frimpong *et al*., 2008b). Leafless softwood cuttings of *T. scleroxylon* that failed to root were attributed to the rapid depletion of carbohydrates in stem, implying that the leaves were the main source of carbohydrates for the cuttings (Leakey *et al*., 1982a). Opuni-Frimpong *et al.* (2008b) also suggested that leafless cuttings of *K. anthotheca* that survived the period of experiment but failed to root, could imply that the presence of leaves has an additional physiological property to stimulate rooting aside supplying

carbohydrates. Some of the functions of the leaf in addition to providing carbohydrates include producing auxins (Hartmann and Kester, 1983; Newton *et al.*, 1992a and b; Hartmann *et al*., 1997) and its influence on the water status of cuttings (Leakey *et al*., 1982a; Leakey and Coutts, 1989).

Excessive transpiration of cuttings is minimized by trimming of leaves as well as removing some leaves from multi-node cuttings (Leakey *et al*., 1982a). Even though cuttings of some species may root without leaves, others require some optimum leaf area to promote the development of roots. The optimum leaf area may differ from one species to another for roots to develop (Leakey *et al*., 1982a; Tchoundjeu, 1989). *K. anthotheca* and *K. ivorensis* cuttings required leaf areas of 30-50 cm^2 and 10-30 cm^2 respectively for best rooting (Tchoundjeu and Leakey, 1996; Opuni-Frimpong *et al*., 2008b). Opuni-Frimpong *et al.* (2008b) attributed the differences in the leaf area requirement of the two species to the adaptations to maximise available light, as *K. ivorensis* naturally has smaller leaves while *K. anthotheca* has much larger leaves (Hawthorne, 1990). Tchoundjeu *et al.* (2002) also attributed the small leaf area requirement of *Prunus africana* to its inherent small leaves.

2.3.3 Environmental factors that affect rooting of stem cuttings

2.3.3.1 Temperature

There is little information existing on the effects of temperature on rooting of cuttings (Hartmann *et al*., 1997; 2002). However, care should be taken to prevent loss of water in cuttings through transpiration due to extremely high temperatures. Hartmann *et al*. (1997)

suggested that generally ease of rooting of cuttings is not affected by the air temperature of stock-plants. He stated, however, that there is the existence of a complex interaction between temperature and stock-plant photoperiod on the level of endogenous auxins and other hormones.

2.3.3.2 Rooting medium

Ideally, there is no known mix of rooting media for rooting of stem cuttings. However, the species, cutting type, season and propagation system, are those that determine an appropriate propagation medium (Hartmann *et al*., 1997). Macdonald (1993) stated that the percentage of rooting and the quality of roots can, in many instances, be directly linked to the rooting medium itself. The rooting medium provides four main functions: physical support; moisture; air; and reducing light penetration to the base of the cutting (Hartmann *et al*., 1997; 2002). Criteria considered when selecting a rooting medium for propagation include cost, quality and physical structure. The composition of the rooting medium is often critical for rooting and can vary between species, and clones/cultivars (Leakey, 2004). Tchoudjeu *et al.* (2002) recorded a significantly greater ($P < 0.05$) percentage rooting in sawdust (80%) as compared to those in sand alone (72%) or a mix with sawdust (71%). In *Irvingia gabonensis*, (Shiembo *et al*., 1996) rooting media had significant influence on rooting percentage and number of roots. An interaction between rooting media and leaf area treatment had an influence on the number of roots and an interaction between 75cm^2 leaf area, IBA and sand (rooting media) recorded the highest rooting percentage in *Baillonella toxisperma* (Ngo Mpeck and Atangana, 2007).

2.3.3.3 Seasonal changes

The development of adventitious roots in stem cuttings of many plant species can be influenced by the time in the year of collecting the shoots (Hartmann *et al*., 1997; 2002). Seasonal effects on cuttings may be due to the varying physiological conditions of stock-plants throughout the year as they respond to the changing climatic conditions (Hartmann *et al*., 1997). The physiology of stock-plants and prevailing environmental conditions can also determine success of rooting of cuttings as cuttings respond variably to rooting depending on the time of year they are collected (Hartmann *et al*., 1997).

2.4 Descriptions of the Meliaceae family

The family Meliaceae contains some of the economically important genera on the global market including the *Swietenia* Jacq., *Lovoa* Harms, *Entandrophragma* C. DC. and *Khaya* A. Juss (Taylor, 1960; Hawthorne, 1990; Hawthorne and Jongkind, 2006). Economically important species of the Meliaceae in Ghana include the African mahogany, West African cedars and the African walnuts. According to Hawthorne (1990), most species in the Meliaceae have a noticeable clustering of compound leaves towards the ends of twigs, and it is most prominent in the *Entandrophragma* species.

2.4.1 The genera Entandrophragma and Khaya

The *Entandrophragma* and *Khaya* genera are two of the world's most important hardwood species, in terms of merchantable timber, as well as for their non-timber products locally. The *Entandrophragma*, comprising about 10 species, is endemic to tropical Africa (Tchinda, 2008; Nyemb, 2008; Kémeuzé, 2008; Lemmens, 2008a and b;

Mujuni, 2008) and includes these species: *E. angolense*, *E. candollei*, *E. cylindricum* and *E. utile* which have all been recorded in Ghana. The genus *Khaya* comprises 4 species in mainland Africa with 1 or 2 endemic to Comoros and Madagascar (Maroyi, 2008; Opuni-Frimpong, 2008; Lemmens, 2008b). The *Khaya* species have very strong resemblance to each other in flowers and fruits, with differences most prominent in their leaflets (Maroyi, 2008; Opuni-Frimpong, 2008; Lemmens, 2008b; Pasternak and Nikiema, 2008). The woody capsules that contain winged seeds are globose in *Khaya* species and elongated in the *Entandrophragma* species (Hawthorne, 1990). Seed dispersal in both genera is by wind (Maroyi, 2008; Opuni-Frimpong, 2008; Lemmens, 2008a and b).

2.4.2 Entandrophragma angolense (Welw.) C.DC.

Entandrophragma angolense, locally known as Edinam (trade name- Edinam, Tiama and Gedu Nohor) is a large tree with maximum height and diameter at breast height (dbh) of about 50-60 m and 5 m respectively (Hawthorne and Jongkind, 2006; Irvine, 1961; Poorter *et al*., 2004; Taylor, 1960). The bole of *E. angolense* is straight, cylindrical and branchless for up to about 30-40 m. The bark is grey, becoming much whiter higher up; the slash is dark-red and pink with white radial streaks and a faint 'cedar' smell (Hawthorne, 1990; Irvine, 1961; Oteng-Amoako, 2006). The leaves of *E. angolense* are glossy and glaborous at seedling and sapling stages (Irvine, 1961; Poorter *et al*., 2004; Oteng-Amoako, 2006). Seed germination rate is very good (about 90%), however, seeds lose their viability very fast and should be sown few days after falling (Irvine, 1961; Taylor, 1960). Seedlings grow about1-1.2 m per year (Hawthorne, 1995; Irvine, 1960; Poorter *et al*., 2004; Taylor, 1960). *E. angolense* is a widespread species, occurring from

Guinea to Uganda and Angola even though it listed as a vulnerable (red) species. It is found in upland evergreen, moist evergreen, moist semi-deciduous and dry semi-deciduous forest types (Hawthorne, 1995; 2006; Oteng-Amoako, 2006; Irvine, 1961; Taylor, 1960).

The wood saws and works well with both hand and machine tools. The wood of *E. angolense* is highly valued for furniture, veneer and plywood, ship building, interior trim, exterior and interior joinery and for flooring. The bark is used in treatment of various ailments. The bark decoction is taken for treatment of fever. External applications of the bark are also used as an anodyne against stomach-ache and peptic ulcers, earache, kidney, rheumatic/arthritic pains. External applications are also used to treat ophthalmia, swellings and ulcers (Irvine, 1961; Tchinda, 2008). The stem-bark is used to treat cough and asthma, while the seeds are used to treat malaria (Oteng-Amoako, 2006). The bark also produces a brown dye (Abbiw, 1990; Irvine, 1961).

2.4.3 *Entandrophragma utile* (Dawe & Sprague) Sprague

E. utile, locally known as Efoobrodedwo (Gh), with trade names, Utile, Sipo and Sapele, occurs from Sierra Leone east to Uganda, and south to Angola and DR Congo (Mujuni, 2008). It is found in upland evergreen, moist semi-deciduous and dry semi-deciduous forest types and is a red list species (Hawthorne, 1995; Irvine, 1961; Oteng-Amoako, 2006; Poorter *et al*., 2004). *E. utile* grows to a height of about 50-60 m and a dbh of about 250 cm, with a straight, cylindrical bole and short but well-developed buttresses; it is the largest species in its genus. *E. utile* has grey-brown bark with regular longitudinal

fissures (Hawthorne, 1990). The slash is thick reddish-brown with paler lines and is unscented. Seeds have adequate viability period; the growth of seedlings is very slow, (about 1.5 m height growth in 4 years) due to slow root development (Hawthorne, 1995; Oteng-Amoako, 2006; Poorter *et al*., 2004). Seedlings of this species are particularly susceptible to immense predation by rodents. *E. utile* is susceptible to shoot-borer and leaf defoliators; the wood is also liable to insect attack (Irvine, 1961; Oteng-Amoako, 2006).

The wood of *E. utile* is dark, works easily with all tools and takes a finish and polishes well; it takes nails and stains easily. It is useful for house construction, dug-out canoes, cabinet-work, interior work in ships and railway carriages, luxury and decorative furniture; and also as a rotary-cut plywood (Irvine, 1961; Oteng-Amoako, 2006; Poorter *et al*., 2004). In Central Africa, the bark sap is taken or used as a wash to treat stomach-ache and kidney pain; it is rubbed to relieve rheumatism; and it is dropped into the eyes to treat eye inflammation and into the ear to treat otitis. A massage with bark maceration is considered useful as a tonic and stimulant. The charred and pulverized bark in a mixture with salt and palm oil is rubbed into scarifications to treat headache. The bark is also used to treat malaria in Cameroon, with a claim to heal peptic ulcers in Nigeria. The sawdust of *E. utile* may however, cause dermatitis.

2.4.4 Khaya grandifoliola C.DC.

K. grandifoliola, trade names African mahogany and acajou d'Afrique (local names, Odupon/ Dubini), occurs from Guinea east to Sudan and Uganda (Poorter *et al*., 2004; Opuni-Frimpong, 2008). *K. grandifoliola*, a red list species, is found mostly in dry semi-deciduous forests and also in gallery forests (Irvine, 1961; Poorter *et al*., 2004). Trees of *K. grandifoliola* attain a maximum height of about 50 m and diameter of about 120-200 cm (Irvine, 1961; Poorter *et al*., 2004; Opuni-Frimpong, 2008; Taylor, 1960). The bole is branchless for up to 23 m, is often twisted or leaning near the top; the tree is usually with high buttresses up to 3 m high. The bark is grayish brown and exfoliates in small circular scales (Irvine, 1961; Poorter *et al*., 2004; Opuni-Frimpong, 2008). 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 6.7 cm dbh in 15 years (Irvine, 1961). *K. grandifoliola* trees are very susceptible to the shootborer, *Hypsipyla robusta* while seeds are usually attacked by seed-boring beetles (including while on the tree) and are also eaten by small rodents (Hall, 2008; Newton *et al*., 1993; Opuni-Frimpong *et al*., 2008; Opuni-Frimpong, 2008). Logs of *K. grandifoliola* are susceptible to attack by longhorn beetles while sapwood is attacked by the ambrosia beetles.

Trees of *K. grandifoliola* and *K. anthotheca* are usually confused for each other, particularly in the smaller size classes; there may be the existence of hybrids of these two species (Hawthorne, 1990).

The wood of *K. grandifoliola* resembles that of the 'true' mahogany, *Swietenia macrophylla*, more than the other species in its genus and is thus used mostly for the same purposes as the true mahogany (Irvine, 1961). It is denser and heavier and may therefore be a better tree for sawn timber. It is used for making canoes locally. It is valued 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 (Opuni-Frimpong, 2008). The bark is used in Ghana for treatment of fevers caused by malaria (Abbiw, 1990). A decoction of the bark is taken for treating stomach problems including gastric ulcers, pain after birth, and skin diseases. A bark infusion is taken in Sudan to treat diarrhoea caused by intestinal parasites. Root bark decoctions are drunk to treat gonorrhoea while the pulverized root bark is applied externally to skin diseases. In Uganda, the bark is used as fish poison and used to wash clothes in DR Congo (Opuni-Frimpong, 2008).

2.4.5 *Khaya ivorensis* A. Chev.

K. ivorensis, variously called Dubini in Ghana, acajou rouge/red mahogany, has the trade name African mahogany (Irvine, 1961; Oteng-Amoako, 2006). It is a vulnerable species, occurring in West and Central Africa from Cote d'Ivoire east to Cameroon and Angola (Lemmens, 2008b). 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 very common in Ghana. They are sometimes the biggest and tallest trees where they are found (Irvine, 1961). It attains a maximum height of about 50 – 60 m above buttress while the diameter can reach 150 – 210 cm. The bole can be

straight and branchless up to 30 m (Irvine, 1961; 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 paneling, window frames, doors, shipbuilding, vehicle bodies, and precision equipment among others. 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 (Lemmens, 2008b). Root pulp is applied as an enema to treat dysentery (Taylor, 1960). Ground young shoots and leaves are applied externally as an anodyne. The seeds are used in making soap.

CHAPTER THREE

3.0 METHODOLOGY

3.1 Experimental site

The experiments testing the rooting ability of stem cuttings were conducted at the nursery of the Forestry Research Institute of Ghana (FORIG), Kumasi (mean annual rainfall, 1500-1750mm; geographical location, 6°44´N, 1°30´W; and relief, 280 m above sea level). FORIG is located at Fumesua 15 km from Kumasi, on the Accra-Kumasi highway in the Moist Semi-deciduous Forest Zone of Ghana.

3.2 Stock-plants employed in production of leafy stem cuttings

Shoots were harvested from 1-, 4-, 7- and 12-year old stock-plants of *K. grandifoliola* (Plate 1) for the experiments testing the effect of age of stock-plant on rooting ability and from 12-year old stock-plants of *E. angolense, E. utile, K. ivorensis* and *K. grandifoliola* from plantations at the Mesewam Research Nursery of FORIG (mean annual rainfall, 1520 mm; 6°30´N, 1°50´W). These plants were cut-back to a height of 15 cm for the 1-year old stock-plant and 50 cm for the 4-, 7- and 12-year old plants. The shoots were allowed to grow for 10 weeks before they were harvested for propagation.

3.3 Preparation of leafy stem cuttings for propagation

Shoots were harvested early in the morning (between 6 and 7 am) from stock-plants which had been watered the previous evening. The cut shoots were kept in polythene bags and sprayed with a fine mist of water, using a mist sprayer as was described by Ofori *et al.* (1996). The apical 2-3 cm softwood portions were discarded as they died within a week inside the propagator.

Plate 1 Coppiced stumps (CS) and sprouted shoots (S) of *K. grandifoliola*

The shoots were severed into cuttings of 4-6 cm long; all leaflets were removed leaving only two at the top node. The remaining leaflets (Plate 2) on each cutting were then trimmed to an area of approximately 40 cm^2, using a paper template made by using a leaf

area metre. The stem bases of the cuttings were dipped into a rooting powder ('Hormodin 3' - Indole-3-butyric acid) prior to insertion in the rooting medium.

Plate 2 Setup of stem cuttings in bowls showing trimmed leaflets (L) on cuttings in river-sand

3.4 Propagation system

Appropriate-technology non-mist propagators (Plate 3) were constructed using a design by Leakey and Longman (1988), and further modified by Leakey *et al* (1990). The propagators were made out of a wooden frame enclosed in a clear polythene to make the base water-tight. Their base layers were filled with a layer of sand to about 5 cm. Successive layers of large stones (diameter of 6-10 cm) to a depth of 10-15 cm, small stones (3-6 cm in diameter) and gravel to a depth of 20 cm and then covered with the

rooting medium to a depth of about 5 cm. The propagators were filled with water to a depth of about 5 cm below the rooting medium.

Plate 3 Non-mist propagators (np) used for the experiments

The propagators were covered with tight fitting hinged lids also covered with clear polythene to maintain high humidity around the cuttings and allow the penetration of light into the propagators. The non-mist propagators were simple and cheap to construct, having no requirements for electricity or piped water as do the more sophisticated mist and fog systems. The non-mist propagators have proven to be effective in the propagation of many tropical trees including *Milicia excelsa* (Ofori *et al*., 1996), *Prunus africana* (Tchoundjeu *et al*., 2002), *Baillonella toxisperma* (Ngo Mpeck and Atangana, 2007), and

K. anthotheca, *K. ivorensis* (Opuni-Frimpong *et al*., 2008b) and *Annickia chlorantha* (Ngo Mpeck *et al*., 2009).

3.5 Rooting medium for the propagation of leafy stem cuttings

River sand, top soil and a mixture of the two that is, river-sand and top soil (50:50 by volume; hereafter referred to as mixed medium) were used as the rooting media. They were all sterilized by heating water-saturated soil samples to dryness.

3.6 Propagation techniques employed in the rooting of the stem cuttings

Three non-mist propagators were constructed and placed under a shade screen (82-85% light interception) to prevent excessive temperatures. The shade was made of green palm fronds placed at a height of about 2.5 m above the ground. The cuttings were sprayed with a fine mist of water from a knapsack sprayer whenever the propagators were opened. The cuttings were inserted to a depth of 1-2 cm in the rooting media. The water table was maintained just below the cutting bases by regular observation using an open cylinder made from the internode section of bamboo inserted into the medium and stones. This bamboo was used as the filling point for the water and allowed a regular check of the water table. To prevent foliar desiccation, the cuttings were sprayed with a fine mist of water from a knapsack sprayer, at least once a day. The temperature within the propagators was 28-30°C while the humidity was around 70-80% after watering.

3.7 Weaning of rooted stem cuttings

Rooted cuttings (Plates 4 and 8) were potted into black polythene bags (30 cm long x 25 cm wide) containing sandy loam soil when the longest root was at least 1 mm. The potted cuttings were kept under a heavily shaded area for a week for acclimatization and then transferred to the shade house.

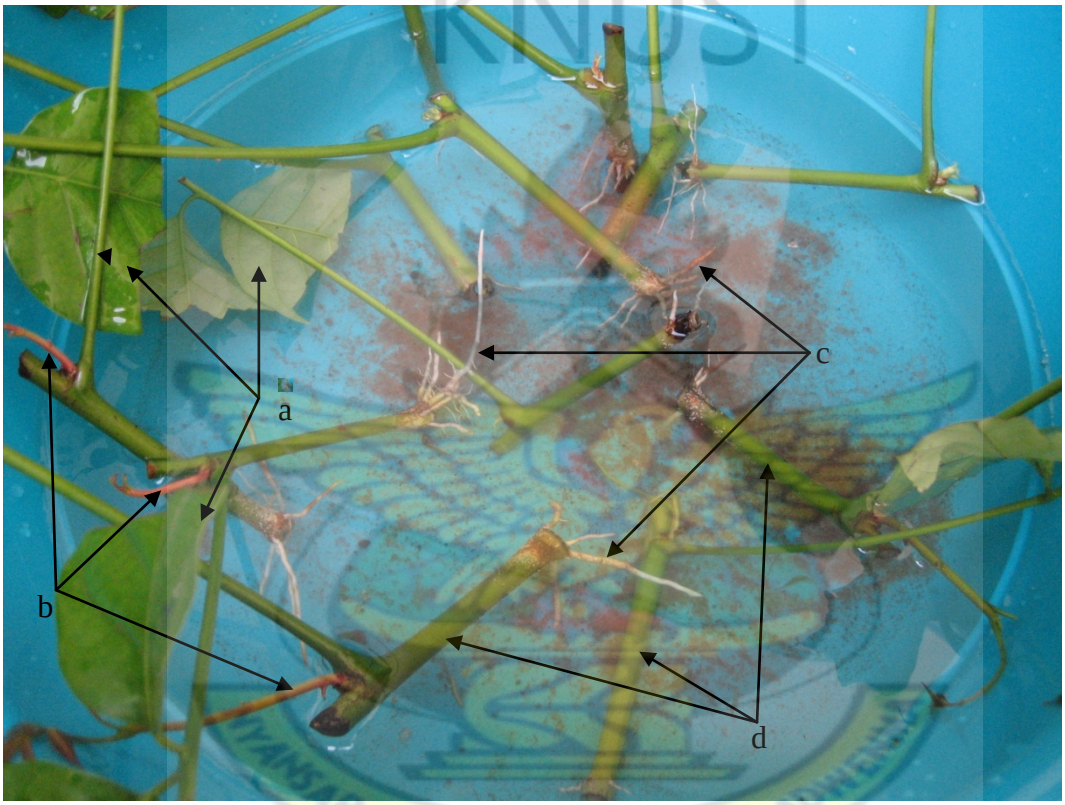


Plate 4 Rooted stem cuttings ready for potting showing leaves (a), shoots (b), roots (c) and stems (d)

3.8 Treatments for rooting of stem cuttings

The main treatments were: (a) species (i.e. *K. grandifoliola*, *K. ivorensis*, *E. angolense* and *E. utile*), (b) rooting medium (i.e. top soil, river-sand and mixed medium), (c) age of stock-plant of *K. grandifoliola* in years (1, 4, 7 and 12) and (d) position of cutting on

shoot (top, middle and base). The effect of species was tested in all three rooting media, while the effect of rooting medium on rooting ability of stem cuttings was tested in all four African mahogany species (Plate 5). Rooting ability of stem cuttings from the four different aged stock-plants of *K. grandifoliola* were carried out in river-sand as rooting medium.

To test the effect of cutting position on shoot on the rooting ability of stem cuttings, cuttings were taken sequentially along the shoot, discarding the terminal softwood portions as well as portions without leaves. The position of each cutting was noted and the cuttings grouped according to their positions along the shoot. Depending on length of shoot, 3 cuttings were obtained from each shoot; positions were however mainly assigned to top, middle or base portion. This rooting exercise was carried out in river-sand as rooting medium (Plate 5).

3.8.1 Experimental design and observations on rooting

For each experiment, 20 cuttings per treatment replicated three times, were arranged in a Complete Randomized Design. Data were collected on number of roots per cutting, length of longest root and rooting percentage. Cutting evaluation was done eight weeks after insertion in the rooting media and considered rooted (Plate 7) when it had at least one primary root ≥ 1 mm long. Observations were also made on callus formation at the bases of stem cuttings (Plate 9) but no data were collected.

Plate 5 Leafy stem cuttings inserted in river-sand (a); top soil (b); and mixed medium (c) in the non-mist propagator

3.9 Anatomical data collection

3.9.1 Sampling procedure of shoots for anatomical studies

To capture and describe the range of anatomical variation representative of the various stock-plants, shoots were taken from the same stock-plants as for the rooting experiments in the Mesewam Nursery. Five dominant shoots were collected randomly for each of the 4 species with each shoot from a different stock plant. Five dominant shoots were also collected for each of the 4 different ages of *K. grandifoliola* as for the different species. The total length and mid shoot positions were determined using a 30 cm rule. From each shoot, the top, middle and second basal internode portions were removed. From each of the internodes (top, middle, base) from each shoot, a 4 cm length was removed from the mid internode position for anatomical investigations. The 4 cm-length sample was further divided into 2 flanks, one for microtomy and the other for maceration. Samples were occasionally refrigerated to keep them green for as long as possible during sample preparations.

3.9.2 Slide preparation

Samples for microtomy were kept in a mixture of ethanol and glycerol (1:1) in labeled containers for an average period of 7(top) or up to 14 (middle or base) days for softening depending on the position of sample on the shoot and also for preservation. The samples were, however, not saturated in water before putting them in the mixture of ethanol and glycerol as they were taken from fresh, soft and succulent shoots.

Five transverse sections (Plates 6, 7 and 11) with thickness 15-25 µm were made from each sample on a sliding microtome. The sections were first washed in water and then stained in 1% Safranin in 50% ethanol solution for 10-20 minutes, washed in water and dehydrated in increasing concentrations of ethanol: 30, 50, 70, 85, 90 and 100%. The sections were then kept in cedarwood oil for hardening before mounting them in Canada balsam on glass slides. The prepared slides were dried in an oven at 60° C overnight.

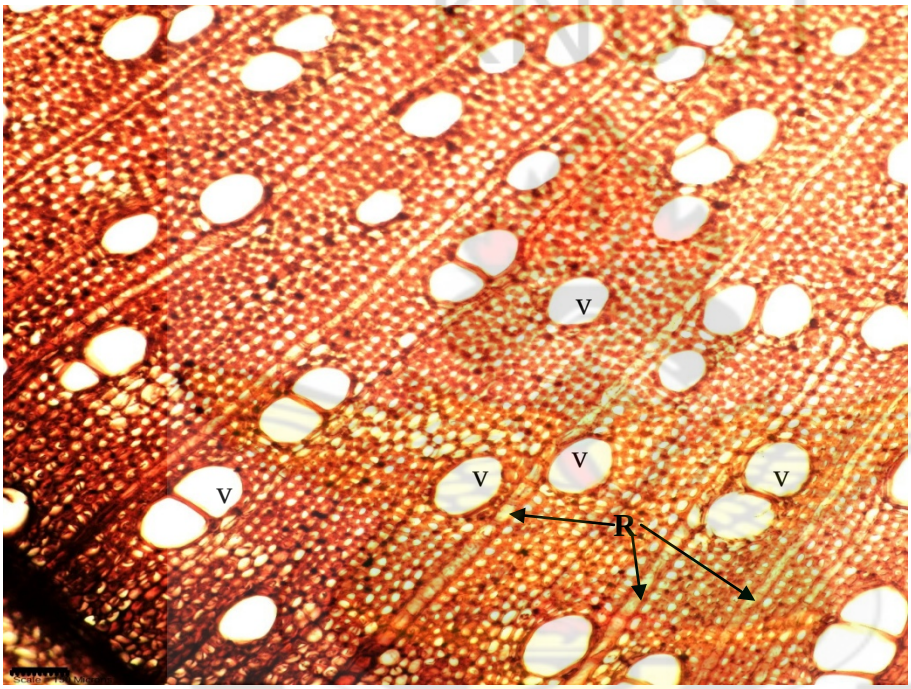


Plate 6 Transverse section at x10 magnification, showing: parenchyma (P), ray parenchyma (R) and vessels (v)

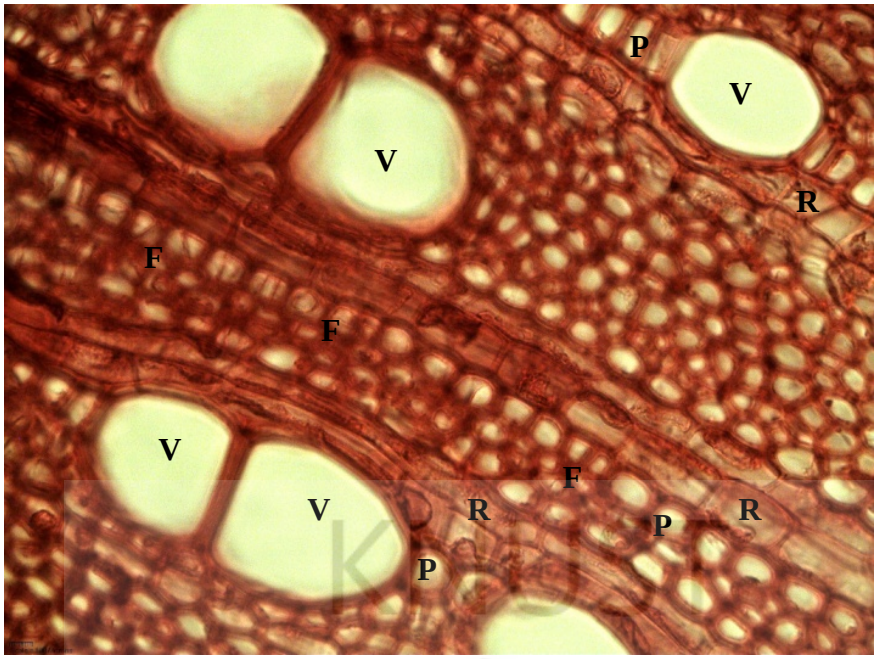


Plate 7 Transverse section at x40 magnification, showing: fibre (F), parenchyma (P), ray parenchyma (R) and vessels (v)

3.9.3 Maceration

Small split of matchstick size (2 mm x 2mm x 4 mm) was taken from each wood portion and kept in a vial containing a mixture of 6% hydrogen peroxide and 97% acetic acid (1:1 by volume). The specimens were placed in an oven at 60°C for 2 days to obtain complete macerations. The macerated samples were rinsed with water and mounted temporarily in glycerol for measurement of fibre and vessel dimensions (Plate 8).

3.9.4 Measurement of tissue proportions

Fibre, vessel and parenchyma (ray and normal parenchyma) proportions were estimated on the transverse sections with an electronic microscope. Fibre, vessel and parenchyma proportions were determined from each sample using a 10x objective lens and 10x eye-piece with a dot-grid scale of 20 points. The dot-grid scale was placed three times progressively from the periphery towards the centre of the central cylinder. At each

placement, the number of points covering any tissue was counted and expressed as a percentage of the total number of points.

Fibre length, width, lumen diameter and double fibre wall thickness were measured on 50 straight fibres per macerated sample (Plate 8). Vessel length and diameter were also measured on 25 vessels per macerated sample. Fibre and vessel lengths as well as vessel diameter were measured using a 10x objective lens and 10x eye-piece with a scale of 100 divisions. Fibre diameter, fibre lumen diameter and double fibre wall thickness were also measured using a 40x objective lens and 10x eye-piece with a scale of 100 divisions.

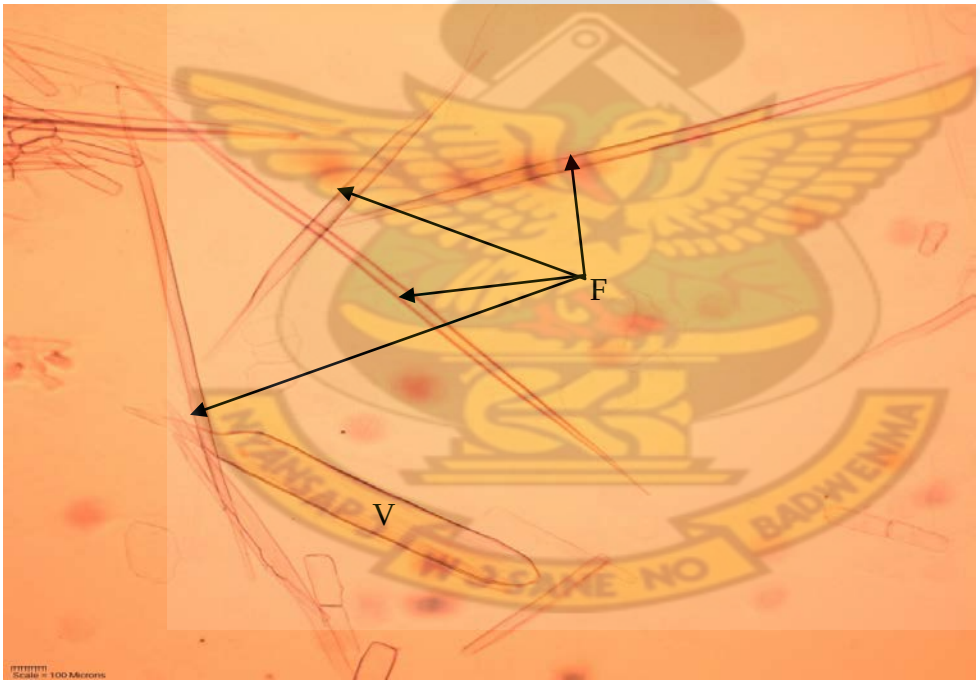


Plate 8 Teased macerated samples showing a vessel (V); and complete fibres (F)

3.10 Data analyses

Data were analysed by calculating means and standard errors and subjecting to analysis of variance (ANOVA) using software by statistiXL (V 1.8, 2007). Where significant differences were observed between treatments, the means were separated by comparing them using the Tukey's studentized range test of statistiXL (V 1.8, 2007) at $\alpha = 0.05$. Differences are described as significant where $P < 0.05$.

Quantitative anatomical data variation were evaluated between species (species effect), different ages (age effect) and between the three different positions on the shoot (position effect)

Linear regression (SPSS 16.0, 2007) was used to determine the relationship between the tissue (fibre, vessel and parenchyma) proportions and rooting percentages of all the four species as well as the four different ages of *K. grandifoliola*.

CHAPTER 4

4.0 RESULTS

4.1 Effect of African mahogany species on the rooting behaviour of stem cuttings in different rooting media

4.1.1 Effect of African mahogany species on rooting behaviour of stem cuttings in mixed medium

Appendices 16 and 17 show that number of roots per cutting was highest in the two *Khaya* species than in the two *Endrophragma* species. The type of species significantly affected the number of roots per cutting, root length and rooting percentage at $P < 0.05$ (Table 1). Of the 4 species tested, *K. grandifoliola* had the highest rooting percentage (73.33 %), the longest root (6 cm) as well as highest number of roots per cutting (4.87). Rooting ability ranked as follows in the four African mahoganies: *K. grandifoliola* > *K. ivorensis* > *E. angolense* > *E. utile* in the mixed medium. The least rooting percentage (35 %), number of roots per cutting (1.47) and shortest root length (1.93 cm) in the mixed medium was recorded for *E. utile*. Roots per cutting, longest root and rooting percentage were not significantly different between the two *Khaya* species, (i.e. *K. grandifoliola* and *K. ivorensis*), and also between the two *Entandrophragma* species, (i.e. *E. angolense* and *E. utile*) at $P < 0.05$ (Table 1). Root length was significantly different between *K. grandifoliola* and the two *Endrophragmas* but was not significant between *K. ivorensis* and *E. angolense* at $P < 0.05$ (Table 1). There was significant difference in root length between *K grandifoliola* and the two *Entandrophragma* species and also between *K.*

ivorensis and the *Entandrophragma* species. Rooting percentage was not significantly different between the two *Khaya* species (*K. grandifoliola* and *K. ivorensis*), the two *Entandrophragma* species (*E. angolense* and *E. utile*) and also between *K. ivorensis* and *E. angolense* (Table 1).

4.1.2 Effect of species on rooting behavior of stem cuttings in the top soil

In the top soil, the type of species significantly influenced roots per cutting, the root length and the rooting percentage at $P < 0.05$ (Table 1). These were all highest for the *Khaya* species than in the *Entandrophragma* species (Appendices 16 and 17). In the top soil, the rooting percentage and roots per cutting ranked as follows among the four African mahoganies: *K. grandifoliola* > *K. ivorensis* > *E. angolense* > *E. utile*, while root length ranked as follows: *K. grandifoliola* > *K. ivorensis* > *E. utile* > *E. angolense*. The type of species had significant influence on the roots per cutting at $P < 0.05$ with significant differences between *K. grandifoliola* (4.33) and the three other African mahogany species (*K. ivorensis* – 2.50; *E. angolense* – 1.60; *E. utile* – 1.47). However, between *K. ivorensis* (2.50), *E. angolense* (1.60) and *E. utile* (1.50), there were no significant differences at $P < 0.05$ (Table 1) for roots per cutting. Thus, with respect to roots per cutting, there was significant difference ($P < 0.05$) between the two *Khaya* species but not between the *Entandrophragma* species.

The type of species affected length of roots, with significant differences ($P < 0.05$) occurring between *K. grandifoliola* and the two *Entandrophragma* species (Table 1). The type of species also affected the rooting percentage, with significant differences ($P <$

0.05) occurring between *K. grandifoliola* (66.67 %) and the two *Entandrophragma* species (46.67 % for *E. angolense* and 40 % for *E. utile*) and also between *K. ivorensis* (60 %) and *E. utile* (40 %). In the top soil, rooting percentage was not significantly different ($P < 0.05$) within the *Entandrophragma* species and also within the *Khaya* species (Table 1).

4.1.3 Effects of species on rooting behavior of stem cuttings in river-sand

In river-sand, the type of species affected the roots per cutting, root length and rooting percentage (Table 1). Roots per cutting, the root length and rooting percentage were all highest in the *Khaya* species than in the *Entandrophragma* species (Appendices 1 and 2). Roots per cutting were highly significant with the differences ($P < 0.00$) occurring between the two *Khaya* species and the *Entandrophragma* species. There were, however, no significant differences between *K. grandifoliola* (3.80) and *K. ivorensis* (3.00) and also between *E. angolense* (1.17) and *E. utile* (1.50) (Table 1).

Type of species also had significant influence on root length, with significant differences ($P < 0.00$) between the two *Khaya* species (*K. grandifoliola* and *K. ivorensis*) and the two *Entandrophragna* species (*E. angolense* and *E. utile*). However, there were no differences within the two *Khaya* species or within the two *Entandrophragma* species. Mean root lengths were 8.57 cm, 7.33 cm, 4.60 cm and 3.60 cm in *K. grandifoliola*, *K. ivorensis*, *E. angolense* and *E. utile* respectively. Rooting percentage of the cuttings was also affected by the type of species used in river-sand. Cuttings from *K. grandifoliola* had the highest rooting percentage (60%) as compared to 55%, 36.67% and 30% for *K.*

ivorensis, *E. angolense* and *E. utile* respectively. These differences were highly significant ($P < 0.004$) at $P < 0.05$ (Table 1).

Plate 9 Termite-infested cutting showing area of infestation (a); unrooted cutting (b); and rooted stem cutting showing roots (c)

4.2 Effects of rooting medium on rooting behaviour of stem cuttings of the four African mahogany species

Generally, the number of roots per cutting for all the four species was highest in the mixed medium and lowest in the river-sand (Appendix 16a). However, despite the differences in the roots per cutting in the three rooting media, type of rooting medium had no significant influence ($P < 0.05$) on the number of roots per cutting (Table 1) in any of the four species.

In terms of root length, type of rooting media had no significant influence ($P < 0.05$) on *K. grandifoliola* and *E. angolense* but significantly differed for *K. ivorensis* and *E. utile*.

Type of rooting media had no significant influence ($P < 0.05$) on the rooting percentage in any of the four species.

Table 1 Effect of species on mean number of roots per cutting, root length and rooting percentage, after 8 weeks in rooting media

Variables	African mahogany species	Type of soil		
		Mixture	Top soil	River-sand
Roots/cutting	***K. grandifoliola***	4.87 ± 0.41^{a}	4.33 ± 0.44^{a}	3.80 ± 0.23^{a}
	K. ivorensis	$4.07 \pm 0.68^{a,b}$	2.50 ± 0.61^{b}	3.00 ± 0.21^{a}
	E. angolense	$2.20 \pm 0.61^{b,c}$	1.60 ± 0.21^{b}	1.17 ± 0.12^{b}
	E. utile	1.47 ± 0.29^{c}	1.50 ± 0.12^{b}	1.50 ± 0.40^{b}
Root length (cm)	***K. grandifoliola***	6.00 ± 0.35^{a}	9.87 ± 1.90^{a}	8.57 ± 0.49^{a}
	K. ivorensis	$5.53 \pm 0.48^{a,*}$	$7.40 \pm 0.26^{a,b,*}$	$7.33 \pm 0.42^{a,*}$
	E. angolense	2.30 ± 0.66^{b}	4.20 ± 1.23^{b}	4.60 ± 0.64^{b}
	E. utile	$1.93 \pm 0.35^{b,*}$	$4.53 \pm 0.66^{b,*}$	$3.60 \pm 0.49^{b,*}$
Rooting %	***K. grandifoliola***	73.33 ± 4.41a	66.67 ± 4.41a	60.00 ± 2.89a
	K. ivorensis	$65.00 \pm 5.00^{a,b}$	$60.00 \pm 2.87^{a,b}$	$55.00 \pm 2.87^{a,b}$
	E. angolense	$43.33 \pm 7.26^{b,c}$	$46.67 \pm 4.41^{b,c}$	$36.67 \pm 6.01^{b,c}$
	E. utile	35.00 ± 5.77^{c}	40.00 ± 5.00^{c}	30.00 ± 5.00^{c}

Means ± SE for a variable on the same column with the same letter(s) are not significantly different ($P < 0.05$). Means ± SE with * on the same row are also significantly different at $P < 0.05$. Differences are significant where $P < 0.05$.

4.3 Effect of cutting position on shoot on the rooting behaviour of the four African mahogany species

The position of the cutting on the shoot had significant effects ($P < 0.05$) on the rooting percentage of the species tested for their rooting behaviour. The highest rooting percentage occurred in the middle portions of shoots in all the four species (Appendix 18c). The differences between the top, middle and base portions were significant in all

four African mahogany species, *K. grandifoliola* (P < 0.003); *K. ivorensis* (P < 0.009); *E. angolense* (P < 0.021); and *E. utile* (P < 0.003) (Table 2).

The length of longest root was significantly affected by the position of cutting on shoot in *K. grandifoliola* (P < 0.005) but was not significantly different in the remaining three species (Appendix 18b).

Mean number of roots per cutting was also affected by the position of cutting on shoot in *K. grandifoliola* (P < 0.007) and *K. ivorensis* (P < 0.020), (Table 2). In the two *Entandrophragma* species, even though there were differences in the mean number of roots per cutting for the various portions (Appendix 18a), they did not differ significantly at P < 0.05.

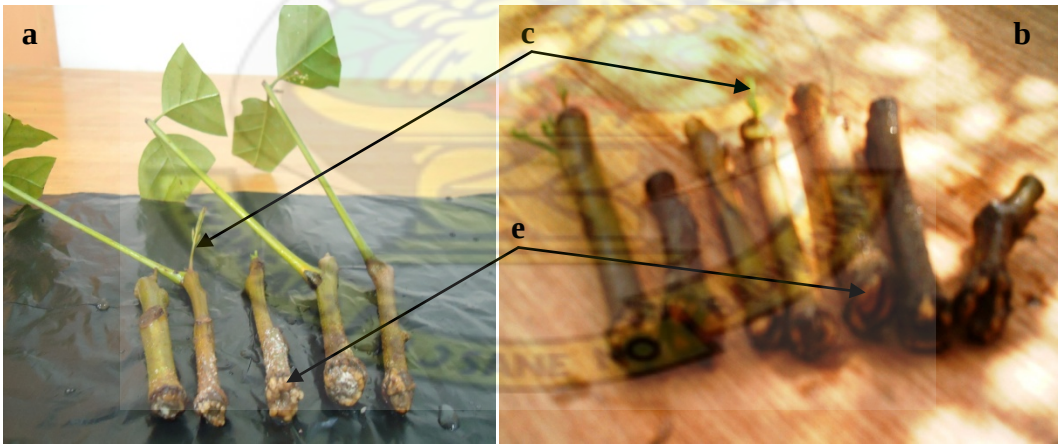


Plate 10 Callus formed at the bases of stem cuttings of: *K. grandifoliola* (a) and *E. angolense* (b); showing: shoots(c) and callus (e)

Table 2 Effect of cutting position on shoot on the rooting ability of stem cuttings from four African mahogany species

African mahogany species	Position of cutting on shoot	Roots/cutting	Root length (cm)	Rooting (%)
K. grandifoliola	**Top**	2.97 ± 0.38[a]	3.77 ± 0.18[a]	61.67 ± 1.67[a]
	Middle	5.07 ± 0.33[b]	6.77 ± 0.79[b]	73.33 ± 1.67[b]
	Base	3.77 ± 0.15[a]	7.03 ± 0.18[b]	55.00 ± 2.89[a]
K. ivorensis	**Top**	1.63 ± 0.24[a]	4.53 ± 0.61[a]	51.67 ± 1.67[a]
	Middle	2.40 ± 0.61[a,b]	5.10 ± 0.60[a]	65.00 ± 2.89[b]
	Base	3.93 ± 0.30[a]	5.57 ± 0.32[a]	53.33 ± 1.67[a]
E. angolense	**Top**	1.33 ± 0.33[a]	2.77 ± 0.64[a]	43.33 ± 1.67[a,b]
	Middle	2.37 ± 0.22[a]	4.17 ± 1.16[a]	51.67 ± 1.67[a]
	Base	1.77 ± 0.37[a]	5.13 ± 1.03[a]	40.00 ± 2.89[b]
E. utile	**Top**	1.50 ± 0.25[a]	2.20 ± 0.81[a]	26.67 ± 1.67[a]
	Middle	2.27 ± 0.15[a]	4.00 ± 0.36[a]	45.00 ± 2.89[b]
	Base	1.70 ± 0.21[a]	3.67 ± 0.22[a]	36.67 ± 1.67[b]

Mean + SE for a species followed by the same letter(s) in the same column are not significantly different

4.4 Effect of age of stock-plant on the rooting behaviour of *K. grandifoliola* cuttings

In general, the age of stock-plant had significant ($P < 0.05$) influence on number of roots per cutting, root length and rooting percentage (Table 3). All these decreased as age of stock-plant increased from age 1 to 12 (Figure 4). The differences in the rooting characteristics for the different ages were all significant at $P < 0.05$ (Table 3).

Table 3 Rooting ability of cuttings from 1-, 4-, 7- and 12-year old stock-plants of *K. grandifoliola*

Age of stock-plants (yr)	Number of roots/cutting	Root length (cm)	Rooting (%)
1	5.70 ± 0.40^{b}	13.8 ± 1.20^{b}	76.67 ± 4.41^{c}
4	4.47 ± 0.52^{a}	$9.20 \pm 0.82^{a,b}$	$70.00 \pm 2.89^{b,c}$
7	$4.70 \pm 0.25^{a,b}$	$9.63 \pm 0.98^{a,b}$	68.33 ± 1.67^{b}
12	3.87 ± 0.35^{a}	7.20 ± 1.12^{a}	60.00 ± 8.66^{a}

Means ± SE followed by the same letter(s) in the same column are not significantly different. Differences are significant where $P < 0.05$.

4.5 Effect of cutting position on shoot on the rooting behaviour of cuttings from different aged stock-plants of *K. grandifoliola*

The highest rooting percentage occurred in cuttings taken from the middle portion of shoots from stock-plants of ages 4-, 7- and 12-years (Appendix 20c; Table 4). This was different in the cuttings from 1-year old stock-plants which had the highest rooting occurring in the base portion (Appendix 20c). The rooting percentage of the cuttings from 1, 4, 7 and 12 year old stock-plants of *K. grandifoliola* were all significantly influenced by the position of cutting on shoot at $P < 0.05$ (Table 4).

The longest root occurred in the middle for all the different aged stock-plants except for cuttings from 12-year old stock-plants which had the longest root occurring in cuttings from the base portions (Appendix 20b; Table 4). Even though there were differences in root length for the cuttings from the three portions of the different ages, only cuttings from 4- and 12-year old stock-plants were significantly influenced by the cutting position on shoot at $P < 0.05$ (Table 4).

Roots per cutting differed significantly with position on shoot for only cuttings from 4-year stock-plants at $P < 0.05$ (Table 4).

Table 4 Effect of cutting position on shoot on the rooting ability of stem cuttings from shoots of different aged stock-plants of *K. grandifoliola*

Age of stock-plant in years	Position of cutting on shoot	Roots/cutting	Root length (cm)	Rooting (%)
1	Top	4.77 ± 0.18[a]	11.53 ± 1.01[a]	63.33 ± 1.67[a]
	Middle	5.83 ± 0.64[a]	13.80 ± 2.00[a]	71.67±1.67[a,b]
	Base	4.73 ± 0.23[a]	10.87 ± 0.80[a]	80.00 ± 2.89[b]
4	Top	3.80 ± 0.21[a]	6.07 ± 0.30[a]	58.33 ± 1.67[a]
	Middle	5.27± 0.38[b]	8.70 ± 0.61[b]	70.00±2.89[a,b]
	Base	4.30 ±0.32[a,b]	8.23 ± 0.73[a,b]	56.67 ± 4.41[b]
7	Top	4.17 ± 0.39[a]	6.27 ± 0.15[a]	46.67 ± 1.67[a]
	Middle	4.40 ± 0.31[a]	7.70 ± 0.44[a]	60.00 ±2.89[b]
	Base	4.23 ± 0.54[a]	5.40 ± 0.32[a]	55.00±2.89[a,b]
12	Top	3.73 ± 0.47[a]	4.50 ± 0.61[a]	40.00 ± 2.89[a]
	Middle	3.87 ± 0.35[a]	6.73 ± 0.23[a,b]	55.00 ± 2.89[b]
	Base	2.93 ± 0.52[a]	8.23 ± 0.79[b]	43.33 ± 1.67[a]

Mean + SE for an age followed by the same letter(s) in the same column are not significantly different. Differences are significant where $P < 0.05$

4.6 Effects of African mahogany species and position of internode on shoot on tissue proportions

4.6.1 Vessel proportion

Vessels were generally greater at the basal portions of the shoots than at the top and middle portions but did not vary significantly with position of internode on shoot for all

the four African mahogany species investigated at $P < 0.05$ (Appendix 21a; Table 5). Type of species did not have any significant influence on percentage of vessel at $P < 0.05$ (Appendix 21b; Table 5).

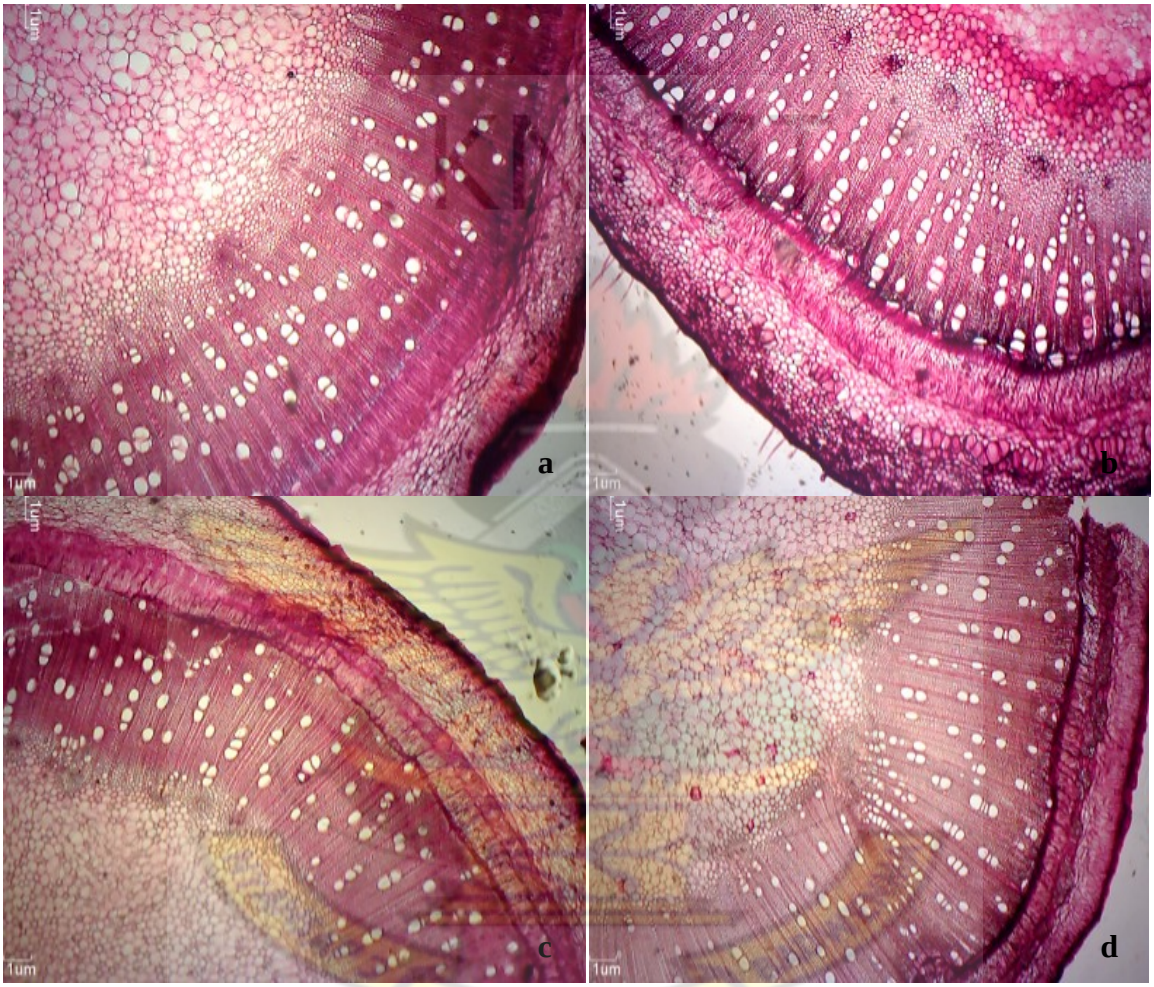


Plate 11 Transverse sections of *E. angolense* (a), *E. utile* (b), *K. grandifoliola* (c) and *K. ivorensis* (d)

4.6.2 Fibre proportion

Generally, the percentage of fibre increased from the top portions of the shoots to the base portions. The differences at the three different portions of the shoots were significant for *K. grandifoliola*, *K. ivorensis*, *E. angolense* and *E. utile* (Appendix 21a; Table 5).

Even though fibre percentage was highest in the *Entandrophragma* species than in the *Khaya* species, it did not differ significantly with the type of species (Appendix 21b; Table 5).

Table 5 Effects of internode position on shoot and African mahogany species on tissue proportion

African mahogany species	Position on shoot	Anatomical features		
		Vessel (%)	Parenchyma (%)	Fibre (%)
K.grandifoliola	**Top**	25.50 ± 0.61[a]	37.88 ± 0.48[a]	36.38 ± 0.36[a]
	Middle	26.38 ± 0.31[a]	35.88 ± 0.67[b]	37.50 ± 0.68[a,b]
	Base	27.00 ± 0.54[a]	34.13 ± 0.32[b]	39.38 ± 0.91[b]
	Mean	**26.29 ± 0.44[a]**	**35.96 ± 1.08[a]**	**37.75 ± 0.88[a]**
K. ivorensis	**Top**	26.13 ± 0.61[a]	37.25 ± 0.42[a]	36.63 ± 0.32[a]
	Middle	26.50 ± 0.42[a]	35.63 ± 0.52[a]	38.13 ± 0.56[a]
	Base	27.25 ± 0.51[a]	31.88 ± 0.71[b]	40.25 ± 0.64[b]
	Mean	**26.63 ± 0.33[a]**	**34.92 ± 1.59[a]**	**38.33 ± 1.05[a]**
E. angolense	**Top**	26.00 ± 0.51[a]	38.00 ± 0.05[a]	36.88 ± 0.77[a]
	Middle	27.38 ± 0.36[a]	34.00 ± 1.00[b]	37.88 ± 0.94[a]
	Base	27.38 ± 0.50[a]	30.75 ± 0.72[c]	41.63 ± 0.34[b]
	Mean	**26.92 ± 0.46[a]**	**34.25 ± 2.10[a]**	**38.79 ± 1.45[a]**
E. utile	**Top**	26.13 ± 0.13[a]	37.63 ± 0.50[a]	35.88 ± 0.54[a]
	Middle	25.88 ± 0.88[a]	37.00 ± 0.72[a]	37.38 ± 0.41[a]
	Base	26.50 ± 0.61[a]	33.13 ± 0.86[b]	40.25 ± 0.38[b]
	Mean	**26.17 ± 0.18[a]**	**35.92 ± 1.42[a]**	**37.83 ± 1.28[a]**

Means ± SE for a species in a column with the same letter(s) are not significantly different. Mean (for species) in a column with the same letter(s) are not significantly different. Differences are significant where $P < 0.05$.

4.6.3 Parenchyma proportion

Percentage of parenchyma varied significantly ($P < 0.05$) from top to basal internodes for *K. grandifoliola*, *K. ivorensis*, *E. angolense* and *E. utile*, (Appendix 21a; Table 5). Type of species, however, did not have any significant influence ($P < 0.05$) on percentage of parenchyma (Appendix 21b; Table 5).

4.7 Effects of age of stock-plant and internode position on shoot on tissue proportions of *K. grandifoliola*

4.7.1 Vessel proportion

Generally, percentage of vessel increased marginally from top to basal portions (Appendix 22a; Table 6) and did not vary significantly ($P < 0.05$) between the three different portions for shoots from 1-, 4- and 12-year old stock-plants of *K. grandifoliola*. Vessel proportion was however significantly different between the 3 portions from shoots from stock-plants of age 7 at $P < 0.05$ (Table 6).

The mean percentage of vessels varied from 22.00 % in sections of shoots from 1-year old stock-plants to 26.29 % in sections of shoots from 12-year old stock-plants (Appendix 22). Differences in percentage of vessels between the four different ages were highly significant at $P < 0.05$ with the differences occurring between sections from shoots of 1-year old stock-plants and sections from shoots of the 7- and 12-year old stock-plants of *K. grandifoliola* (Table 6).

4.7.2 Parenchyma proportion

The highest percentage of parenchyma was in sections from top portions of shoots of 1-year old stock-plants (45.75%), reducing to 34.13% in sections from the basal portions of shoots from 12-year old stock-plants (Appendix 22). Percentage of parenchyma generally decreased from top portions to basal portions in all the different aged stock-plants. The differences in the parenchyma proportion from top to basal internodes varied significantly in cuttings from all 4 different aged stock-plants of *K. grandifoliola* (Table 6). Between the four different ages, parenchyma proportion did not vary significantly ($P < 0.05$) even though it decreased as age of stock-plant increased from 1- to 12-years (Table 6; Appendix 22b).

4.7.3 Fibre proportion

Percentage of fibres increased slightly from top to basal portions (Appendix 22a; Table 6) in cuttings from 1-, 4-, 7- and 12-year old stock-plants, while differences between these three portions were significant in sections from shoots of 4- ($P < 0.037$), 7- ($P < 0.002$) and 12-year old stock-plants ($P < 0.029$) but not in sections from shoots of 1-year old stock-plants. Between the four different aged stock-plants, however, variations in percentage of fibre were not significant at $P < 0.05$ even though it increased from ages 1 to 12 (Appendix 22b; Table 6).

Table 6 Effects of internode position on shoot and age of stock-plant on tissue proportion

Age of stock-plant (yr)	Position on shoot	Anatomical features		
		Vessel (%)	Parenchyma (%)	Fibre (%)
1	**Top**	21.50 ± 1.51[a]	45.75 ± 1.22[a]	32.50 ± 1.86[a]
	Middle	21.63 ± 2.46[a]	42.88 ± 2.02[a,b]	35.25 ± 0.58[a]
	Base	23.37 ± 0.47[a]	39.38 ± 0.88[b]	35.75 ± 0.61[a]
	Mean	**22.17 ± 0.61[a]**	**42.67 ± 1.84[a]**	**34.50 ± 1.01[a]**
4	**Top**	23.00 ± 1.57[a]	42.38 ± 1.30[a]	34.88 ± 0.67[a]
	Middle	24.63 ± 0.15[a]	38.88 ± 1.11[a,b]	35.63 ± 0.71[a,b]
	Base	24.88 ± 0.94[a]	37.50 ± 1.06[b]	37.75 ± 0.76[b]
	Mean	**24.17 ± 0.59[a,b]**	**39.58 ± 1.45[a]**	**36.08 ± 0.86[a]**
7	**Top**	24.38 ± 0.66[a]	40.63 ± 0.52[a]	35.00 ± 0.52[a]
	Middle	26.13 ± 0.13[a,b]	36.25 ± 0.44[b]	37.75 ± 0.51[b]
	Base	26.38 ± 0.57[b]	34.25 ± 0.85[b]	39.13 ± 0.83[b]
	Mean	**25.63 ± 0.63[b]**	**37.04 ± 1.88[a]**	**37.29 ± 1.21[a]**
12	**Top**	25.50 ± 0.61[a]	37.88 ± 0.47[a]	36.38 ± 0.36[a]
	Middle	26.38 ± 0.31[a]	35.88 ± 0.67[b]	37.50 ± 0.68[a,b]
	Base	27.00 ± 0.54[a]	34.13 ± 0.32[b]	39.38 ± 0.91[b]
	Mean	**26.29 ± 0.44[b]**	**35.96 ± 1.08[a]**	**37.75 ± 0.88[a]**

Means ± SE for an age a same column with the same letter(s) are not significantly different. Means (for ages) on a column with the same letter(s) are not significantly different. Differences are significant where $P < 0.05$.

4.8 Relationship between tissue proportion and rooting percentage of cuttings of shoots from four African mahogany species

In *K. grandifoliola* and *K. ivorensis*, vessel proportion for sections from the middle of the shoots was lower than those from the base and higher than those from the top and corresponded with higher rooting percentage than the top and base (Tables 2 and 5; Figure 2). In *E. angolense*, middle portion had the same vessel proportion as the base but was higher than in the top portions with the rooting pattern as those from the different portions of *K. grandifoliola* and *K. ivorensis* (Tables 2 and 5; Figure 2). Vessel proportion in the middle of shoots from *E. utile* was, however, lower than those of both the top and basal portions with the corresponding percentage ranking: middle > base > top (Tables 2 and 5; Figure 2). While there were marginal increases in vessel proportion from 26.29 % in *K. grandifoliola*, followed by 26.63 % in K. ivorensis to 26.92 % in *E. angolense*, there was a corresponding decrease in rooting ability of cuttings from *K. grandifoliola* to *E. angolense* (Tables 1 and 5; Figure 1a). However, sections from *E. utile* had the least vessel and rooting percentages in all the three rooting media (Tables 1 and 5; Figure 1a).

Parenchyma proportion in middle portions of the shoots were lower than those from the top portions and higher than those from base, also recorded the highest rooting percentage among the three portions of the shoots in all the four African mahogany species (Tables 2 and 5; Figure 2). Parenchyma proportion decreased from 35.95 % in *K. grandifoliola* to 34.92 and 34.25 in *K. ivorensis* and *E. angolense* respectively. There was a corresponding decrease in rooting percentage from *K. grandifoliola* to *E. angolense*

(Tables 1 and 5; Figure 1b) in all three different rooting media. Parenchyma proportion in *E. utile* (35.91 %) and its corresponding rooting percentage however deviated from this trend as it rather had the lowest rooting in all the three rooting media (35.00 % for mixed medium; 40.00 % for top soil and 30.00 % in river-sand) even though the parenchyma percentage was higher *E. utile* than in *K. ivorensis* and *E. angolense* (Tables 1 and 5; Figure 1b).

Fibre proportion in the sections ranked as follows: top < middle < base, and corresponded with higher rooting percentage in the middle portions than in both the top and basal portions (Tables 2 and 5; Figure 2). Higher proportion of fibre in *K. ivorensis* and *E. angolense* as compared to *K. grandifoliola*, even though marginal, corresponded with lower rooting percentage than that of *K. grandifoliola* in all the three rooting media (Figure 1c; Tables 1 and 5). *E. utile* which had almost the same fibre proportion as *K. grandifoliola* and also lower than those of *K. ivorensis* and *E. angolense*, however, had the lowest rooting ability than all the three other African mahogany species in all the three rooting media. Rooting percentage had positive correlation with vessel - *K. ivorensis* (0.84) and *E. angolense* (0.51), fibre - *K. ivorensis* (0.86) and *E. utile* (0.99) and parenchyma - *K. ivorensis* (0.87) and *E. utile* (0.98), Table 5. The correlation between rooting percentage and fibre proportion in *E. utile* was significant (Table 5).

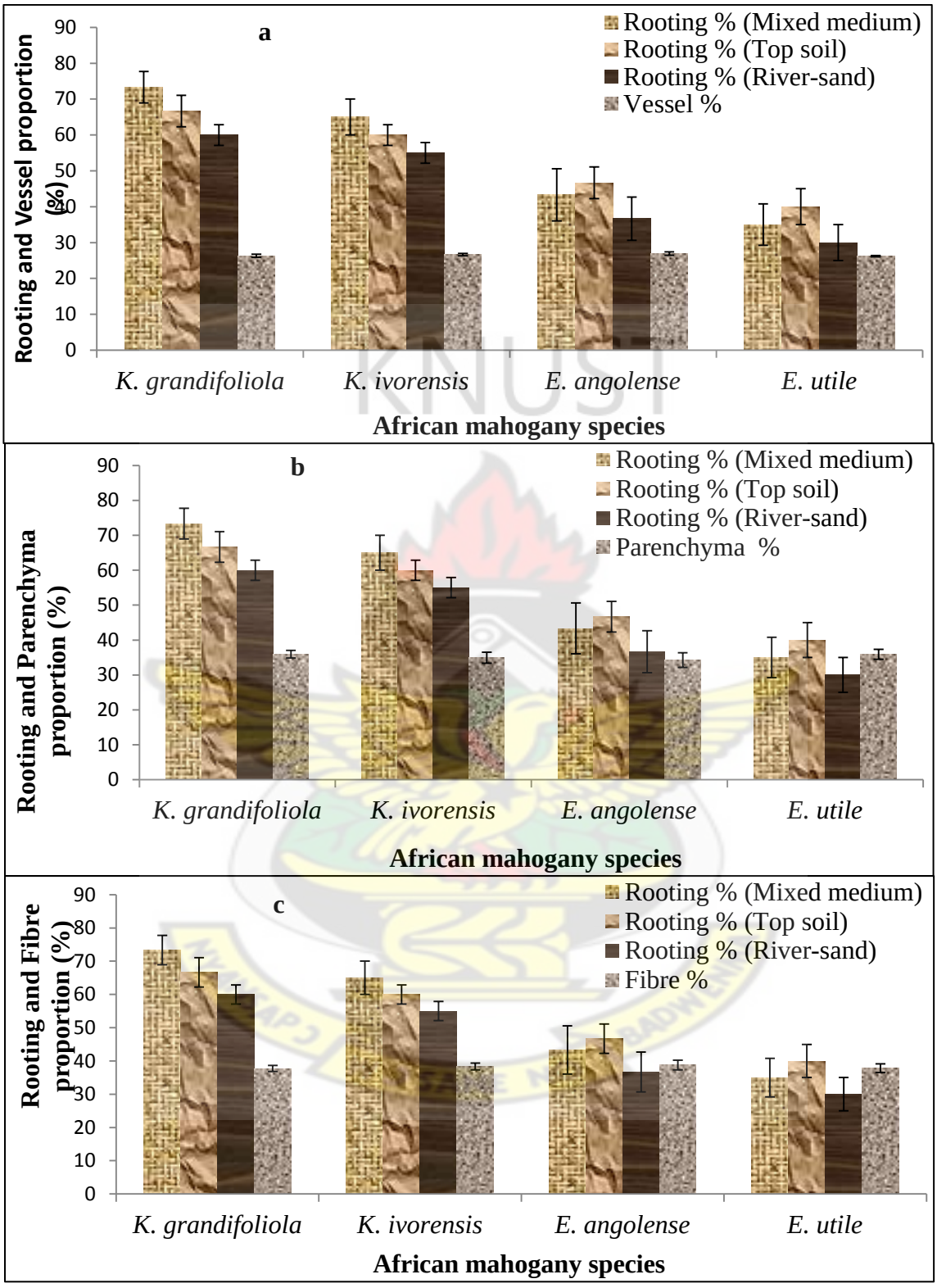


Fig. 1 Rooting and: vessel (a); parenchyma (b) and fibre (c) proportions (%) of cuttings from shoots of four African mahogany species. Errors bars = ± SE

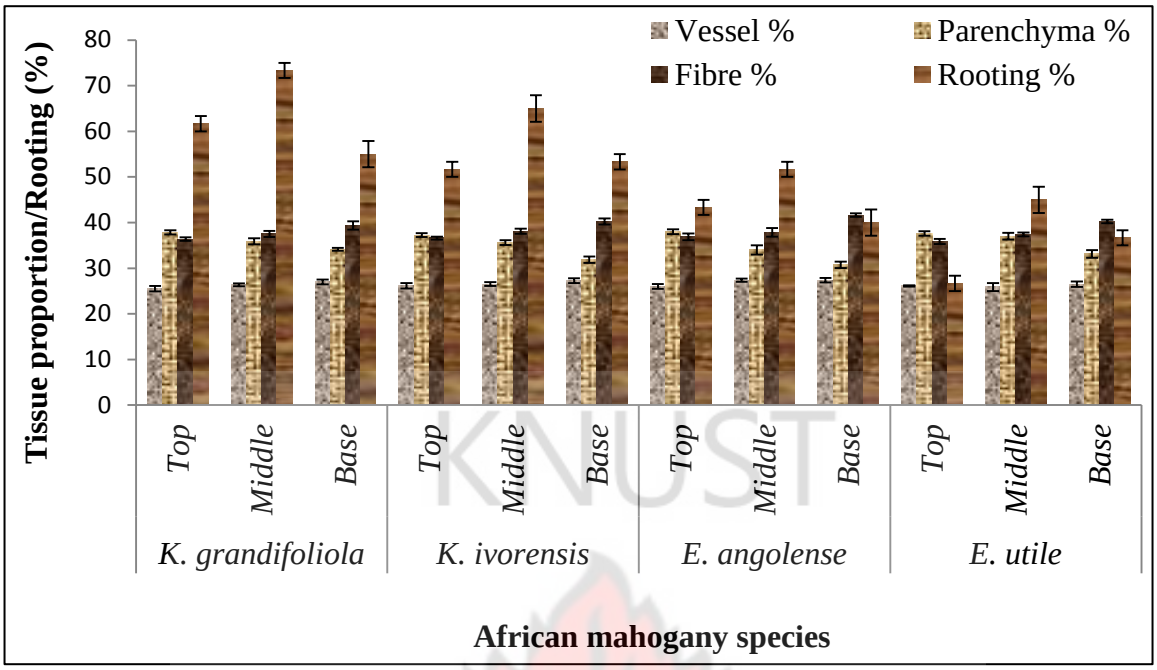


Fig. 2 Rooting and tissue proportions (%) of cuttings from different portions of shoots of four African mahogany species

The correlation between vessel, fibre and parenchyma proportions and rooting percentages of *K. grandifoliola* and *E. angolense* as well as that between rooting percentage and vessel proportion of *E. utile* were all positive and weak (Table 5). Higher percentage of fibres corresponded with lower rooting percentage in *E. agolense* and *K. ivorensis* (Tables 1 and 3; Figure 3) even though the differences in fibre proportions between the species were small. Low percentage of fibre in *K. grandifoliola* corresponded with its higher rooting percentage but in *E. utile*, the low percentage of fibre rather corresponded with lower rooting percentage (Tables 1 and 3; Figure 3).

Table 7 R^2 values from regression analyses of rooting percentage and tissue proportion

African mahogany species	R^2 value		
	% Rooting /Vessel proportion	% Rooting /Fibre proportion	% Rooting /Parenchyma proportion
K. grandifoliola	0.24	0.19	0.20
K. ivorensis	0.84	0.86	0.87
E. angolense	0.51	0.15	0.19
E. utile	0.21	0.99	0.98

4.9 Relationships between tissue proportions and rooting percentage of cuttings from shoots of different aged stock-plants of *K. grandifoliola*

In general, vessel proportion increased from the top to the basal portions in shoots from all the four different aged stock-plants of *K. grandfoliola*. Aside stem cuttings from age 1, higher rooting percentage were recorded in the middle portions than both the top and base portions (Tables 4 and 6; Figure 3b) in the other three different ages. Generally, vessel proportion increased as age of stock-plants increased from age 1 to age 12 (Table 4). There was, however, a decrease in rooting percentage of the cuttings as the age increased (Table 6) from age 1 to age 12 (Figure 3a).

Parenchyma decreased from the top to the base of shoots in all the four different aged stock-plant of *K. grandifoliola* and with exception of age 1 which had its best rooting occurring in the base, recorded higher rooting in the middle portions for the other three

different ages. Both parenchyma and rooting percentages decreased with increasing age of stock-plant (Table 4; Figures 3a and b).

Fibre proportion increased from the top to the basal portions in all the four different aged stock-plants of *K. grandifoliola*, with rooting percentage being highest in the middle portions for ages 4, 7 and 12 (Tables 4 and 6; Figure 3a). As rooting percentage decreased with increasing age of stock-plants, fibre proportion increased (Tables 3 and 6; Figure 3b).

Table 8 R^2 values from regression analyses of rooting percentage and tissue proportions

Age of stock-plant in years	R^2 value		
	% Rooting/Vessel proportion	% Rooting /Fibre proportion	% Rooting /Parenchyma proportion
1	0.80	0.89	1.00
4	0.08	0.03	0.07
7	0.71	0.99	0.91
12	0.14	0.43	0.41

The regression analyses between vessel proportions and rooting percentage were positive and insignificant in both ages 1 and 12 (Table 6). The correlation between rooting percentage and fibre proportion was positive for both age 1 (r^2 = 0.89) and age 7 (r^2 = 0.99) but the correlation was significant in only age 7. Rooting percentage also correlated positively with parenchyma proportion in ages 1 (r^2 = 1.00) and 12 (r^2 = 0.91), with the

correlation being significant in age 1. In ages 4 and 12, however, there were only weak positive correlations between rooting percentage and the three tissue proportions (Table 8).

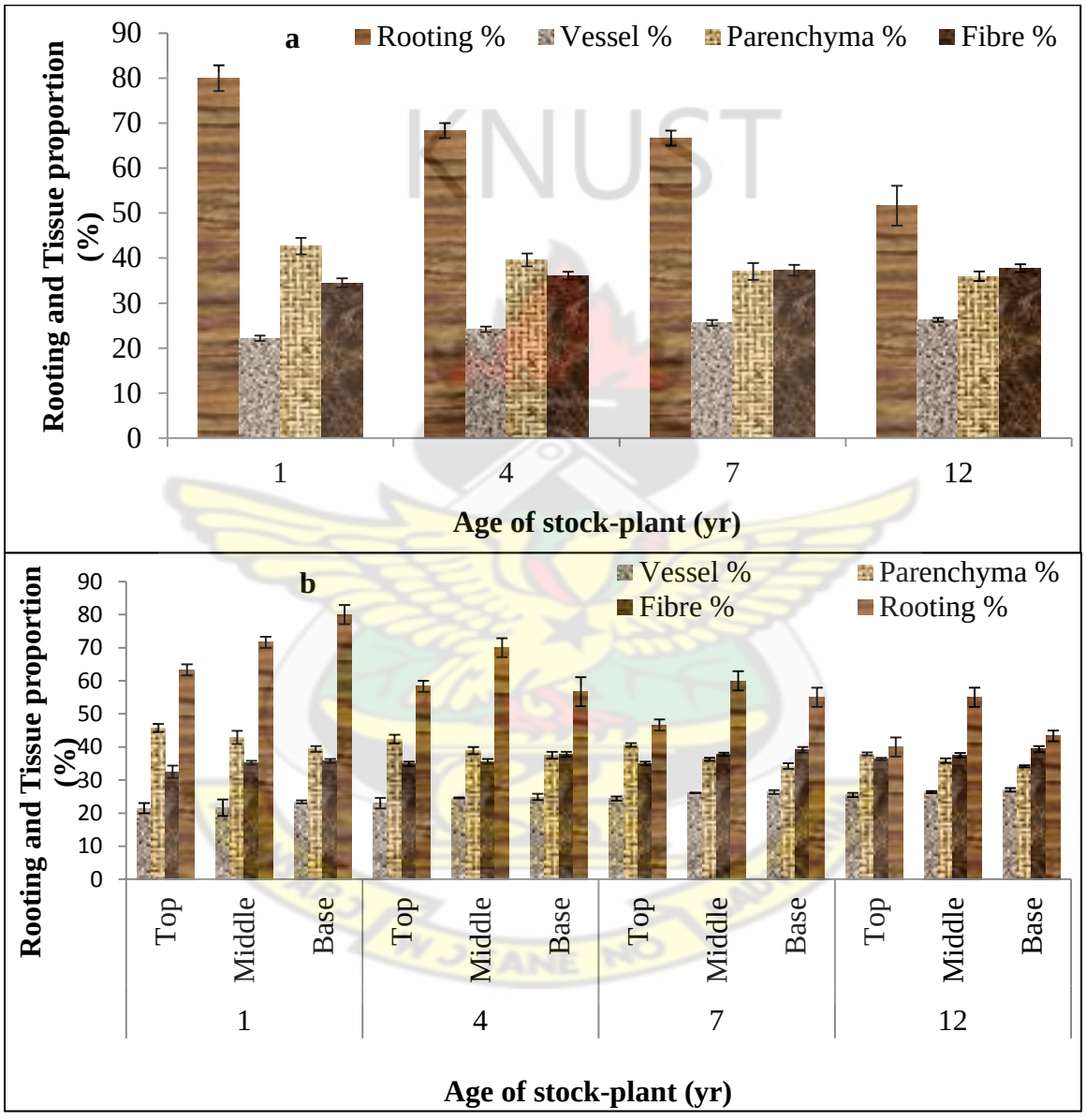


Fig. 3 Rooting and tissue proportions (%) of cuttings from shoots of: different aged stock-plants (a), and position on shoot from the different aged stock-plants (b) of *K. grandifoliola*. Error bars = ± SE

4.10 Effects of species and stem position on fibre and vessel dimensions

4.10.1 Fibre length

Mean fibre length varied significantly with stem position in *K. grandifoliola*, *K. ivorensis*, *E. angolense* and *E. utile* at $P < 0.05$ (Table 9). Besides *E. angolense* which had slightly longer fibres at the middle portions than the top and basal portions (Figure 11), fibre length decreased from the base to the top in the other three African mahogany species (Table 9; Appendix 23).

In spite of the differences between the four species, fibre length did not vary significantly with type of African mahogany species (Appendix 24; Table 9).

4.10.2 Fibre diameter

Fibre diameter did not vary significantly with position on shoot in *K. grandifoliola*, *K. ivorensis* and *E. utile* but varied well for in *E. angolense* at $P < 0.05$ (Table 9; Appendix 23). Mean diameter ranged from 15.97 µm in *K. ivorensis* to 20.67 µm in *E. utile*. Fibre diameter differed significantly with type of African mahogany species at $P < 0.05$ (Table 9; Appendix 24).

4.10.3 Fibre lumen diameter

Fibre lumen diameter varied significantly with position on shoot in only *E. utile* ($P < 0.011$) but not in the three other African mahogany species (Appendix 23; Table 9).

Mean fibre lumen diameter in the four species ranged from as 8.72 µm in *K. ivorensis* to 11.90 µm in *E. utile*. Mean fibre lumen diameter differed significantly with type of African mahogany species at $P < 0.05$ (Table 9; Appendix 24).

4.10.4 Double fibre wall thickness

Regardless of type of African mahogany species, mean double fibre wall thickness generally increased from the top internodes to the basal internodes (Appendix 23). These variations were, however, not significant in all the African mahogany species except in *K. grandifoliola* at $P < 0.05$ (Table 9). With respect to the type of African mahogany species, mean double fibre wall thickness ranged from 7.26 µm in *K. ivorensis* to 8.77 µm in *E. utile* (Appendix 24). Type of species had no significant influence on mean double fibre wall thickness (Table 9).

Table 9 Effect of position on shoot and species on fibre and vessel dimensions of four African mahogany species

African mahogany species	Position on shoot	Anatomical features					
		Fibre length (µm)	Fibre diameter (µm)	Fibre lumen diameter (µm)	Double fibre wall thickness (µm)	Vessel length (µm)	Vessel diameter (µm)
	Top	652.70 ± 8.03^{a}	16.41 ± 0.75^{a}	9.68 ± 0.89^{a}	6.73±0.25^{a}	335.80±17.82^{a}	42.65±0.26^{a}
K.grandifoliola	**Middle**	670.53±13.85^{a}	16.43 ± 0.32^{a}	9.00 ± 0.34^{a}	7.43±0.27^{a}	400.27 ± 7.60^{b}	42.62±0.94^{a}
	Base	753.45±25.96^{b}	18.10 ± 0.50^{a}	9.45 ± 0.45^{a}	8.65±0.23^{b}	422.20±10.70^{b}	40.51±0.49^{a}
	Mean	**692.23±31.04^{a}**	**16.98±0.56^{a,b}**	**9.38±0.20^{a,b}**	**7.61±0.56^{a}**	**386.08±25.93^{a}**	**41.92±0.71^{a}**
K. ivorensis	**Top**	678.14 ± 6.81^{a}	15.90 ± 0.74^{a}	8.81 ± 0.67^{a}	7.09±0.33^{a}	323.76 ± 6.70^{a}	50.85±0.49^{a}
	Middle	684.64 ± 9.78^{a}	16.07 ± 0.46^{a}	9.02 ± 0.65^{a}	7.04±0.31^{a}	356.96 ± 4.72^{b}	47.91±0.85^{b}
	Base	743.40 ± 6.63^{b}	15.95 ± 0.65^{a}	8.31 ± 0.71^{a}	7.64±0.34^{a}	373.27 ± 3.52^{b}	42.20±0.77^{c}
	Mean	**702.06±20.75^{a}**	**15.97 ± 0.05^{a}**	**8.72 ± 0.21^{a}**	**7.25±0.19^{a}**	**351.33±14.57^{a}**	**46.98±2.54^{a}**
E. angolense	**Top**	694.01 ± 5.37^{a}	19.31±0.89^{a,b}	11.54±1.17^{a}	7.77±0.86^{a}	341.90±12.51^{a}	49.10±1.80^{a}
	Middle	783.90±12.49^{b}	17.58 ± 0.48^{a}	10.31±0.56^{a}	7.27±0.27^{a}	368.45±5.32^{a,b}	45.62±0.92^{a}
	Base	776.25±13.27^{b}	21.37 ± 0.50^{b}	12.73 ±0.84^{a}	8.64±1.18^{a}	391.20 ± 8.39^{b}	39.85±1.31^{b}
	Mean	**751.39±28.77^{a}**	**19.42±1.09b^{c}**	**11.53 0.70^{b}**	**7.89±0.40^{a}**	**367.18±14.25^{a}**	**44.86±2.70^{a}**
E. utile	**Top**	650.25 ±7.15^{a}	21.46 ± 1.07^{a}	13.76±0.84^{a}	7.70±1.04^{a}	401.40±26.18^{a}	48.80±3.42^{a}
	Middle	741.71±19.18^{b}	20.36 ± 1.07^{a}	11.0.6±0.56^{b}	9.30±0.84^{a}	379.33±10.71^{a}	44.49±0.38^{a,b}
	Base	749.29±16.57^{b}	20.19 ± 0.85^{a}	10.88 ±0.34^{b}	9.31±0.82^{a}	396.31 ± 5.94^{a}	39.87 ±1.59^{b}
	Mean	**713.75±31.83^{a}**	**20.67 ± 0.40^{c}**	**11.90±0.93^{b}**	**8.77±0.54^{a}**	**392.35 ± 6.67^{a}**	**44.39 ±2.58^{a}**

Means ± SE for species in a column with the same letter (s) are not significantly different. Means (for species) in a column with the same letter(s) are not significantly different. Difference are significant where $P < 0.05$.

4.10.5 Vessel length

Vessel length increased generally from the top to the base of the shoots in all the species except in *E. utile* where longer vessels occurred slightly in the top internodes (Appendix 23). Vessel length differed significantly with the position on shoot at $P < 0.05$ in *K. grandifoliola, K. ivorensis* and *E. angolense* but not in *E. utile* (Table 9; Appndix 23a). Mean vessel length varied from 351.33 µm in *K. ivorensis* to 392.35 µm in *E. utile*. Mean vessel length, however, did not differ significantly with the type of African mahogany species (Table 9; Appendix 24).

4.10.6 Vessel diameter

Generally, vessel diameter narrowed from the top to the basal internodes in all the four species (Appendix 23). Thus, position on shoot significantly affected the vessel diameters of the various species: *K. grandifoliola* ($P < 0.053$); *K. ivorensis* ($P < 0.000$); *E. angolense* ($P < 0.002$); and *E. utile* ($P < 0.042$) (Table 9). Mean vessel diameter ranked as follows: 41.92 µm in *K. grandifoliola* < 44.39 µm in *E. utile* < 44.86 µm in *E. angolense* < 46.98 µm in *K. ivorensis*. Mean vessel diameter did not differ significantly with the type of African mahogany species (Appendiix 24; Table 9).

4.11 Effects of age and stem position on fibre and vessel dimensions

4.11.1 Fibre length

Mean fibre length varied well with stem position at $P < 0.05$ in cuttings from all four ages of *K. grandifoliola* (Appendix 25; Table 10). Fibre length generally decreased from the top to the base internodes in all the four different ages. Mean fibre length increased as age of stock-plant increased from 1-year (630. 20 µm) to 12-years (692.23 µm). Mean fibre length did not differ significantly with age of stock-plant (Appendix 26; Table 10).

4.11.2 Fibre diameter

With the exception of cuttings from the 4-year old stock-plants which had slightly wider mean fibre diameter at the top internodes than the middle and base internodes, the three other ages exhibited increasing diameters from the top to the basal internodes (Appendix 25; Table 10). Stem position had no significant effect on fiber diameter in the different ages except in cuttings of the 7-year old stock-plants ($P < 0.022$) (Table 10). Mean fibre diameter increased with increasing age of stock-plant; 1 (14.49) < 4 (14.85) < 7 (16.83) < 12 (16.98) (Appendix 26). Fibre diameter differed significantly with age of stock-plant at $P < 0.05$, with the differences occurring between age 1 and ages 7 and 12 and also between age 4 and age 12 (Table 10).

4.11.3 Fibre lumen diameter

Mean fibre lumen diameter generally decreased from the top to the basal internodes in the different ages except in age 7 which increased from the top to base internodes (Appendix 25). Stem position had no significant effect on fibre lumen diameter in any of the samples studied for the four different ages (Table 10). Mean fibre lumen diameter increased from 7.93 µm in age 1 to 9.67 µm in age 7 which was slightly wider than that of age 12 (9.38 µm) (Appendix 26). Age significantly influenced mean fibre lumen diameter with the significant differences between age 1 and ages 7 and 12, and also between age 4 and age 7 at $P < 0.05$ (Table 10).

4.11.4 Double fibre wall thickness

Mean double fibre wall thickness increased from the top to the basal internodes in ages 1, 4, 7 and 12, (Appendix 25; Table 10). Stem position significantly affected double fiber wall thickness ($P < 0.05$) in all the four different ages (Table 10). Mean double fibre wall thickness increased from 6.56 µm in age 1 to 7.61 µm in age 12. It did not differ significantly with age despite the differences in the values (Appendix 26; Table 10).

4.11.5 Vessel length

Mean vessel length increased from top to basal internodes in ages 1, 4, 7 and 12 (Appendix 25; Table 10). Stem position significantly influenced vessel length in all the four different ages at $P < 0.05$ (Table 10). Mean vessel length increased with increasing age but did not differ significantly with age of stock-plant at $P < 0.05$ (Appendix 26; Table 10).

4.11.6 Vessel diameter

Mean vessel diameter decreased from top to basal internodes in ages 1, 4 and 12 (Appendix 25; Table 10). In age 7, however, the middle internodes had wider vessel diameter than the top and basal internodes (Appendix 25; Table 10). Stem position significantly influenced vessel diameter in ages 1 ($P < 0.00$), 4 ($P < 0.00$) and 12 ($P < 0.053$), but had no significant effect on samples from age 7 (Table 10). Mean vessel diameter decreased from age 1 (47.13 µm) to 41.92 µm in age 12 (Appendix 26). Age had no significant influence on mean vessel diameter (Table 10).

Table 10 Effect of position on shoot and age of stock-plant on fiber and vessel dimensions

Age of stock-plant (yr)	Position on shoot	Anatomical features					
		Fiber length (µm)	Fiber diameter (µm)	Fiber lumen diameter (µm)	Double fiber thickness (µm)	Vessel length (µm)	Vessel diameter (µm)
1	**Top**	597.24 ± 5.03[a]	14.21 ± 0.11[a]	8.26 ± 0.20a	5.95±0.10[a]	254.00 ± 7.18[a]	50.60±0.78[a]
	Middle	620.15±17.13[a]	14.42 ± 0.43[a]	7.85 ± 0.41a	6.57±0.06[b]	312.20 ± 3.25[b]	48.15±0.79[a]
	Base	673.2 ± 10.60[b]	14.84 ± 0.57[c]	7.69 ± 0.59a	7.15±0.04[c]	353.80±23.20[b]	42.65±1.05[b]
	Mean	**630.20±22.50[a]**	**14.49 ± 0.19[c]**	**7.93 ±0.17[b,c]**	**6.56±0.35[a]**	**306.67±28.94[a]**	**47.13±2.35[a]**
4	**Top**	616.40± 6.58[a]	15.34 ± 0.76[a]	9.19 ± 0.82[a]	6.15±0.07[a]	304.40±10.30[a]	42.30±0.79[a]
	Middle	648.05±10.43[a]	14.32 ± 0.59[a]	7.71 ± 0.56[a]	6.61±0.07[b]	364.90 ± 6.36[b]	46.25±0.41[a]
	Base	707.10±14.17[b]	14.90 ± 0.66[a]	7.33 ± 0.61[a]	7.57±0.15[c]	391.30±16.59[b]	48.75±0.81[b]
	Mean	**657.18±26.58[a]**	**14.85±0.29[b,c]**	**8.08 ± 0.57[b]**	**6.78±0.42[a]**	**353.53±25.72[a]**	**45.77±1.88[a]**
7	**Top**	624.25±12.63[a]	15.75 ± 0.68[a]	9.40 ± 0.62[a]	6.35±0.16[a]	327.30±11.06[a]	43.44±0.47[a]
	Middle	673.38 11.94[a]	16.72±0.33[a,b]	9.67 ± 0.25[a]	7.06±0.18[b]	382.48 ± 8.37[b]	44.13±0.99[a]
	Base	772.73±13.78[b]	18.01 ± 0.40[b]	9.94 ± 0.42a	8.08±0.20[c]	408.55 ± 5.79[b]	41.81±0.58[a]
	Mean	**690.12±43.67[a]**	**16.83±0.66[a,b]**	**9.67±0.16a,c**	**7.16±0.50[a]**	**372.78±23.95[a]**	**43.13±0.69[a]**
12	**Top**	652.70 ±8.03[a]	16.41 ± 0.75[a]	9.68 ± 0.89[a]	6.73±0.25[a]	335.80±17.82[a]	42.65±0.26[a]
	Middle	670.53±13.85[a]	16.43 ± 0.32[a]	9.00 ± 0.34[a]	7.43±0.27[a]	400.27 ± 7.60[b]	42.62±0.94[a]
	Base	753.45±25.96[b]	18.10 ± 0.50[a]	9.45 ± 0.45[a]	8.65±0.23[b]	422.20±10.70[b]	40.51±0.49[a]
	Mean	**692.23±31.04[a]**	**16.98 ± 0.56[a]**	**9.38 ± 0.20[a]**	**7.61±0.56[a]**	**386.08±25.93[a]**	**41.92±0.71[a]**

Means ± SE for an age in a column with the same letter (s) are not significantly different. Mean (for ages) on column with the same letter(s)aresignificantlydifferent.DifferencesaresignificantwhereP<(0.05)

CHAPTER FIVE

5.0 DISCUSSION

5.1 Effects of African mahogany species on rooting ability of leafy stem cuttings

This study shows that 12-year old stock-plants of all the four African mahogany species (i.e. *K. grandifoliola, K. ivorensis, E. angolense* and *E. utile*) can be vegetatively propagated using leafy stem cuttings. For the rooting abilities of the four species of the Meliaceae, the *Khaya* species exhibited better rooting ability in all the three rooting media than the *Entandrophragma* species. Within the same genera, *K. grandifoliola* exhibited higher rooting ability than *K. ivorensis,* and *E. angolense* than *E. utile* in all the three rooting media. Differences in rooting ability for the four African mahoganies may be attributed to their genetic make-up and their adaptive environments. *K. ivorensis*, *E. utile* and *E. angolense* are all adapted to areas with high rainfall thus higher humidity as compared to *K. grandifoliola* which is found mostly in the dry semi-deciduous and the transition zones between the high forest and savannah regions. Leafy stems cuttings are easily affected by environmental stress conditions such as light, temperature and humidity. Thus, cuttings taken from plants mostly used to very wet environments may experience more environmental stress post-severance from stock-plants and also in the non-mist propagators, which will affect their rooting abilities. Thus, even though the environment within the propagators were controlled to a large extent, minute changes in some of these environmental factors might have contributed to the low rooting abilities observed in the three African mahoganies apart from *K. grandifoliola*.

The reasons for variation in rooting ability of stem cuttings from different species of the same family and genus are not well understood even though physiological, stock-plant and environmental factors that may influence rooting capabilities in stem cuttings have been investigated. Studies by Alegre *et al.* (1998) on two species of the same genus (*Dorycnium pentaphyllum* and *D. hirsutum*) showed different rooting abilities when the same auxin treatment, temperature of rooting environment and source of cutting, were applied to the two species. *D. pentaphyllum* softwood cuttings showed a markedly higher rooting ability than those of *D. hirsutum* even though the rooting factors applied to them were the same for each of the two species. Opuni-Frimpong *et al*. (2008b) investigated the rooting ability and efficiency of two *Khaya* species (*K. anthotheca* and *K. ivorensis*), and found out that *K. anthotheca* stem cuttings exhibited higher rooting ability than *K. ivorensis* stem cuttings of the same age of stock-plant in the same propagation environment. *Quercus bicolor* cuttings exhibited higher rooting ability as compared to lower percentage rooting ability in *Q. macrocarpa* cuttings under the same propagation conditions even though they are from the same genus (Amissah *et al*., 2008). These differences in the rooting ability of stem cuttings have been attributed to the anatomy, morphology, physiological pre- and post severance states, the stock-plant adaptive environment as well as the propagation environment all of which together influence the rooting abilities of stem cuttings (Leakey, 2004; Husen and Pal, 2006) and varies from one species to the other.

5.2 Effects of rooting medium on rooting ability of stem cuttings of four African mahogany species

According to Hartmann *et al*. (1997), the factors that influence the selection of an appropriate rooting medium are the type of species, cutting type, season and propagation environment. In the present experiment, the type of rooting media had no significant influence on the rooting percentage and the number of roots per cutting in *K. grandifoliola, K. ivorensis, E. angolense* and *E. utile*. However, as reported in other studies (Ofori *et al*., 1996; Shiembo *et al*., 1996 a & b, 1997; Leakey *et al*., 1990; Mesen *et al*., 1997b), type of rooting medium in this study had no influence on rooting percentage and number of roots per cutting in any of the four species investigated. Rooting percentage was highest in the mixed medium for *K. grandifoliola* and *K. ivorensis*, while *E. angolense* and *E. utile* exhibited higher rooting percentage in the top soil. However, the lowest rooting percentage in all the four species was recorded in river-sand. Ofori *et al*. (1996) also reported lower rooting percentage in river-sand for *M. excelsa* stem cuttings which he attributed to its relatively low water holding capacity. Studies on other species' preference for different rooting media have been demonstrated in previous investigations with sawdust being suitable for *M. excelsa* (Ofori *et al*., 1996), *Irvingia gabonensis* (Shiembo *et al*., 1996b), *Gnetum africanum, Ricinodendron heudolitii* (Shiembo *et al*., 1996a; 1997); sand/gravel suitable for *Vochysia hondurensis* (Leakey *et al*., 1990), *Cordia alliodora* (Mesen *et al*., 1997a) and a mixture of sand/gravel and sawdust suitable for *Eucalyptus deglupta* (Leakey *et al*., 1990).

One of the major differences between different rooting media is their water-holding capacity since it determines the availability of water to the cutting which influences the rooting physiology and rootability of the cutting (Leakey *et al*., 1990; Newton *et al*., 1992). The results of the present study indicates that as in *Pausinystalia johimbe* (Tchoudjeu *et al*., 2004), leafy stem cuttings of the four African mahogany species are not very sensitive to the different rooting media used even though rooting ability was best in the mixed medium for the *Khaya* species and in the top soil for the *Entandrophragma* species. However, this lack of any pronounced effect of rooting medium variation on the final rooting percentage as stated by Tchoundjeu *et al*. (2004) is unusual as reports on the effects of rooting media on rooting ability of other species have shown significant influences (Leakey *et al*., 1990; Ofori *et al*., 1996; Shiembo *et al*., 1996; 1997; Mesen *et al.*, 1997a) Top soil is mostly known for its high concentration of organic matter which is important for water retention (Leakey *et al*., 1990), while sand is noted for its high aeration. These four African mahogany species are mostly found on well-drained soils (Lemmens, 2008 a and b; Mujuni, 2008; Opuni-Frimpong, 2008; Tchinda, 2008). With the exception of *K. grandifoliola*, however, the three other African mahoganies prefer, in addition to being well-drained, soils that are moist and have good water-holding capacity (Lemmens, 2008 a and b; Mujuni, 2008; Tchinda, 2008). Thus the high rooting ability of the *Entandrophragma* species in the top soil could be attributed to their adaptation to their native range of occurrence, which is mostly in the moist forests with high water-holding soil types. In the case of the *Khaya* species, their preference for the mixed medium may be attributed to their adaptation to semi-deciduous forest types and their preference for well-drained soils. Tchoundjeu *et al*. (2002) also suggested that even

though these preferences by the various species are not clear, it could be attributed to the adaptation of the various species to their environment. Their studies suggested that species from drier ecological regions may root better in river-sand, while those from wet ecological regions may prefer top soil. Further investigations into rooting media with respect to the ecological region of stock-plant would have to be considered in any further studies.

5.3 Effects of age of stock-plant on rooting ability of *K. grandifoliola* stem cuttings

Several studies support the fact that the rooting ability of stem cuttings decreases as age of stock-plants increases in many species. Some of the reasons for the reduced rooting of cuttings, as age of stock-plants increase, include accumulation of rooting inhibitors (such as gibberellins, cytokinnins and kinetin, even though some of these inhibitors could promote adventitious root formation at some dosages), decrease in the endogenous content of auxin and/or root promoters and decreased sensitivity of tissues to auxins with physiological aging of stock-plant (Hartmann *et al*., 1997; Ofori *et al*., 1997; Bhardwaj and Mishra, 2005; Husen and Pal, 2006; Opuni-Frimpong *et al*., 2008b; Amri *et al*., 2010). The results of the present study support this phenomenon since stem cuttings of *K. grandifoliola* taken from 1-year old stock-plants showed higher rooting ability in terms of rooting percentage, number of roots per cutting and length of longest root than stem cuttings from stock-plants of 4, 7 and 12 years.

However, accurate determination of tolerance to the *Hypsipyla robusta*, shoot borer, in *Khaya* trees is mostly not identified until after the first 3 – 5 years (Opuni-Frimpong *et*

al., 2008b), necessitating the vegetative propagation of trees that have attained these ages and beyond. The rooting abilities of the stem cuttings from the 4-, 7- and 12-year old stock-plants of *K. grandifoliola* were high in this experiment even though they were not as much as exhibited in the stem cuttings from the 1-year old stock-plants. Opuni-Frimpong *et al*. (2008b) emphasized the critical importance of being able to vegetatively propagate older aged African mahogany plants. The findings of the present study, therefore, indicate the possibility of mass propagation through the rooting of stem cuttings of *K. grandifoliola* from older stock-plants which show tolerance to the mahogany shoot-borer.

The stem cuttings for the present studies were obtained from rejuvenated coppiced shoots as recommended by earlier studies (Ofori *et al*., 1997; Tetsumura *et al*., 2001). Tetsumura *et al*. (2001) reported that there is a typical enhanced rooting and vegetative vigour associated with the juvenile phase which can improve the rooting of stem cuttings by coppicing. The results of the present study support the findings of Ofori *et al*. (1997), who reported that stem cuttings from coppiced shoots of 10-year old *M. excelsa* had improved rooting ability. However, since the rooting percentage of the stem cuttings from the older stock-plants of *K. grandifoliola* were lower than those from the younger stock-plants, the degree of reinvigoration gained by coppicing, as suggested by Ofori *et al*., (1997), would be dependent on the age of the stock-plant. Thus, the present study suggests that stem cuttings taken from younger aged stock-plants will be economically more productive, as it yields significantly higher rooting ability than those of the older stock-plants. However, the appreciably higher rooting ability of the stem cuttings from

older stock-plants provides an opportunity for vegetatively propagating African mahoganies that express resistance/tolerance to the shoot-borer.

5.4 Effects of cutting position on shoot on the rooting ability of leafy stem cuttings

The origin of cuttings in shoots is closely related to their rooting abilities in a number of tropical tree species (Leakey and Coutts 1989; Dick *et al*., 1991). Dick *et al*. (1999) suggested that cuttings taken sequentially down the main stem of a shoot might respond negatively or positively to rooting depending on the type of species. Many researchers have reported a decrease in rooting ability from the top to the basal portions of shoots in species such as *T. scleroxylon* (Leakey, 1983), *Nauclea diderrichii* (Matin, 1989) and *M. excelsa* (Ofori *et al*., 1997). Other species like *Khaya ivorensis* (Tchoundjeu and Leakey, 1996), *Arbutus andrachne* (Al-salem and Karam, 2001), *Dalbergia sissoo* (Husen, 2004), *Ulmus villosa* (Bhardwaj and Mishra, 2005) and *Dalbergia melanoxylon* (Amri *et al*., 2010) have exhibited higher rooting ability in the basal portions than the top and middle portions. Stem cuttings collected from the middle portions of harvested shoots for the present study had significantly higher rooting percentage than from the top and basal portions in all the four species studied; significantly longer roots in *K. grandifoliola* and higher root numbers in *K. grandifoliola* and *K. ivorensis* than those from the top and basal portions. In the cuttings from the different aged stock-plants of *K. grandifoliola*, rooting ability was generally also higher in middle portions than in the apical and basal portions. The high rooting percentage in the middle portions of the shoots for the four species conforms to studies on *Tectona grandis*, (Husen and Pal, 2007b), *Leucaena*

leucocephala (Dick *et al*., 1999), *Shorea bracteolata* (Aminah, 1990) and *S. macrophylla* (Lo, 1985), which also had higher rooting percentage from the middle portions.

According to Leakey and Mohammed (1985), there are numerous gradients of variation within any shoot from the top to the basal portions that affect the internode length and diameter and stem lignifications, implying that no two portions in a shoot will have the same anatomical features. According to Dickison (2000), there are various differences in anatomical characters within an individual plant, species or group of related taxa, and that some of these variations in qualitative and quantitative aspects of anatomical structures may be due to the age of a plant or the location of the sample within a plant. Variations in anatomical characters can also be attributed to seasonal changes, geographic range of distribution and environmental factors such as degree of crowding, availability of water, light and altitudinal adaptation as well as genetic factors (Dickison, 2000). Thus, shoots from the same stock-plants, age or species may exhibit different anatomical properties. Husen and Pal (2006) suggested that various changes accompany the transition from the juvenile to mature phases of physiological aging in plants including changes in their anatomical features.

5.5 Effects of African mahogany species and age of stock-plant of *K. grandifoliola* on tissue proportions

The results of the present study showed significant decreases in the proportion of parenchyma from the top portions to the basal portions and significant increases in fiber proportion from the top to basal portions in all the four African mahoganies. Dickison

(2000) stated that variations may exist in the quantitative aspects of anatomical characters with respect to the location of the sample on the plant. The results, however, indicated that tissue proportions in the cross sections across the four African mahogany species of the Meliaceae family did not have any significant variations. This is similar to observations made by Ayoub and Qrunfleh (2006) in a study of two olive cultivars (Nabali and Raseei), which had similar trends in tissue proportion.

Maturation is an integral part of the life cycle of all vascular plants which is accompanied by decreased growth rates, increased plagiotropism, changes in reproductive competence, branching characteristics and foliar morphology in woody plants (Husen and Pal, 2006). In addition to the morphological changes, maturation also comes with numerous physiological, anatomical and biochemical changes into the adult phase (Greenwood, 1987; Bonga and von Anderkas, 1993; Greenwood and Hutchinson, 1993). The results of the present study indicate a more definite pattern of varying proportions of fibre and parenchyma from the top to the basal portions of the shoots from the four different ages. Cross sections from the top portions of 1-, 4-, 7- and 12-year old stock-plants exhibited higher percentage of parenchyma which decreased to the basal portions while the percentage of fibre increased from the top to basal portions of the shoots. Even though not significantly different, percentage of parenchyma decreased from age 1 to age 12 while percentage of fibre increased from age 1 to age 12. An increase in the number fibre elements, tracheids with increasing age of stock-plants have been reported in other tree species including *Pinus caribaea* var. *bahamensis*, *Populus deltoides* and teak by Pande (1995), Chauhan *et al*. (2001) and Husen and Pal (2006) respectively.

5.6 Effect of African mahogany species and age of stock-plant of *K. grandifoliola* on fibre and vessel dimensions

The fibre length and double fiber wall thickness in the four species generally increased from the top to the basal portions. There was no uniform pattern in fiber width and fiber lumen diameter, as they varied in size with position on shoot. While *K. grandifoliola* and *E. angolense* had wider diameters at the basal portions, *K. ivorensis* and *E. utile* had wider diameters at the middle and top respectively.

Fibre diameter and double fibre wall thickness increased with increasing age of stock-plant, while fibre lumen diameter decreased with increasing age of the stock-plant. An increase in the length of fibres with age has been reported in several other tree species such as *T. grandis* (Husen and Pal, 2006), *Pinus caribaea* var. *bahamensis* (Pande, 1995) and *Populus deltoides* (Chauhan *et al*., 2001). The results of this study suggests that the anatomical features of the stem cuttings of *K. grandifoliola* can be used as good indicators of aging and maturity as was observed in teak by Husen and Pal (2006).

5.7 Relationships between tissue proportions and rooting percentages of cuttings from four African mahogany species and four different aged stock-plants of *K. grandifoliola*

The factors reported to cause poor rooting ability among plant species include accumulation of rooting inhibitors (Hartmann *et al*., 1997) and the presence of physical barriers in the vicinity of the area of root formation (Beakbane, 1961; Edwards and Thomas, 1980) that may prevent root initiation and/or root emergence. These physical barriers could be due to the presence of a sclerenchyma layer or fiber sheathes, which could act as a physiological barrier to adventitious root initiation or a mechanical barrier to root emergence (Beakbane, 1961; Liu *et al*., 1997; Yi *et al*., 2000; Zhang *et al*., 2009). Stem cuttings of *Feijoa sellowiana*, which showed longer rooting time, thus, poor rooting ability were associated with the presence of a sclerenchymatic ring (Zhang *et al*., 2009). However, Ayoub and Qrunfleh (2006) observed that even though continuous sclerenchyma rings existed in sections of two olive cultivars, they did not act as mechanical barriers to the formation and emergence of adventitious roots. In the current study, fibre proportion did not have significant variation across the four species, however, rooting varied significantly across the four species. It can be inferred therefore, that other factors such as the physiological, stock-plant and propagation environment could account for the differences in the rooting abilities of the species.

The results of the present study hypothesizes a relationship between rooting percentage and tissue proportions of the four African mahogany species as well as the four different aged stock-plants of *K. grandifoliola*. In the present study, *K. grandifoliola* stem cuttings

exhibited higher rooting percentage in all the three different rooting media followed by *K. ivorensis*, *E. angolense* and *E. utile* respectively. Among the four species, fibre proportion was highest in *E. angolense*, while proportion of parenchyma was highest in *K. grandifoliola*. Rooting ability of stem cuttings from root-stocks of *Pyrus communis* L., *Fagus sylvatica* L. and *Malus* Mill. was observed to be inversely proportional to the percentage of fibres and the integrity of the sclerenchyma ring (Beakbane, 1961). A similar observation was made in *Quercus bicolor* and *Q. macrocarpa*, which had good correlation between percentage rooting and percentage parenchymatous gaps in the perivascular region (Amissah *et al*., 2008). *Q. macrocarpa*, which had low percentage parenchyma gaps, had a corresponding low percentage rooting while *Q. bicolor*, which had a higher percentage parenchyma gaps, had a corresponding high rooting percentage. The results of the present study supports the findings of Amissah *et al*. (2008) and Beakbane (1961), as the highest rooting percentage occurred in *K. grandifoliola*, which also had the highest proportion of parenchyma and the least proportion of fibres. This study supports the findings of Ayoub and Qrunfleh (2006) and attributes the high rooting ability in *K. grandifoliola* to faster formation of the root primordia from the parenchyma as compared to the other three African mahoganies. In addition, Ayoub and Qrunfleh (2006) found that during root formation in two cultivars of olives, the sclerenchyma ring dissolved gradually thus, it can be inferred that the sclerenchyma ring forming a mechanical barrier for adventitious root formation may not hold true for all plant species. Stem cuttings from *E. angolense*, which also showed low rooting percentage, might be attributed to the use of the stored assimilates in the cuttings in the formation of callus. This was also observed by Ayoub and Qrunfleh (2006) for the olive cultivar 'Nabali',

which tended to form callus with low rooting ability as compared to the other cultivar 'Raseei'. However, even though cuttings from *E. utile* also had a high proportion of parenchyma, it rather exhibited the lowest rooting percentage among the four African mahogany species. As compared to the other three African mahoganies, the stems of the shoots of *E. utile* were more succulent and the base more susceptible to rotting leading to less rooting within the non-mist propagators. Thus, it can be inferred that even though the anatomy of the shoot may play a role in the rooting ability of cuttings, it may be a combination of the physiological status, genetic make-up, environmental factors and the plant's morphological structure in addition to the anatomy that influence their rooting abilities.

For cuttings from the different aged stock-plants, proportion of parenchyma decreased with increasing age of stock-plant, while fibre and vessel proportions increased; this was observed by Husen and Pal (2006) for teak cuttings. The rooting percentage of cuttings also decreased from age 1 to age 12. The decreasing proportion of parenchyma with increasing age had a corresponding decrease in percentage rooting. Amissah *et al*. (2008) also observed a decrease in the percentage of parenchyma gaps with increasing stem age and a simultaneous decrease in rooting ability in *Quercus bicolor* stem cuttings. The decreasing rooting ability with increasing age of stock-plant may be attributed to the delay in cell division for the formation of root primordia as the cuttings possess more fibres which will need more energy to dedifferenciate into meristamatic cells (Esau, 1977; Hartmann *et al*., 1997).

According to Husen and Pal (2006), maturation is an integral part of the life cycle of all vascular plants, which is accompanied by decreased growth rates, increased plagiotropism, changes in reproductive competence, branching characteristics and foliar morphology in woody plants. The variations in the tissue proportions in this study goes to support the findings of Ofori *et al*. (1997) and Opuni-Frimpong *et al*. (2008b) who reported decreased rooting ability with increasing age of stock-plants in *M. excelsa* and 2 *Khaya* species respectively. With the varying tissue proportions, as age of stock-plants increase, change in anatomical features of plants may be one of the factors that accompany maturation in vascular plants and could be one of the major factors that influence the rooting ability of stem cuttings. Consequently, more research into the anatomical features of shoots from matured trees as compared to that of coppiced shoots of the same aged trees will be important in making more conclusive remarks on the effects of anatomical features on the rooting ability of stem cuttings of older trees.

CHAPTER 6

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The results of this study indicate that individual plants of *K. grandifoliola, K. ivorensis*, *E. angolense* and *E. utile*, can be vegetatively propagated using leafy stem cuttings in non-mist propagators. *K. grandifoliola* had the highest rooting ability in terms of rooting percentage, number of roots per cutting and length of the longest root, while *E. utile* generally recorded the least.

The number of roots per cutting and rooting percentage of the individual species were not affected by the type of rooting medium used. Type of rooting media, however, influenced the length of longest root in *K. ivorensis* and *E. utile*. *K. grandifoliola* and *K. ivorensis* both rooted best in the mixed medium, while the two *Entandrophragma* species rooted best in the top soil. Thus, rooting of these African mahogany species is more affected by the type of species than by the rooting medium used in their propagation.

Position of cutting on shoot influenced the rooting percentage in the four species, the highest occurring in cuttings from the middle portions of the shoots. Position of cutting on shoot influenced the length of longest root in *K. grandifoliola* and number of roots per cutting in both *Khaya* species.

The results of this study support the possibility of vegetative propagation of trees beyond 5 years of age through coppicing to obtain rejuvenated shoots. Age of stock-plant had significant influence on the rooting ability of stem cuttings from different aged stock-plants of *K. grandifoliola*. Rooting of stem cuttings increased significantly with decreasing age even though rooting ability of stem cuttings from the coppiced shoots of the older trees were appreciable.

Position of cutting on shoot significantly influenced the rooting percentage of stem cuttings of 1-, 4-, 7- and 12-year old stock-plants of *K. grandifoliola*. Position of cutting on shoot influenced number of roots per cutting in stem cuttings from 4-year old stock-plants and length of root of stem cuttings from 4- and 12-year old stock-plants of *K. grandifoliola*. Rooting ability of the stem cuttings from all the four different aged stock-plants was generally highest in cuttings from the middle portions.

Position on stem had major influence on fibre and parenchyma proportions but not on the vessel proportion of the African mahogany species. Type of species did not have major effect on tissue proportion.

Position on stem influenced vessel proportion in stem cuttings from 7-year old stock-plants of *K. grandifoliola*. Age of stock-plant of *K. grandifoliola* had major effect on the vessel proportion but not on fibre and parenchyma proportion. Position on stem also had major influence on parenchyma and fibre proportions in 1-, 4-, 7- and 12-year old stock-plants of *K. grandifoliola* but not on the fibre proportion of sections from 1-year old stock-plants.

The effect of type of species on fibre length, double fibre wall thickness, vessel length and vessel diameter were not significant, however, they affected the fibre diameter and the fibre lumen diameter. In *K. grandifoliola*, position on shoot had major influence on all the fibre and vessel dimensions studied except fibre lumen diameter. Position on shoot had major influence on fibre length, fibre diameter, vessel length, vessel diameter but not on fibre lumen diameter and double fibre wall thickness of *K. ivorensis*. Position on shoot significantly affected the vessel dimensions as well as the fibre length but not the other three fibre dimensions in *E. angolense*. In *E. utile*, position on shoot did not affect double fibre wall thickness and vessel length but affected all the other fibre and vessel dimensions studied.

With the exception of fibre diameter and fibre lumen diameter, age of stock-plant of *K. grandifoliola* had no major effect on fibre length, double fibre wall thickness and the vessel dimensions. In sections from 1-, 4- and 12-year old stock-plants of *K. grandifoliola,* position on shoot affected significantly fibre length, double fibre wall thickness, vessel length and vessel diameter but not on fibre diameter and fibre lumen diameter. In sections from 7-year old stock-plant, position on shoot had major effect on fibre length, fibre diameter, double fibre wall thickness and vessel length but not on fibre lumen diameter and vessel diameter.

The varying relationships between the tissue proportions and the rooting percentages of the four African mahogany species as well as in the four different ages of stock-plants of *K. grandifoliola* make it difficult to establish a clear relationship between the two

parameters measured. Whereas high proportion of parenchyma corresponded with high percentage rooting in *K. granddifoliola*, high proportion of parenchyma in *E. utile* corresponded with rather low percentage rooting of cuttings. However, the reduced rooting ability in the *Entandrophragma* species and the older aged trees of *K. grandifoliola* might be more as a result of their cuttings inability to form root primordia or a prevention of the expansion and proliferation needed for root initiation rather than as a result of restrictions by the presence of a higher proportion of fibres. Since the anatomical properties of the different species as well as in the different ages of stock-plants of *K. grandifoliola* as like other factors that influence the rooting ability of cuttings, are all affected by the physiology of the trees, the differences in the tissue proportions may be attributed to the physiological states of the trees as well as their genetic make-up. Even though the proportion of fibres may have been influenced by the rooting ability of the cuttings in a way, as in Amissah *et al*., (2008), it can be speculated that the quantitative differences in the tissue proportions of the different species as well as the different ages may be a reflection of the physiological states of the trees that control the anatomical properties and consequently the ability for cell proliferation. Therefore, the correlations between the tissue proportions and the rooting percentages might be due to the fact that the factors that influence rooting in cuttings, which include the physiology of trees, may also affect the anatomical properties of the plants.

6.2 Recommendations for further studies

Further investigations into rooting media with respect to the ecological region of stock-plant would have to be considered in any further studies.

Stem cuttings taken from the crowns of trees should be propagated and their rooting ability compared to the rooting ability of stem cuttings taken from coppiced shoots of the same tree or the same age.

Anatomical studies of cuttings should also be done taking samples from the crowns of trees as well as from coppiced shoots of the same tree or age to enable the comparison of the anatomical features of the samples from the mature crowns to the coppiced shoots.

Propagation of root cuttings should be done on the species studied as root cuttings of some other species are known to have good rooting and shooting capacity.

Rooted stem cuttings from each of the four African mahogany species as well as from the four different ages of *K. grandifoliola* should be planted in hedges and used in vegetative propagation to determine if the plants can retain or have improved rooting ability.

Propagation of stem cuttings in the major seasons of Ghana, wet and dry seasons should be done to determine the effect of the season on the propagation of stem cuttings in the non-mist propagators.

Propagation of stem cuttings from sprouted shoots from bent trees of mahoganies should be investigated as these have been successfully propagated in Australia.

Wood used in the construction of non-mist propagators as well as the medium used in the propagators should be treated prior to insertion of cuttings into the propagators to prevent insect as well as fungal attacks within the propagators as termite tunnels were found on the wood of the propagators and fungal growth on the rooting media.

REFERENCES

Abbiw, D. 1990. Useful plants of Ghana. Intermediate Technology Publications and The Royal Botanic Gardens, Kew; London, 337 pp.

Alder, D. 1989. Natural forest increment, growth and yield. In: Ghana Forest Inventory Project Seminar Proceedings. (J. LG. Wong; ed) Ghana Forestry Commission/ Overseas Development Administration. 29-30 March, 1989. Accra, Ghana. 101pp.

Alegre, J., Toledo, J. L., Martinez, A., Mora, O., De Andrés, E. F. 1998. Rooting ability of *Dorycnium* spp. under different conditions. *Scientia Horticulturae* 76: 123-129.

Al-salem, M. M., Karam, N. S. 2001. Auxin, wounding and propagation medium affect response of stem cuttings of *Arbuntus andrachne*. *Journal of Horticultural Science* 36: 976-988.

Aminah, H.A. 1990. A note on the rooting of: *Shorea bracteolata* stem cuttings. *Tropical Forest Science* 3(S): 187- 188.

Amissah, J. N., Paolillo, D. J., Bassuk, N. 2008. Adventitious root formation in stem cuttings of *Quercus bicolor* and *Quercus macrocarpa* and its relationship to stem anatomy. *Journal of American Society for Horticultural Science* 133(4):479-486.

Amri, E., Lyaruu, H.V.M., Nyomora, A.S.,Kanyeka, Z.L. 2010. Vegetative propagation of African Blackwood (*Dalbergia melanoxylon* Guill. & Perr.): effects of age of donor plant, IBA treatment and cutting position on rooting ability of stem cuttings. *New Forest* 39:183-194.

Atuahene, S.K.N. 2001. The forest resources of Ghana and research on *Hypsipyla robusta* (Moore) (Lepidoptera: Pyralidae) control in mahogany plantations in Ghana. In: Floyd, F. Hauxwell, C. (Eds.) Proceedings of an International Workshop on Hypsipyla shoot borers of the Meliaceae, Kandy, Srilanka, 1996. ACIAR Proceedings No. 97 Canberra, 58-62.

Ayoub, A.S., Qrunfleh M.M. 2006. Anatomical aspects of rooting 'Nabali' and 'Raseei' olive semi-hardwood stem cuttings. *Jordan Journal of Agricultural Science.* 2:1.

Beakbane, B. 1961. Structure of the plant stem in relation to adventitious rooting. *Nature* 192: 954-955.

Bhardwaj, D. R., Mishra, V. K. 2005. Vegetative propagation of *Ulmus villosa*: effects of plant growth regulators, collection time, type of donor and position of shoot on adventitious root formation in stem cuttings. *New Forest* 29: 105-116.

Bonga, J.M., Von Anderkas, P. 1993. Rejuvenation and tissues from mature conifers and its implication for propagation in vitro. In: Ahuja, M.R., Libby, W.J. (eds), Clonal Forestry Vol. 1. Springer-Verlag, Berlin Heidelberg, New York, pp. 182-200.

Chauhan, L., Gupta, S., Madhwal, R.C., Pandey, R., Pal, M. 2001. Interclonal, intraclonal and within tree variation in wood parameters of different clones of *Populus deltoides*. *Indian Forester* 127(7):777-784. In: Husen, A. and Pal, M. 2006. Variation in shoot anatomy and rooting behaviour of stem cuttings in relation to age of donor plants in teak (*Tectona grandis* Linn. F.). *New Forests*, 31:57-73.

Dick, J.McP., East, K., Leakey, R.R.B. 1991. Influence of propagation environment and cutting length on rooting of *Prosopis juliflora* (Swartz) DC. Nitrogen Fixing Tree Research Reports, 9: 114-116.

Dick, JMcP, Magingo, F, Smith, RI and McBeath, C. 1999. Rooting ability of *Leucaena leucocephala* stem cuttings. *Agroforestry Systems* **42**, 149-157.

Dickison C. W. 2000: Integrative Plant Anatomy. Harcourt Academic Press, San Diego, San Francisco, New York Boston, London, Tonronto, Sydney, Tokyo. 533pp.

Edwards, R.A., Thomas M.B.1980. Observations on physical barriers to root formation in cuttings. Plant Prop. 26: 6-8. In: Amissah, J. N., Paolillo, D. J., Bassuk, N. 2008. Adventitious root formation in stem cuttings of *Quercus bicolor* and *Quercus*

macrocarpa and its relationship to stem anatomy. *Journal of American Society for Horticultural Science* 133(4):479-486.

Esau, K. 1965. Plant anatomy (2nd edition). John Wiley and Sons Inc., New York, N.Y.

Esau, K. 1977. Anatomy of seed plants. 2nd ed. Wiley, New York, N.Y.

FAO (Food and Agricultural Organization) 1993. Conservation of genetic resources in tropical forest management- principles and concepts. FAO Forestry Paper107. Rome, Italy.

Greenwood, M.S. 1987. Rejuvenation of forest trees. *Plant Growth Regul*. 6: 1-12. In: Husen, A. and Pal, M. 2006. Variation in shoot anatomy and rooting behaviour of stem cuttings in relation to age of donor plants in teak (*Tectona grandis* Linn. F.). *New Forests*, 31:57-73.

Greenwood, M.S., Hutchinson, K.W. 1993. Maturation as a developmental process. In: Ahuja, M.R., Libby, W.J. (eds), *Clonal Forestry* Vol. 1. Springer-Verlag, Berlin Heidelberg, New York, pp. 14-33.

Grogan, J., Galvão, J. 2006. Factors limiting post-logging regeneration by big-leaf mahogany (*Swietenia macrophylla*) in southeastern Amazonia, Brazil, and implications for sustainable management. *Biotropica* 38: 219-228.

Hall, J.B., Swain, M.D. 1981. Distribution and ecology of vascular plants in a tropical rain forest, forest vegetation in Ghana. Dr. W. Junk Publisher, London.

Hall, J.S., Medjibe, V., Ashton, P.M.S. 2003. The effects of logging on forest structure and tree species composition in a Central African forest: implications for management of conservation areas. *Forest Ecology and Management* 183: 249-264.

Hall, J.S., 2008. Seed and seedling survival of African mahogany (*Entandrophragma* spp.) in Central African Republic: implications for forest management. *Forest Ecology and Management* 255: 292-299.

Hartmann, H.T., Kester, J.D. 1983. Plant propagation: Principles and practices. Prentice Hall International, London, 321pp.

Hartmann, H.T., Kester, D.E., Davies, F.T. 1990. Plant propagation: Principles and practices. 5th edn. Prentice Hall, International, Englewood Cliffs, NJ, USA, 647pp.

Hartmann, T.H., Kester, D.E., Davies, F.T., Geneve, R.L. 1997. Plant propagation: Principles and practices. 6th Ed. Prentice Hall Inc. Upper Saddle River, New Jersey, USA, 770pp.

Hartmann, H.T, Kester, J.D., Davies, F.T., Geneve, R.L. 2002. Plant propagation: Principles and practices. 7th edn, Prentice Hall, Inc., Upper Saddle River, NJ, USA, 770 pp.

Hawthorne, W., Jongkind, C. 2006. Woody plants of western African forests: a guide to the forest trees, shrubs and lianes from Senegal to Ghana. Kew Publishing, Royal Botanic Gardens, Kew, United Kingdom. 1023 pp.

Hawthorne, W.D. 1990. Field guide to the forest trees of Ghana. Chatham: Natural Resources Institute, for Overseas Development Administration, London. Ghana Forest Series 1, VI 278 pp.

Hawthorne W. 1993. Forest reserves of Ghana: Geographical information exhibitor. ODA/FIMP/Ghana Forestry Department.

Hawthorne, W.D. 1995. Ecological profiles of Ghanaian forest trees. Tropical Forestry Paper, 29. Oxford Forestry Institute, Oxford, UK, 345pp.

Husen, A. 2004. Clonal propagation of *Dalbergia sissoo* Roxb. by softwood nodal cuttings: effects of genotypes, application of IBA and position of cuttings on shoots. *Silvae Genetica* 53: 50-55.

Husen, A. and Pal, M. 2006. Variation in shoot anatomy and rooting behaviour of stem cuttings in relation to age of donor plants in teak (*Tectona grandis* Linn. F.). *New Forests*, 31:57-73.

Husen, A., Pal, M. 2007a. Metabolic changes during adventitious root primordium development in Tectona grandis Linn. f. (teak) cuttings as affected by age of donor plants and auxin (IBA and NAA) treatment. New Forests 33: 309-323.

Husen, A., Pal, M. 2007b. Effect of branch position and auxin treatment on clonal propagation of *Tectona grandis* Linn. f. *New Forests* 34: 223-233.

Husen, A. 2008. Clonal propagation of Dalbergia sissoo Roxb. And associated metabolic changes during adventitious root primordium development. New Forests 36: 13-27.

Irvine, F.R. 1961. Woody plants of Ghana. Oxford University Press, London, pp 868.

Kémeuzé, V. A. 2008. Entandrophragma cylindricum (Sprague) Sprague. In: Louppe, D., Oteng-Amoako, A.A. & Brink, M. (Editors). Plant Resources of Tropical Africa 7(1). Timbers 1. PROTA Foundation,Wageningen, Netherlands /Backhuys Publishers, Leiden, Netherlands / CTA, Wageningen, Netherlands. 239 – 243pp.

Kozlowski, T.T., Pallardy, S.G. 1997. Growth control in woody plants. San Diego, USA.

Lamb, F.B. 1966. Mahogany of Tropical America: Its Ecology and Management. University Michigan Press, Ann Arbor, MI, USA.

Leakey, R. R. B., Chapman, V. R., Longman, K. A. 1982a. Physiological studies for tropical tree improvement and conservation. Some factors affecting root initiation in cuttings of *T. scleroxylon* K. Schum. *Forest Ecology and Management* 4: 53-66.

Leakey, R. R. B., Last, F. T., Longman, K. A. 1982b. Domestication of tropical trees: An approach searching future productivity and diversity in managed ecosystems. *Commonwealth Forestry Review,* 61(1):33-42.

Leakey, R.R.B. 1983. Stockplant factors affecting root initiation in cuttings of *Triplochiton scleroxylon* K. Schum., an indigenous hardwood of West Africa. *Journal of Horticultural Science* 58: 277-290.

Leakey, R. R. B. 1985. Capacity for vegetative propagation in trees. In: Cannell MGR and Jackson J (eds) Attributes of trees as crop plants. Institute of Terrestrial Ecology, Monks Wood, Huntingdon, England, pp 110 -133.

Leakey, R. R. B., Mohammed, H. R. S. 1985. Effects of stem length on root initiation in sequential single-node cuttings of *Triplochiton scleroxylon* K. Schum. *Journal of Horticultural Science* 60: 431-437.

Leakey, R.R.B. 1986. Cloned tropical hardwoods: quicker genetic gain. *SPAN* 29:35-37

Leakey, R. R. B., Longman, K. A. 1988. Low-technology cloning of tropical trees. Appropriate Technology, 19: 6.

Leakey, R.R.B., Coutts, M.P. 1989. The dynamics of rooting in *Triplochiton scleroxylon* cuttings: their relation to leaf area, node position, dry weight accumulation, leaf water potential and carbohydrate composition. *Tree Physiology* 5: 135-146.

Leakey, R. R. B. 1990. *Nauclea diderrichii*: rooting of stem cuttings, clonal variation in shoot dominance and plant plagiotropism. *Trees*, 4:164-169.

Leakey, R.R.B., Mesen, J.F., Tchoundjeu, Z. 1990. Low-technology techniques for the vegetative propagation of tropical trees. *Commonwealth Forest Review* 69: 247-257.

Leakey, R. R. B., Storeton-West, R. 1992. The rooting ability of *Triplochiton scleroxylon* cuttings: the interactions between stock-plant irradiance, light quality and nutrients. *Forest Ecology and Management* 49: 133-150.

Leakey R.R.B., Dick J.McP., Newton, A.C. 1992. Stock-plant derived variation in rooting ability: the source of physiological youth. In: Mass production technology for genetically improved fast growing forest tree species. Vol. 1, AFOCEL Nangis France, 171-178.

Leakey, R.R.B. 2004. Physiology of vegetative reproduction. In: Encyclopaedia of Forest Sciences (Eds J. Burley, J. Evans, and J.A.Younquist). Academic Press, London, UK. 1655-1668.

Lemmens, R. H. M. J. 2008a. *Entandrophragma excelsum* (Dawe and Sprague) Sprague. In: Louppe, D., Oteng-Amoako, A.A. & Brink, M. (Editors). Plant Resources of Tropical Africa 7(1). Timbers 1. PROTA Foundation,Wageningen, Netherlands /Backhuys Publishers, Leiden, Netherlands / CTA, Wageningen, Netherlands. Pp 243 – 245.

Lemmens, R. H. M. J. 2008b. *Khaya ivorensis* A. Chev. In: Louppe, D., Oteng-Amoako, A.A. & Brink, M. (Editors). Plant Resources of Tropical Africa 7(1). Timbers 1. PROTA Foundation,Wageningen, Netherlands /Backhuys Publishers, Leiden, Netherlands / CTA, Wageningen, Netherlands. Pp 333 – 339.

Liu, W.D., Wan, C.K., Rao, L.B., Shen, Z.H. 1997. Anatomical studies of the rooting of Eucalyptus cuttings. J. Central South For. Univ., 17(4):32-36. In: Zhang, M., Tang, H.R., Wang, D., Ren, S.X., Liu R.D. 2009. A study of rooting characteristics and anatomical structure of Feijoa cuttings. *Agricultural Journal* 4(2): 86-90.

Liu, Y., Zhan, Y.G., Liu, Y.X., Luan, S.H., Zhao, Z.X., Li, J.Y., Lin, D.B. 1996. The anatomical study on formation of adventitious roots of softwood cuttings in *Betulla platyphylla*. Journal of Northeast Forest Universit, 24 (3): 15-19. In: Zhang, M., Tang,

H.R., Wang, D., Ren, S.X., Liu R.D. 2009. A study of rooting characteristics and anatomical structure of Feijoa cuttings. *Agricultural Journal* 4(2): 86-90.

Lo, Y. N. 1985. Root initiation of *Shorea macrophylla* cuttings: effects of node position, growth regulators and misting regime. *Forest Ecology and Management* 12: 43-52.

Longman, K.A. 1993. Rooting of cuttings of tropical trees: Propagation and materials. Vol. F1. Common wealth Sci. Council, London, UK.

MacDonald, C. 1993. Practical woody propagation for nursery growers. Timber Press Inc. Portland, Oregon, USA, 669 pp.

Maroyi, A. 2008. *Khaya anthotheca* (Welw.) C.DC. In: Louppe, D., Oteng-Amoako, A.A. & Brink, M. (Editors). Plant Resources of Tropical Africa 7(1). Timbers 1. PROTA Foundation,Wageningen, Netherlands /Backhuys Publishers, Leiden, Netherlands / CTA, Wageningen, Netherlands. Pp 324 – 329.

Matin, M.A. 1989. Carbon economy during rooting of cuttings of *Nauclea diderrichii* (de. Wild and Th. Dur.) Merill. M.Phil, University of Edinburgh, UK, pp. 123. In: Kaul, K. 2008. Variationn in rooting behavior of stem cuttings in relation to their origin in Taxus wallichiana Zucc. *New Forests* 36: 217-224.

Maynard, B. K., Bassuk, N. L. 1996. Stock plant etiolation, shading and banding effects on cutting propagation of *Carpinus betulus*. *Journal of American Society for Horticultural Science* 117: 740-744.

Mesén, F. 1993. Vegetative propagation of Central American hardwoods. Ph.D thesis, University of Edinburgh. In: Shiembo, P. N., Newton, A. C., Leakey, R. R. B. 1996a. Vegetative propagation of *Irvingia gabonensis*, a West African fruit tree. *Forest Ecology and Management* 87: 185-192.

Mesén, F., Newton, A.C., Leakey, R.R.B. 1997a. The effects of propagation environment and foliar areas on rooting physiology of *Cordia alliodora* (Ruiz & Pavon) Oken cuttings. *Trees* 11: 401-411.

Mesén, F., Newton, A. C., Leakey, R. R. B. 1997b. Vegetative propagation of *Cordia alliodora* (Ruiz and Pavon) Oken: the effects of IBA concentration, propagation medium and cutting origin. *Forest Ecology and Management* 92: 45-54.

Mujuni, D. B. 2008. *Entandrophragma utile* (Dawe and Sprague) Sprague. In: Louppe, D., Oteng-Amoako, A.A. & Brink, M. (Editors). Plant Resources of Tropical Africa 7(1). Timbers 1. PROTA Foundation,Wageningen, Netherlands /Backhuys Publishers, Leiden, Netherlands / CTA, Wageningen, Netherlands. Pp 245 – 249.

Negreros-Castillo, P., Snook, L., Mize. C. W. 2003. Regenerating mahogany (*Swietenia macrophylla*) from seed in Quintana Roo, Mexico: the effects of sowing method and clearing treatment. *Forest Ecology and Management* Vol. 183, Issues 1-3, Pages 351-362.

Newton, A. C., Muthoka, P. N., Dick, J. Mc. P. 1992a. The influence of leaf area on the rooting physiology of leafy stem cuttings of *Terminalia spinosa* Engl. *Trees*, 6:210-215.

Newton, A. C., Mesén, J. F., Dick, J. Mc. P., Leakey, R. R. B. 1992b. Low technology propagation of tropical trees: rooting physiology and its practical implications. In: Mass Production for Genetically Improved Fast Growing Forest Tree Species. ACTES proceedings, Bordeaux, September 14-18, AFOCEL Pub., France, 417-424.

Newton, A.C., Baker, P., Ramnarine, S., Mesen, J.F. and Leakey, R.R.B. 1993. The mahogany shoot-borer, prospects for control. *Forest Ecology and Management* 57: 301-328.

Newton, A.C., Cornelius, J.P., Baker, P., Gillies, A.C.M., Hernandez, M., Ramnarine, S., Mesen, J.F., Watt, A.D. 1996. Mahogany as a genetic resource. *Botanical Journal of Linnean Society*, 122: 61-73.

Ngo Mpeck, M.-L., Atangana, A. 2007. Rooting of leafy stem cuttings of *Baillonella toxipserma*. *Forest Science*, 53(5): 571-579

Ngo Mpeck, M., Atangana, A.R., Omgba, A.M. 2009. Temporal variation in rooting of *Annickia chlorantha* leafy stem cuttings. *New Forests*, 38: 273-283

Nikiema, A., Pasternak, D. 2008. *Khaya senegalensis* (Desr.)A.Juss. In: Louppe, D., Oteng-Amoako, A.A. & Brink, M. (Editors). Plant Resources of Tropical Africa 7(1). Timbers 1. PROTA Foundation,Wageningen, Netherlands /Backhuys Publishers, Leiden, Netherlands / CTA, Wageningen, Netherlands. Pp 339 – 344.

Nyemb, N. 2008. *Entandrophragma candollei* Harms. In: Louppe, D., Oteng-Amoako, A.A. & Brink, M. (Editors). Plant Resources of Tropical Africa 7(1). Timbers 1. PROTA Foundation,Wageningen, Netherlands /Backhuys Publishers, Leiden, Netherlands / CTA, Wageningen, Netherlands. Pp 236 – 239.

Ofori, D. A. 1994. Vegetative propagation of *M. excelsa* Welw. by leafy stem and root cuttings. MPhil. Thesis. University of Edinburgh. 177pp.

Ofori, D. A., Newton, A. C., Leakey, R. R. B., Grace, J. 1996. Vegetative propagation of *Milicia excelsa* by leafy stem cuttings: Effects of auxin concentration, leaf area and rooting medium. *Forest Ecology and Management*, 84: 39-48.

Ofori, D.A., Newton, A.C., Leakey, R.R.B., Grace, J. 1997. Vegetative propagation of *Milicia excelsa* by leafy stem cuttings: effects of maturation, coppicing, cutting length and position on rooting ability. *Journal of Tropical Forest Science* 10: 115-129.

Opuni-Frimpong, E. 2000. Damage to growth and survival of native Meliaceae (African mahogany) by *Hypsipyla robusta* Moore (Lepidoptera: Pyralidae). M.Phil. thesis submitted to Kwame Nkrumah University of Science and Technology, Kumasi, Ghana. 100 pp.

Opuni-Frimpong, E. 2008. *Khaya grandifoliola* C.DC. In: Louppe, D., Oteng-Amoako, A.A. & Brink, M. (Editors). Plant Resources of Tropical Africa 7(1). Timbers 1. PROTA Foundation,Wageningen, Netherlands /Backhuys Publishers, Leiden, Netherlands / CTA, Wageningen, Netherlands. Pp 329 – 333.

Opuni-Frimpong, E., Karnosky D.F., Storer A.J., Abeney E.A. and Cobbinah J.R. 2008. Relative susceptibility of four species of African mahogany to the shoot borer *Hypsipyla robusta* (Lepidoptera: Pyralidae) in the moist semi-deciduous forest of Ghana. *Forest Ecology and Management* 255:313-319.

Opuni-Frimpong, E., Karnosky D.F., Storer A.J., and Cobbinah J.R. 2008. Key roles of leaves, stockplant age and auxin concentration in vegetative propagation of two African mahoganies: *Khaya anthotheca* Welw. and *Khaya ivorensis* A. Chev. *New Forests* 36:115-123.

Oteng-Amoako, A.A. (Ed), 2006. 100 tropical African timber trees from Ghana: tree description and wood identification with notes on distribution, ecology, silviculture, ethnobotany and wood uses. 304 pp.

Pande, P.K. 1995. Variation in the dimensions of tracheid elements of *Pinus caribaea* var. *bahamensis*. J. Top. For. Prod. 1(2): 117-123. In: Husen, A., Pal, M. 2006. Variation in shoot anatomy and rooting behaviour of stem cuttings in relation to age of donor plants in teak (*Tectona grandis* Linn. F.). *New Forests*, 31:57-73.

Poorter, L., Bongers, F., Kouamé, F.Y.N., Hawthorne, W.D. 2004. Biodiversity of West African forests: An ecological atlas of woody plant species. CAB International, Oxon, UK.

Shiembo, P. N., Newton, A. C., Leakey, R. R. B. 1997. Vegetative propagation of *Ricinodendron heudelotii*, a West African fruit tree. *Journal of Tropical Forest Science*, **9** : 514-525.

Shiembo, P. N., Newton, A. C., Leakey, R. R. B. 1996a. Vegetative propagation of *Gnetum africanum*, a leafy vegetable from West Africa. *Journal of Horticultural Science*, 71(1):149-155.

Shiembo, P. N., Newton, A. C., Leakey, R. R. B. 1996b. Vegetative propagation of *Irvingia gabonensis*, a West African fruit tree. *Forest Ecology and Management* 87: 185-192.

SPSS (Statitstical Package for Social Scientists), 2007. Version 16.0. SPSS Inc. 233 South Wacker Drive, 11th Floor, Chicago, IL

Stenvall, N., Haapala, T., Pulkkinen, P. 2004. Effect of genotype, age and treatment of stock plants on propagation of Hybrid Aspen (*Populus tremula* x *Populus tremuloides*) by root cuttings. *Scandinavian Journal of Forest Research*, 19: 303-311.

Taylor, C.J. 1960. Synecology and silviculture in Ghana. Thomas Nelson and Sons Ltd. Edinburgh, 417 pp.

Tchinda, A. T. 2008. *Entandrophragma angolense* (Welw.) C.DC. In: Louppe, D., Oteng-Amoako, A.A. & Brink, M. (Editors). Plant Resources of Tropical Africa 7(1). Timbers 1. PROTA Foundation,Wageningen, Netherlands /Backhuys Publishers, Leiden, Netherlands / CTA, Wageningen, Netherlands. Pp 232 – 235.

Tchoundjeu, Z. 1989. Vegetative propagation of tropical hardwoods, *Khaya ivorensis* A. Chev. and *Lovoa trichiloides* Harms. Ph.D Thesis, University of Edinburgh, 263 pp. In: Theresa, N., 1994. Physiological factors influencing the rooting ability of leafy stem

cuttings of *Triplochiton scleroxylon* K. Schum. MPhil. Thesis, University of Edinburgh, 161 pp.

Tchoundjeu, Z., Leakey, R.R.B, 1996. Vegetative propagation of African mahogany: effect of auxin, node position, leaf area and cutting length. *New Forests* 11: 125-136.

Tchoundjeu, Z. and Leakey, R.R.B. 2000. Vegetative propagation of *Khaya ivorensis* (African mahogany): effect of stock-plant flushing cycle, auxin and leaf area on carbohydrate and nutrient dynamics of cuttings. *Journal of Tropical Forest Science*, 12: 77-91.

Tchoundjeu, Z., Leakey, R.R.B. 2001. Vegetative propagation of *Lovoa trichilioides*: effects of provenance, substrate, auxins and leaf area. *Journal of Tropical Forest Science* 13: 116-129.

Tchoundjeu, Z., Avana, M. L., Leakey, R. R. B., Simons, A. J., Asaah, E., Duguma, B., Bell, J. M. 2002. Vegetative propagation of *Prunus africana*: effects of rooting medium, auxin concentrations and leaf area. *Agroforestry Systems*, 54:183-192.

Tchoundjeu, Z., Ngo Mpeck, M.-L., Asaah, E., Amougou, A. 2004. The role of vegetative propagation in the domestication of *Pausinystalia johimbe* (K. Schum), a highly threatened medicinal species of West and Central Africa. *Forest Ecology and Management*, 188: 175-183

Tchoudjeu, Z., Asaah, E.K., Anegbeh, P., Degrande, A., Mbile, P., Facheux, C., Tsobeng, A., Atangana, A.R., Ngo Mpeck, M.-L., Simons, A.J. 2006. Putting participatory domestication into practice in West and Central Africa. Forest Trees Livelihoods, 16: 53-69.

Tetsumura, T, Tao, R, Sugiura, A. 2001. Some factors affecting the rooting of softwood cuttings of Japanese persimmon. *Journal of Japan Society of Horticultural Science*, 70: 275-280.

Wang, Z.Y., Xie, S.J., Yang, P.F., Gu, R.Z. 1986. Studies on the anatomical structures of grapevines. J. Fru. Sci., (4): 6-28. In: Zhang, M., Tang, H.R., Wang, D., Ren, S.X., Liu R.D. 2009. A study of rooting characteristics and anatomical structure of Feijoa cuttings. *Agricultural Journal* 4(2): 86-90.

statistiXL, 2007. Version 1.8. www.statistiXL.com

Yi, Y.M., Luo, S.J., Li, X., Wang, L.S., Xu, W.S. 2000. Studies on anatomical structure of dove tree stem and its formation of callus. J Hubei Inst. Nation., 18(3): 4-6. In: Zhang, M., Tang, H.R., Wang, D., Ren, S.X., Liu R.D. 2009. A study of rooting characteristics and anatomical structure of Feijoa cuttings. *Agricultural Journal* 4(2): 86-90.

Zhang, M., Tang, H.R., Wang, D., Ren, S.X., Liu R.D. 2009. A study of rooting characteristics and anatomical structure of Feijoa cuttings. *Agricultural Journal* 4(2): 86-90

APPENDICES

Appendix 1. ANOVA of effect of species identity on:

a. number of roots per cutting in mixture

Analysis of Variance results for:
Y Variable Range = $B$14:$E$17

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	22.570	3	7.523	9.175	0.006
Error	6.560	8	0.820		
Total	29.130	11			

b. length of longest root in mixture

Analysis of Variance results for:
Y Variable Range = $L$14:$O$17

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	40.496	3	13.499	19.875	0.000
Error	5.433	8	0.679		
Total	45.929	11			

c. percentage rooting in mixture

Analysis of Variance results for:
Y Variable Range = $V$14:$Y$17

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	2908.333	3	969.444	9.901	0.005
Error	783.333	8	97.917		
Total	3691.667	11			

d. number of roots per cutting in top soil

Analysis of Variance results for:
Y Variable Range = $B$14:$E$17

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	15.510	3	5.170	11.098	0.003
Error	3.727	8	0.466		
Total	19.237	11			

e. length of longest root in top soil

Analysis of Variance results for:
Y Variable Range = $L$15:$O$18

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	63.907	3	21.302	5.049	0.030
Error	33.753	8	4.219		
Total	97.660	11			

f. percentage rooting in top soil

Analysis of Variance results for:
Y Variable Range = $V$16:$Y$19

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	1333.333	3	444.444	8.205	0.008
Error	433.333	8	54.167		
Total	1766.667	11			

g. number of roots per cutting in river-sand

Analysis of Variance results for:
Y Variable Range = $B$13:$E$16

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	13.940	3	4.647	21.529	0.000
Error	1.727	8	0.216		
Total	15.667	11			

h. length of longest root in river-sand

Analysis of Variance results for:
Y Variable Range = $L$13:$O$16

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	48.249	3	16.083	20.188	0.000
Error	6.373	8	0.797		
Total	54.622	11			

i. percentage rooting in river-sand

Analysis of Variance results for:
Y Variable Range = $V$13:$Y$16

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	1856.250	3	618.750	10.607	0.004
Error	466.667	8	58.333		
Total	2322.917	11			

Appendix 2. ANOVA of effect of cutting position on shoot on:

a. number of roots per cutting in *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range =
$B$4:$D$7

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	6.740	2	3.370	12.481	0.007
Error	1.620	6	0.270		
Total	8.360	8			

b. length of longest root in *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $B$50:$D$53

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	19.742	2	9.871	14.446	0.005
Error	4.100	6	0.683		
Total	23.842	8			

c. percentage rooting in *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $B$100:$D$103

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	516.667	2	258.333	18.600	0.003
Error	83.333	6	13.889		
Total	600.000	8			

d. number of roots per cutting in *K. ivorensis*

Analysis of Variance results for:
Y Variable Range =
$J$4:$L$7

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	8.229	2	4.114	7.981	0.020
Error	3.093	6	0.516		
Total	11.322	8			

e. length of longest root in *K. ivorensis*

Analysis of Variance results for:
Y Variable Range = $J$51:$L$53

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	0.093	2	0.047	0.066	0.937
Error	2.120	3	0.707		
Total	2.213	5			

f. percentage rooting in *K. ivorensis*

Analysis of Variance results for:
Y Variable Range = $J$100:$L$103

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	316.667	2	158.333	11.400	0.009
Error	83.333	6	13.889		
Total	400.000	8			

g. number of roots per cutting in *E. angolense*

Analysis of Variance results for:
Y Variable Range =
$R$4:$T$7

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	1.616	2	0.808	2.723	0.144
Error	1.780	6	0.297		
Total	3.396	8			

h. length of longest root in *E. angolense*

Analysis of Variance results for:
Y Variable Range = $R$50:$T$53

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	8.496	2	4.248	1.519	0.293
Error	16.780	6	2.797		
Total	25.276	8			

i. percentage rooting in *E. angolense*

Analysis of Variance results for:
Y Variable Range = $R$100:$T$103

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	216.667	2	108.333	7.800	0.021
Error	83.333	6	13.889		
Total	300.000	8			

j. number of roots per cutting in *E. utile*

Analysis of Variance results for:
Y Variable Range =
$Z$4:$AB$7

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	0.949	2	0.474	3.713	0.089
Error	0.767	6	0.128		
Total	1.716	8			

k. length of longest root in *E. utile*

Analysis of Variance results for:
Y Variable Range = $Z$50:$AB$53

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	5.502	2	2.751	3.310	0.107
Error	4.987	6	0.831		
Total	10.489	8			

l. percentage rooting in *E. utile*

Analysis of Variance results for:
Y Variable Range = $Z$100:$AB$103

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	505.556	2	252.778	18.200	0.003
Error	83.333	6	13.889		
Total	588.889	8			

Appendix 3. ANOVA of effect of type of rooting media on:

a. number of roots per cutting in *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range =
$B$5:$D$8

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	1.707	2	0.853	2.053	0.209
Error	2.493	6	0.416		
Total	4.200	8			

b. length of longest root in *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $B$60:$D$63

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	23.229	2	11.614	2.929	0.130
Error	23.793	6	3.966		
Total	47.022	8			

c. percentage rooting in *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $B$120:$D$123

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	266.667	2	133.333	2.824	0.137
Error	283.333	6	47.222		
Total	550.000	8			

d. number of roots per cutting in *K. ivorensis*

Analysis of Variance results for:
Y Variable Range =
$J$5:$L$8

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	3.842	2	1.921	2.180	0.194
Error	5.287	6	0.881		
Total	9.129	8			

e. length of longest root in *K. ivorensis*

Analysis of Variance results for:
Y Variable Range = $J$60:$L$63

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	6.729	2	3.364	7.026	0.027
Error	2.873	6	0.479		
Total	9.602	8			

f. percentage rooting in *K. ivorensis*

Analysis of Variance results for:
Y Variable Range = $J$120:$L$123

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	150.000	2	75.000	1.800	0.244
Error	250.000	6	41.667		
Total	400.000	8			

g. number of roots per cutting in *E. angolense*

Analysis of Variance results for:
Y Variable Range =
$R$5:$T$8

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	1.616	2	0.808	1.818	0.241
Error	2.667	6	0.444		
Total	4.282	8			

h. length of longest root in *E. angolense*

Analysis of Variance results for:
Y Variable Range = $R$60:$T$63

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	9.060	2	4.530	1.933	0.225
Error	14.060	6	2.343		
Total	23.120	8			

i. percentage rooting in *E. angolense*

Analysis of Variance results for:
Y Variable Range = $R$120:$T$123

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	155.556	2	77.778	0.718	0.525
Error	650.000	6	108.333		
Total	805.556	8			

j. number of roots per cutting in *E. utile*

Analysis of Variance results for:
Y Variable Range =
$Z$5:$AB$8

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	0.002	2	0.001	0.004	0.996
Error	1.567	6	0.261		
Total	1.569	8			

k. length of longest root in *E. utile*

Analysis of Variance results for:
Y Variable Range = $Z$60:$AB$63

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	10.409	2	5.204	6.461	0.032
Error	4.833	6	0.806		
Total	15.242	8			

l. percentage rooting in *E. utile*

Analysis of Variance results for:
Y Variable Range = $Z$120:$AB$123

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	150.000	2	75.000	0.900	0.455
Error	500.000	6	83.333		
Total	650.000	8			

Appendix 4. ANOVA of effect of age stock-plant of *K. grandifoliola* on:

a. number of roots per cutting

Analysis of Variance results for:
Y Variable Range =
$C$6:$F$9

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	6.869	3	2.290	6.835	0.013
Error	2.680	8	0.335		
Total	9.549	11			

b. length of longest root

Analysis of Variance results for:
Y Variable Range =
$L$6:$O$9

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	69.143	3	23.048	4.459	0.040
Error	41.347	8	5.168		
Total	110.489	11			

c. percentage rooting

Analysis of Variance results for:
Y Variable Range =
$U$6:$X$9

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	1216.667	3	405.556	16.222	0.001
Error	200.000	8	25.000		
Total	1416.667	11			

Appendix 5. ANOVA of effect of cutting position on shoot on:

a. number of roots per cutting in shoots of 1-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $B$127:$D$130

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	2.349	2	1.174	2.349	0.176
Error	3.000	6	0.500		
Total	5.349	8			

b. length of longest root in shoots of 1-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $J$127:$L$130

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	14.187	2	7.093	1.255	0.350
Error	33.913	6	5.652		
Total	48.100	8			

c. percentage rooting in shoots of 1-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $R$127:$T$130

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	416.667	2	208.333	15.000	0.005
Error	83.333	6	13.889		
Total	500.000	8			

d. number of roots per cutting in shoots of 4-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $B$88:$D$91

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	3.336	2	1.668	5.795	0.040
Error	1.727	6	0.288		
Total	5.062	8			

e. length of longest root in shoots of 4-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $J$88:$L$91

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	11.847	2	5.923	5.970	0.037
Error	5.953	6	0.992		
Total	17.800	8			

f. percentage rooting in shoots of 4-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $R$88:$T$91

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	316.667	2	158.333	5.182	0.049
Error	183.333	6	30.556		
Total	500.000	8			

g. number of roots per cutting in shoots of 7-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $B$38:$D$41

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	0.087	2	0.043	0.081	0.923
Error	3.213	6	0.536		
Total	3.300	8			

h. length of longest root in shoots of 7-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $B$38:$D$41

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	0.087	2	0.043	0.081	0.923
Error	3.213	6	0.536		
Total	3.300	8			

i. percentage rooting in shoots of 7-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $R$38:$T$41

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	272.222	2	136.111	7.000	0.027
Error	116.667	6	19.444		
Total	388.889	8			

j. number of roots per cutting in shoots of 12-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for: Y Variable Range = $B$6:$D$9

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	1.529	2	0.764	1.253	0.351
Error	3.660	6	0.610		
Total	5.189	8			

k. length of longest root in shoots of 12-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for: Y Variable Range = $J$6:$L$9

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	21.176	2	10.588	10.094	0.012
Error	6.293	6	1.049		
Total	27.469	8			

l. percentage rooting in shoots of 12-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for: Y Variable Range = $R$6:$T$9

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	372.222	2	186.111	9.571	0.014
Error	116.667	6	19.444		
Total	488.889	8			

Appendix 6. ANOVA of effect of position on shoot on:

a. vessel proportion in sections of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range =
$B$4:$D$9

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	5.677	2	2.839	2.271	0.146
Error	15.000	12	1.250		
Total	20.677	14			

b. vessel proportion in sections of *K. ivorensis*

Analysis of Variance results for:
Y Variable Range =
$J$4:$L$9

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	3.281	2	1.641	1.223	0.328
Error	16.094	12	1.341		
Total	19.375	14			

c. vessel proportion in sections of *E. angolense*

Analysis of Variance results for:
Y Variable Range =
$R$4:$T$9

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	6.302	2	3.151	2.951	0.091
Error	12.813	12	1.068		
Total	19.115	14			

d. vessel proportion in sections of *E. utile*

Analysis of Variance results for:
Y Variable Range =
$Z$4:$AB$9

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	0.990	2	0.495	0.257	0.778
Error	23.125	12	1.927		
Total	24.115	14			

e. parenchyma proportion in sections of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $B$37:$D$42

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	35.208	2	17.604	13.657	0.001
Error	15.469	12	1.289		
Total	50.677	14			

f. parenchyma proportion in sections of *K. ivorensis*

Analysis of Variance results for:
Y Variable Range = $J$37:$L$42

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	75.990	2	37.995	23.724	0.000
Error	19.219	12	1.602		
Total	95.208	14			

g. parenchyma proportion in sections of *E. angolense*

Analysis of Variance results for:
Y Variable Range = $R$37:$T$42

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	131.875	2	65.937	22.308	0.000
Error	35.469	12	2.956		
Total	167.344	14			

h. parenchyma proportion in sections of *E. utile*

Analysis of Variance results for:
Y Variable Range = $Z$37:$AB$42

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	59.427	2	29.714	11.763	0.001
Error	30.313	12	2.526		
Total	89.740	14			

i. fibre proportion in sections of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $B$72:$D$77

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	22.969	2	11.484	4.846	0.029
Error	28.438	12	2.370		
Total	51.406	14			

j. fibre proportion in sections of *K. ivorensis*

Analysis of Variance results for:
Y Variable Range = $J$72:$L$77

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	33.177	2	16.589	12.019	0.001
Error	16.563	12	1.380		
Total	49.740	14			

k. fibre proportion in sections of *E. angolense*

Analysis of Variance results for:
Y Variable Range = $R$72:$T$77

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	62.708	2	31.354	11.689	0.002
Error	32.188	12	2.682		
Total	94.896	14			

l. fibre proportion in sections of *E. utile*

Analysis of Variance results for:
Y Variable Range = $Z$72:$AB$77

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	49.427	2	24.714	24.333	0.000
Error	12.188	12	1.016		
Total	61.615	14			

Appendix 7. ANOVA of effect of type of species on:

a. vessel proportion

Analysis of Variance results for:
Y Variable Range = $AH$4:$AK$7

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	1.031	3	0.344	0.846	0.506
Error	3.250	8	0.406		
Total	4.281	11			

b. parenchyma proportion

Analysis of Variance results for:
Y Variable Range = $AH$37:$AK$40

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	6.171	3	2.057	0.272	0.844
Error	60.500	8	7.562		
Total	66.671	11			

c. fibre proportion

Analysis of Variance results for:
Y Variable Range = $AH$72:$AK$75

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	2.108	3	0.703	0.167	0.916
Error	33.656	8	4.207		
Total	35.764	11			

Appendix 8. ANOVA of effect of position on shoot on:

a. vessel proportion in sections of 1-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range =
$B$4:$D$9

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	10.990	2	5.495	0.386	0.688
Error	170.938	12	14.245		
Total	181.927	14			

b. vessel proportion in sections of 4-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range =
$K$4:$M$9

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	10.365	2	5.182	0.921	0.424
Error	67.500	12	5.625		
Total	77.865	14			

c. vessel proportion in sections of 7-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range =
$S$4:$U$9

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	11.875	2	5.937	4.606	0.033
Error	15.469	12	1.289		
Total	27.344	14			

d. vessel proportion in sections of 12-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $AA$4:$AC$9

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	5.677	2	2.839	2.271	0.146
Error	15.000	12	1.250		
Total	20.677	14			

e. parenchyma proportion in sections from shoots of 1-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $B$40:$D$45

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	101.927	2	50.964	4.802	0.029
Error	127.344	12	10.612		
Total	229.271	14			

f. parenchyma proportion in sections from shoots of 4-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $K$40:$M$45

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	63.177	2	31.589	4.674	0.032
Error	81.094	12	6.758		
Total	144.271	14			

g. parenchyma proportion in sections from shoots of 7-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $S$40:$U$45

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	106.302	2	53.151	26.855	0.000
Error	23.750	12	1.979		
Total	130.052	14			

h. parenchyma proportion in sections from shoots of 12-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $AA$40:$AC$45

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	35.208	2	17.604	13.657	0.001
Error	15.469	12	1.289		
Total	50.677	14			

i. fibre proportion in sections from shoots of 1-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $B$74:$D$79

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	30.625	2	15.312	2.198	0.154
Error	83.594	12	6.966		
Total	114.219	14			

j. fibre proportion in sections from shoots of 4-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $K$74:$M$79

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	22.240	2	11.120	4.379	0.037
Error	30.469	12	2.539		
Total	52.708	14			

k. fibre proportion in sections from shoots of 7-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $S$74:$U$79

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	44.115	2	22.057	10.859	0.002
Error	24.375	12	2.031		
Total	68.490	14			

l. fibre proportion in sections from shoots of 12-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $AA$74:$AC$79

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	22.969	2	11.484	4.846	0.029
Error	28.438	12	2.370		
Total	51.406	14			

Appendix 9. ANOVA of effect of age of stock-plant on:

a. vessel proportion in sections from shoots of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $AH$4:$AK$7

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	30.047	3	10.016	10.297	0.004
Error	7.781	8	0.973		
Total	37.828	11			

b. parenchyma proportion in sections from shoots of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $AH$40:$AK$43

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	80.193	3	26.731	3.487	0.070
Error	61.323	8	7.665		
Total	141.516	11			

c. fibre proportion in sections from shoots of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $AH$74:$AK$77

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	18.983	3	6.328	2.110	0.177
Error	23.990	8	2.999		
Total	42.973	11			

Appendix 10. ANOVA of effect of position on shoot on:

a. fibre length of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range =
$B$5:$D$10

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	########	2	########	9.322	0.004
Error	########	12	1550.509		
Total	########	14			

b. fibre length of *K. ivorensis*

Analysis of Variance results for:
Y Variable Range =
$J$5:$L$10

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	########	2	6460.346	20.844	0.000
Error	3719.185	12	309.932		
Total	########	14			

c. fibre length of *E. angolense*

Analysis of Variance results for:
Y Variable Range =
$R$5:$T$10

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	########	2	########	20.652	0.000
Error	7215.698	12	601.308		
Total	########	14			

d. fibre length of *E. utile*

Analysis of Variance results for:
Y Variable Range = $AA$5:$AC$10

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	########	2	########	13.143	0.001
Error	########	12	1155.918		
Total	########	14			

e. fibre diameter of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $B$45:$D$50

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	9.399	2	4.700	3.094	0.083
Error	18.230	12	1.519		
Total	27.629	14			

f. fibre diameter of *K. ivorensis*

Analysis of Variance results for:
Y Variable Range = $J$45:$L$50

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	0.071	2	0.035	0.018	0.982
Error	23.492	12	1.958		
Total	23.562	14			

g. fibre diameter of *E. angolense*

Analysis of Variance results for:
Y Variable Range = $R$45:$T$50

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	35.894	2	17.947	8.492	0.005
Error	25.360	12	2.113		
Total	61.254	14			

h. fibre diameter of *E. utile*

Analysis of Variance results for:
Y Variable Range = $AA$45:$AC$50

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	4.770	2	2.385	0.476	0.632
Error	60.103	12	5.009		
Total	64.872	14			

i. fibre lumen diameter of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $B$85:$D$90

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	1.194	2	0.597	0.327	0.728
Error	21.934	12	1.828		
Total	23.128	14			

j. fibre lumen diameter of *K. ivorensis*

Analysis of Variance results for:
Y Variable Range = $J$85:$L$90

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	1.322	2	0.661	0.287	0.756
Error	27.644	12	2.304		
Total	28.966	14			

k. fibre lumen diameter of *E. angolense*

Analysis of Variance results for:
Y Variable Range = $R$85:$T$90

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	14.674	2	7.337	1.853	0.199
Error	47.524	12	3.960		
Total	62.198	14			

l. fibre lumen diameter of *E. utile*

Analysis of Variance results for:
Y Variable Range = $AA$85:$AC$90

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	26.118	2	13.059	6.712	0.011
Error	23.347	12	1.946		
Total	49.466	14			

m. double fibre wall thickness of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $B$125:$D$130

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	9.445	2	4.722	15.347	0.000
Error	3.693	12	0.308		
Total	13.138	14			

n. double fibre wall thickness of *K. ivorensis*

Analysis of Variance results for:
Y Variable Range = $J$125:$L$130

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	1.101	2	0.550	1.022	0.389
Error	6.464	12	0.539		
Total	7.564	14			

o. double fibre wall thickness of *E. angolense*

Analysis of Variance results for:
Y Variable Range = $R$125:$T$130

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	4.750	2	2.375	0.646	0.541
Error	44.113	12	3.676		
Total	48.863	14			

p. double fibre wall thickness of *E. utile*

Analysis of Variance results for:
Y Variable Range = $AA$125:$AC$130

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	8.612	2	4.306	1.050	0.380
Error	49.212	12	4.101		
Total	57.825	14			

q. vessel length of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $B$165:$D$170

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	########	2	########	12.348	0.001
Error	9797.752	12	816.479		
Total	########	14			

r. vessel length of *K. ivorensis*

Analysis of Variance results for:
Y Variable Range = $J$165:$L$170

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	6365.036	2	3182.518	23.984	0.000
Error	1592.307	12	132.692		
Total	7957.342	14			

s. vessel length of *E. angolense*

Analysis of Variance results for:
Y Variable Range = $R$165:$T$170

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	6088.279	2	3044.139	7.413	0.008
Error	4927.982	12	410.665		
Total	########	14			

t. vessel length of *E. utile*

Analysis of Variance results for:
Y Variable Range = $AA$165:$AC$170

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	1334.868	2	667.434	0.479	0.631
Error	########	12	1392.444		
Total	########	14			

u. vessel diameter of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $B$205:$D$210

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	15.073	2	7.537	3.776	0.053
Error	23.952	12	1.996		
Total	39.025	14			

v. vessel diameter of *K. ivorensis*

Analysis of Variance results for:
Y Variable Range = $J$205:$L$210

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	193.698	2	96.849	37.467	0.000
Error	31.019	12	2.585		
Total	224.717	14			

w. vessel diameter of *E. angolense*

Analysis of Variance results for:
Y Variable Range = $R$205:$T$210

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	218.293	2	109.146	11.288	0.002
Error	116.035	12	9.670		
Total	334.328	14			

x. vessel diameter of *E. utile*

Analysis of Variance results for:
Y Variable Range = $AA$205:$AC$210

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	199.369	2	99.685	4.162	0.042
Error	287.402	12	23.950		
Total	486.771	14			

Appendix 11. ANOVA of effect of type of species on:

a. fibre length

Analysis of Variance results for:
Y Variable Range = $AI$5:$AL$8

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	6034.528	3	2011.509	0.829	0.514
Error	########	8	2426.253		
Total	########	11			

b. fibre diameter

Analysis of Variance results for:
Y Variable Range = $AI$45:$AL$48

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	42.029	3	14.010	11.178	0.003
Error	10.027	8	1.253		
Total	52.056	11			

c. fibre lumen diameter

Analysis of Variance results for:
Y Variable Range = $AI$85:$AL$88

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	22.217	3	7.406	6.840	0.013
Error	8.662	8	1.083		
Total	30.879	11			

d. double fibre wall thickness

Analysis of Variance results for:
Y Variable Range = $AI$125:$AL$128

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	3.752	3	1.251	2.093	0.180
Error	4.782	8	0.598		
Total	8.534	11			

e. vessel length

Analysis of Variance results for:
Y Variable Range = $AI$165:$AL$168

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	3128.276	3	1042.759	1.228	0.361
Error	6790.509	8	848.814		
Total	9918.785	11			

f. vessel diameter

Analysis of Variance results for:
Y Variable Range = $AI$205:$AL$208

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	38.881	3	12.960	0.828	0.515
Error	125.287	8	15.661		
Total	164.167	11			

Appendix 12. ANOVA of effect of position on shoot on:

a. fibre length of shoots of 1-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $AA$5:$AC$10

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	########	2	7590.581	10.566	0.002
Error	8620.571	12	718.381		
Total	########	14			

b. fibre length of shoots of 4-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range =
$R$5:$T$10

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	########	2	8059.904	14.181	0.001
Error	6820.300	12	568.358		
Total	########	14			

c. fibre length of shoots of 7-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range =
$J$5:$L$10

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	########	2	########	26.971	0.000
Error	8253.313	12	687.776		
Total	########	14			

d. fibre length of shoots of 12-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range =
$B$5:$D$10

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	########	2	########	9.322	0.004
Error	########	12	1550.509		
Total	########	14			

e. fibre diameter of shoots of 1-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $AA$45:$AC$50

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	1.035	2	0.518	0.591	0.569
Error	10.503	12	0.875		
Total	11.539	14			

f. fibre diameter of shoots of 4-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $R$45:$T$50

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	2.592	2	1.296	0.571	0.580
Error	27.253	12	2.271		
Total	29.845	14			

g. fibre diameter of shoots of 7-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $J$45:$L$50

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	12.940	2	6.470	5.346	0.022
Error	14.521	12	1.210		
Total	27.461	14			

h. fibre diameter of shoots of 12-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $B$45:$D$50

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	9.399	2	4.700	3.094	0.083
Error	18.230	12	1.519		
Total	27.629	14			

i. fibre lumen diameter of shoots of 1-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $AA$90:$AC$95

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	0.862	2	0.431	0.468	0.637
Error	11.045	12	0.920		
Total	11.907	14			

j. fibre lumen diameter of shoots of 4-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $R$90:$T$95

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	9.624	2	4.812	2.140	0.160
Error	26.985	12	2.249		
Total	36.609	14			

k. fibre lumen diameter of shoots of 7-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $J$90:$L$95

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	0.727	2	0.364	0.350	0.712
Error	12.486	12	1.041		
Total	13.214	14			

l. fibre lumen diameter of shoots of 12-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $B$90:$D$95

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	1.194	2	0.597	0.327	0.728
Error	21.934	12	1.828		
Total	23.128	14			

m. double fibre wall thickness of shoots of 1-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $AA$125:$AC$130

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	3.600	2	1.800	74.147	0.000
Error	0.291	12	0.024		
Total	3.891	14			

n. double fibre wall thickness of shoots of 4-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $R$125:$T$130

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	5.232	2	2.616	50.975	0.000
Error	0.616	12	0.051		
Total	5.847	14			

o. double fibre wall thickness of shoots of 7-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $J$125:$L$130

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	7.550	2	3.775	22.956	0.000
Error	1.973	12	0.164		
Total	9.524	14			

p. double fibre wall thickness of shoots of 12-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $B$125:$D$130

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	9.445	2	4.722	15.347	0.000
Error	3.693	12	0.308		
Total	13.138	14			

q. vessel length of shoots of 1-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $AA$170:$AC$175

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	########	2	########	12.553	0.001
Error	########	12	1000.967		
Total	########	14			

r. vessel length of shoots of 4-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $R$170:$T$175

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	########	2	9924.017	14.114	0.001
Error	8437.700	12	703.142		
Total	########	14			

s. vessel length of shoots of 7-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $J$170:$L$175

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	########	2	8604.791	22.848	0.000
Error	4519.238	12	376.603		
Total	########	14			

t. vessel length of shoots of 12-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $B$170:$D$175

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	########	2	########	12.348	0.001
Error	9797.752	12	816.479		
Total	########	14			

u. vessel diameter of shoots of 1-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $AA$215:$AC$220

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	165.795	2	82.897	21.346	0.000
Error	46.603	12	3.884		
Total	212.398	14			

v. vessel diameter of shoots of 4-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $R$215:$T$220

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	105.699	2	52.849	21.937	0.000
Error	28.910	12	2.409		
Total	134.609	14			

w. vessel diameter of shoots of 7-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $J$215:$L$220

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	14.248	2	7.124	2.788	0.101
Error	30.665	12	2.555		
Total	44.913	14			

x. vessel diameter of shoots of 12-year old stock-plants of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $B$215:$D$220

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	15.073	2	7.537	3.776	0.053
Error	23.952	12	1.996		
Total	39.025	14			

Appendix 13. ANOVA of effect of age of stock-plant on:

a. fibre length of shoots of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $AI$5:$AL$8

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	6179.259	3	2059.753	0.847	0.506
Error	########	8	2432.720		
Total	########	11			

b. fibre diameter of shoots of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $AI$45:$AL$48

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	15.212	3	5.071	7.811	0.009
Error	5.193	8	0.649		
Total	20.406	11			

c. fibre lumen diameter of shoots of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $AI$90:$AL$93

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	7.060	3	2.353	7.587	0.010
Error	2.481	8	0.310		
Total	9.542	11			

d. double fibre wall thickness of shoots of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $AI$125:$AL$128

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	1.911	3	0.637	0.986	0.446
Error	5.165	8	0.646		
Total	7.076	11			

e. vessel length of shoots of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $AI$170:$AL$173

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	########	3	3619.686	1.758	0.233
Error	########	8	2058.793		
Total	########	11			

f. vessel diameter of shoots of *K. grandifoliola*

Analysis of Variance results for:
Y Variable Range = $AI$215:$AL$218

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	51.203	3	17.068	2.270	0.157
Error	60.163	8	7.520		
Total	111.366	11			

Appendix 14. Regression analysis between:

a. vessel proportion and percentage rooting of shoots of *K. grandifoliola*

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	27.733	1	27.733	.312	.676[a]
	Residual	88.934	1	88.934		
	Total	116.667	2			

a. Predictors: (Constant), KG Vessel %

b. Dependent Variable: KG Rooting%

b. fibre proportion and rooting percentage of shoots of *K. grandifoliola*

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	22.562	1	22.562	.240	.710[a]
	Residual	94.104	1	94.104		
	Total	116.667	2			

a. Predictors: (Constant), KG Fiber %

b. Dependent Variable: KG Rooting %

c. parenchyma proportion and percentage rooting of shoots of *K. grandifoliola*

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	23.361	1	23.361	.250	.705[a]
	Residual	93.306	1	93.306		
	Total	116.667	2			

a. Predictors: (Constant), KG Parenchyma %

b. Dependent Variable: KG Rooting %

d. vessel proportion and percentage rooting in shoots of *K. ivorensis*

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	125.384	1	125.384	5.094	.266[a]
	Residual	24.616	1	24.616		
	Total	150.000	2			

a. Predictors: (Constant), KI Vessel %

b. Dependent Variable: KI Rooting%

e. fibre proportion and percentage rooting in shoots of *K. ivorensis*

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	128.324	1	128.324	5.920	.248[a]
	Residual	21.676	1	21.676		
	Total	150.000	2			

a. Predictors: (Constant), Fiber %

b. Dependent Variable: Rooting %

f. parenchyma proportion and percentage rooting in shoots of *K. ivorensis*

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	130.549	1	130.549	6.712	.235[a]
	Residual	19.451	1	19.451		
	Total	150.000	2			

a. Predictors: (Constant), KI Parenchyma %

b. Dependent Variable: KI Rooting %

g. vessel proportion and percentage rooting in shoots of *E. angolense*

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	160.649	1	160.649	1.030	.495[a]
	Residual	156.017	1	156.017		
	Total	316.667	2			

a. Predictors: (Constant), EA Vessel %

b. Dependent Variable: EA Rooting%

h. fibre proportion and percentage rooting in shoots of *E. angolense*

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	48.441	1	48.441	.181	.744[a]
	Residual	268.225	1	268.225		
	Total	316.667	2			

a. Predictors: (Constant), EA Fiber %

b. Dependent Variable: EA Rooting %

i. parenchyma proportion and percentage rooting in shoots of *E. angolense*

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	60.061	1	60.061	.234	.713[a]
	Residual	256.605	1	256.605		
	Total	316.667	2			

a. Predictors: (Constant), EA Parenchyma %

b. Dependent Variable: EA Rooting %

j. vessel proportion and percentage rooting in shoots of *E. utile*

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	41.209	1	41.209	.260	.700[a]
	Residual	158.791	1	158.791		
	Total	200.000	2			

a. Predictors: (Constant), EU Vessel %

b. Dependent Variable: EU Rooting%

k. fibre proportion and percentage rooting in shoots of *E. utile*

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	198.592	1	198.592	141.061	.053[a]
	Residual	1.408	1	1.408		
	Total	200.000	2			

a. Predictors: (Constant), EU Fiber %

b. Dependent Variable: EU Rooting %

l. parenchyma proportion and percentage rooting in shoots of *E. utile*

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	196.426	1	196.426	54.955	.085[a]
	Residual	3.574	1	3.574		
	Total	200.000	2			

a. Predictors: (Constant), EU Parenchyma %

b. Dependent Variable: EU Rooting %

Appendix 15. Regression analyses between:

a. vessel proportion and percentage rooting in shoots of 1-year old stock-plants of *K. grandifoliola*

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	111.078	1	111.078	3.994	.295[a]
	Residual	27.811	1	27.811		
	Total	138.889	2			

a. Predictors: (Constant), 1-Vessel %

b. Dependent Variable: 1-Rooting %

b. fibre proportion and percentage rooting in shoots of 1-year old stock-plants of *K. grandifoliola*

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	123.574	1	123.574	8.069	.215[a]
	Residual	15.315	1	15.315		
	Total	138.889	2			

a. Predictors: (Constant), 1-Fiber %

b. Dependent Variable: 1-Rooting %

c. parenchyma proportion and percentage rooting in shoots of 1-year old stock-plants of *K. grandifoliola*

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	138.846	1	138.846	3.267E3	.011[a]
	Residual	.042	1	.042		
	Total	138.889	2			

a. Predictors: (Constant), 1-Parenchyma %

b. Dependent Variable: 1-Rooting %

d. vessel proportion and percentage rooting in shoots of 4-year old stock-plants of *K. grandifoliola*

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	8.375	1	8.375	.086	.818[a]
	Residual	97.180	1	97.180		
	Total	105.556	2			

a. Predictors: (Constant), 4-Vessel %

b. Dependent Variable: 4-Rooting %

e. fibre proportion and percentage rooting in shoots of 4-year old stock-plants of *K. grandifoliola*

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2.657	1	2.657	.026	.899[a]
	Residual	102.898	1	102.898		
	Total	105.556	2			

a. Predictors: (Constant), 4-Fiber %

b. Dependent Variable: 4-Rooting %

f. parenchyma proportion and percentage rooting in shoots of 4-year old stock-plants of *K. grandifoliola*

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	7.462	1	7.462	.076	.829[a]
	Residual	98.094	1	98.094		
	Total	105.556	2			

a. Predictors: (Constant), 4-Parenchyma %

b. Dependent Variable: 4-Rooting %

g. vessel proportion and percentage rooting in shoots of 7-year old stock-plants of *K. graandifoliola*

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	64.286	1	64.286	2.430	.363[a]
	Residual	26.455	1	26.455		
	Total	90.741	2			

a. Predictors: (Constant), 7-Vessel %

b. Dependent Variable: 7-Rooting %

h. fibre proportion and percentage rooting in shoots of 7-year old stock-plants of *K. grandifoliola*

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	90.172	1	90.172	158.413	.050[a]
	Residual	.569	1	.569		
	Total	90.741	2			

a. Predictors: (Constant), 7-Fiber %

b. Dependent Variable: 7-Rooting %

i. parenchyma proportion and percentage rooting in shoots of 7-year old stock-plants of *K. grandifoliola*

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	82.099	1	82.099	9.500	.200[a]
	Residual	8.642	1	8.642		
	Total	90.741	2			

a. Predictors: (Constant), 7-Parenchyma %

b. Dependent Variable: 7-Rooting %

j. vessel proportion and percentage rooting in shoots of 12-year old stock-plants of *K. grandifoliola*

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	16.789	1	16.789	.156	.760[a]
	Residual	107.285	1	107.285		
	Total	124.074	2			

a. Predictors: (Constant), 12-Vessel %

b. Dependent Variable: 12-Rooting %

k. fibre proportion and percentage rooting in shoots of 12-year old stock-plants of *K. grandifoliola*

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	52.739	1	52.739	.739	.548[a]
	Residual	71.335	1	71.335		
	Total	124.074	2			

a. Predictors: (Constant), 12-Fiber %

b. Dependent Variable: 12-Rooting %

l. parenchyma proportion and percentage rooting in shoots of 12-year old stock-plants of *K. grandifoliola*

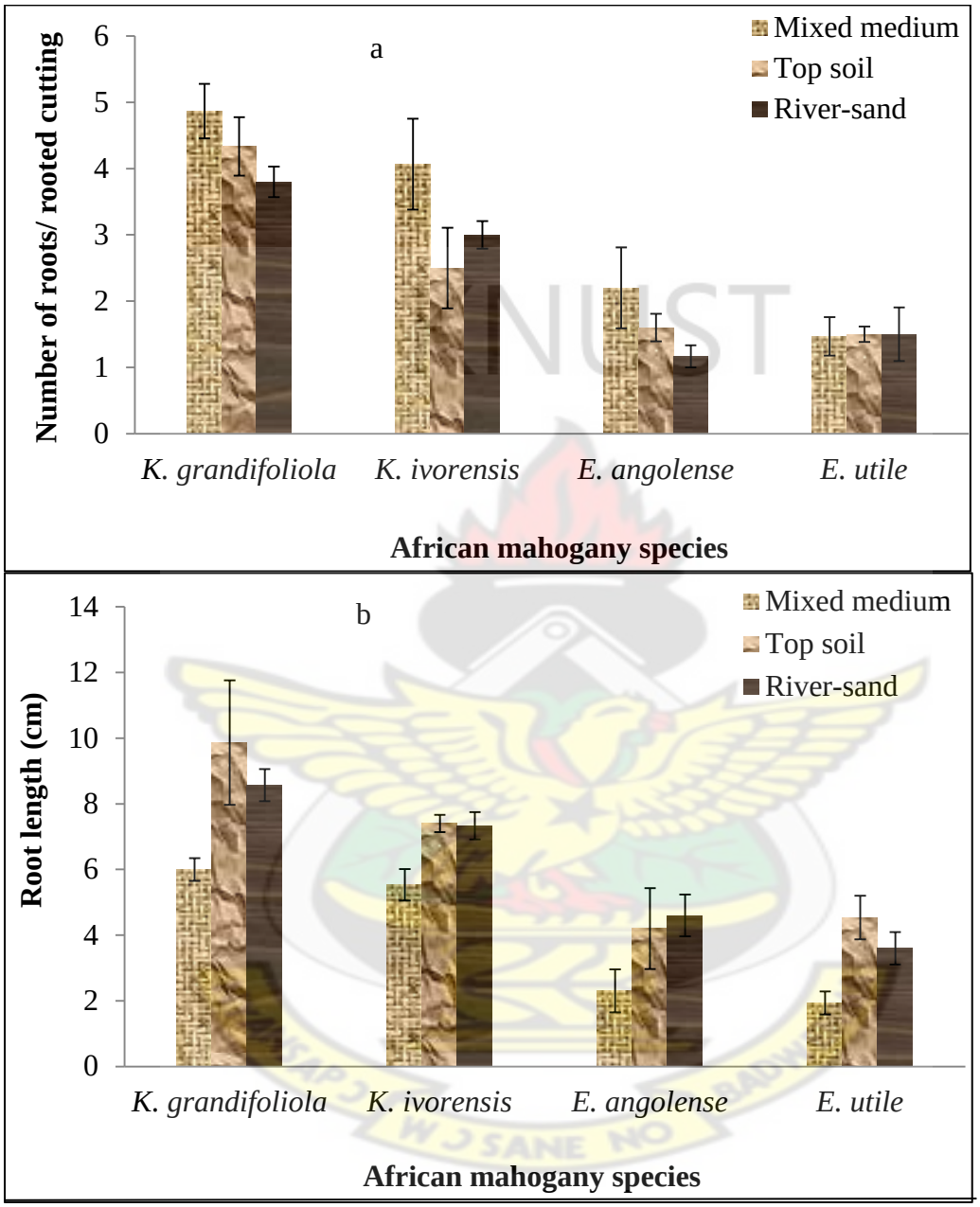
ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	50.955	1	50.955	.697	.557[a]
	Residual	73.119	1	73.119		
	Total	124.074	2			

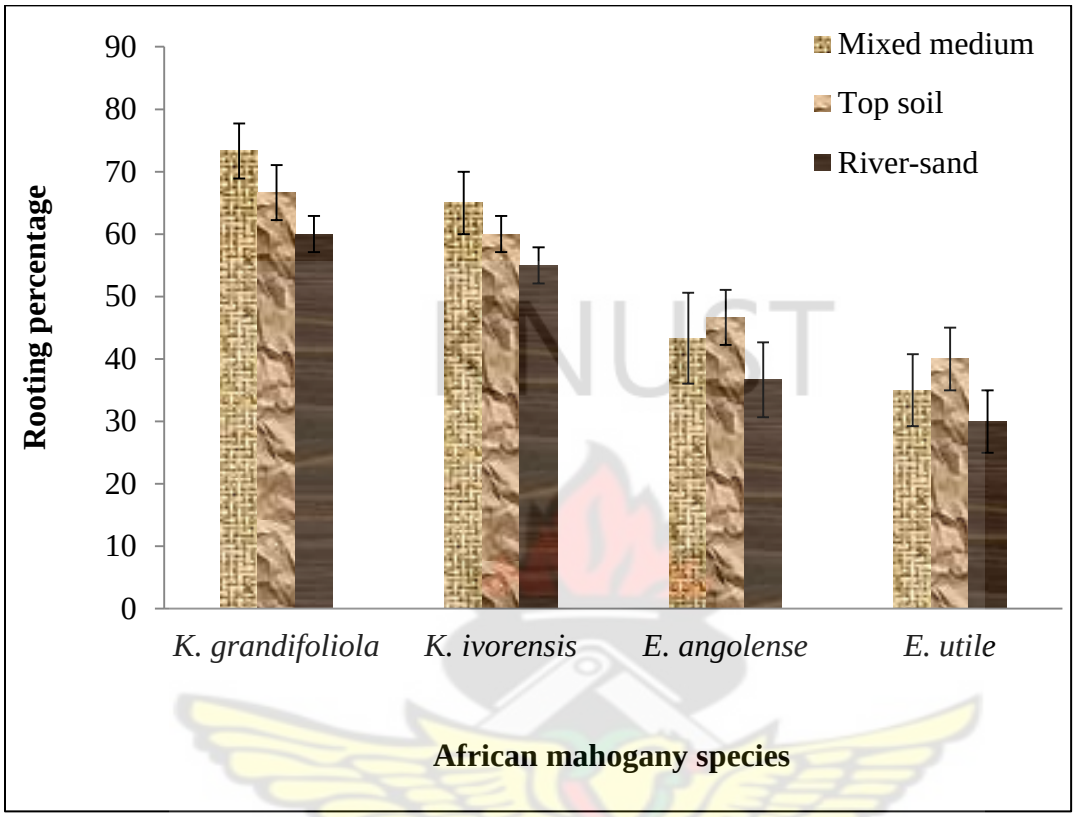
a. Predictors: (Constant), 12-Parenchyma %

b. Dependent Variable: 12-Rooting %

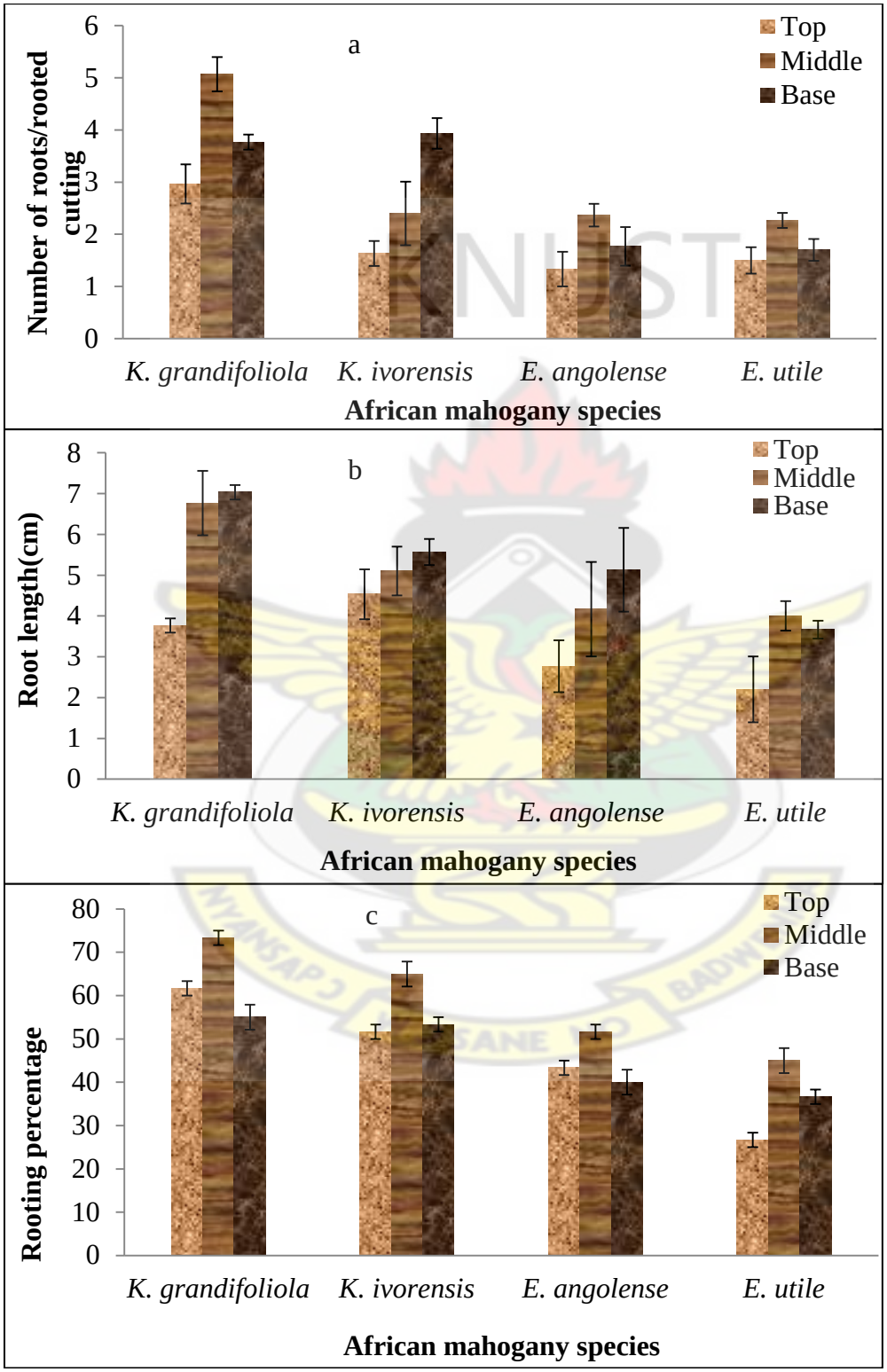
Appendix 16: Effect of species on number of roots per cutting (a) and root length in different rooting media



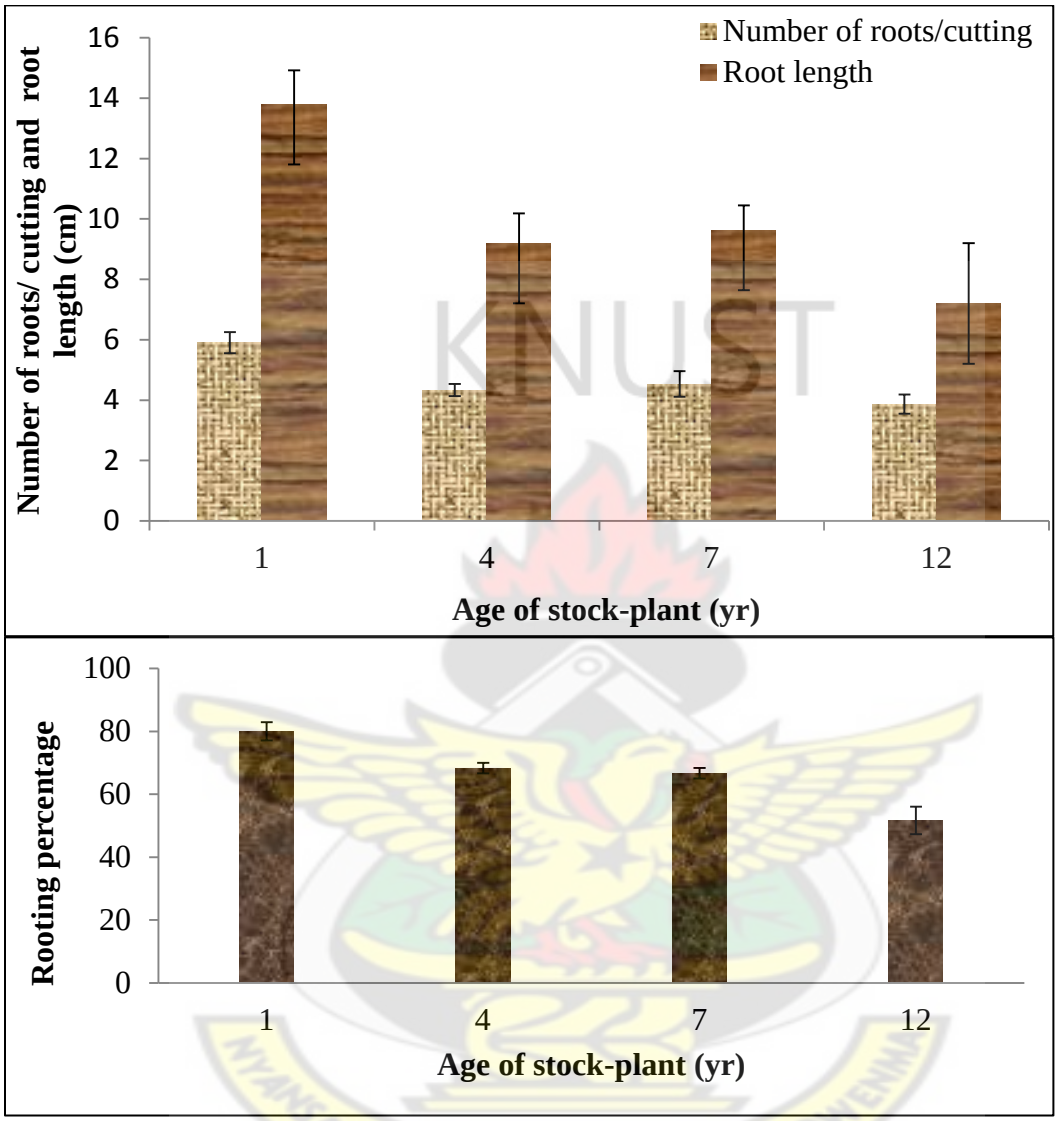
Appendix 17: Effect species on rooting percentage of cuttings in different rooting media



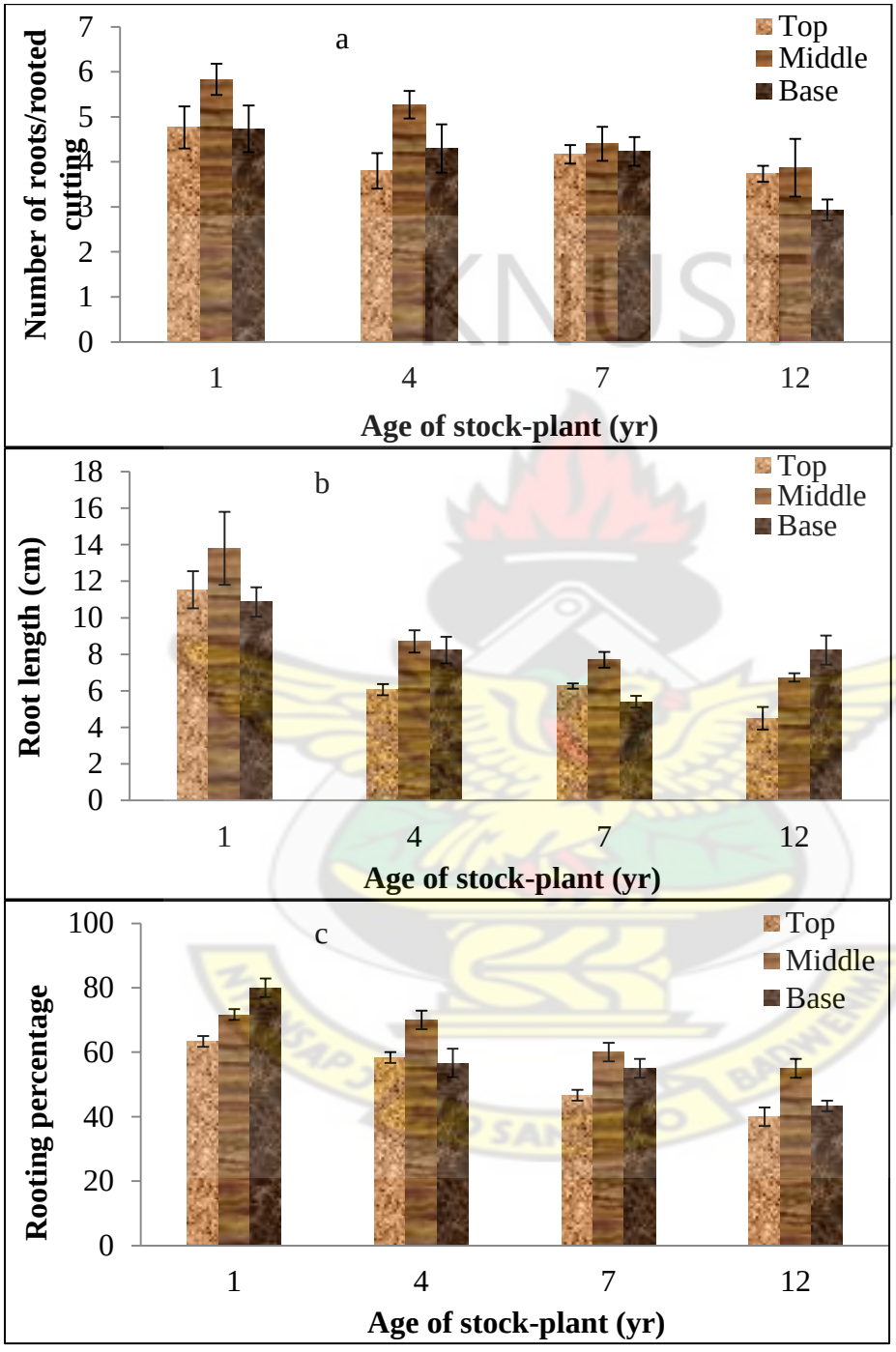
Appendix 18: Effects of cutting position on shoot on: number of roots per cutting (a), root length (b) and rooting percentage (c) of four African mahogany species. Error bars = ± SE



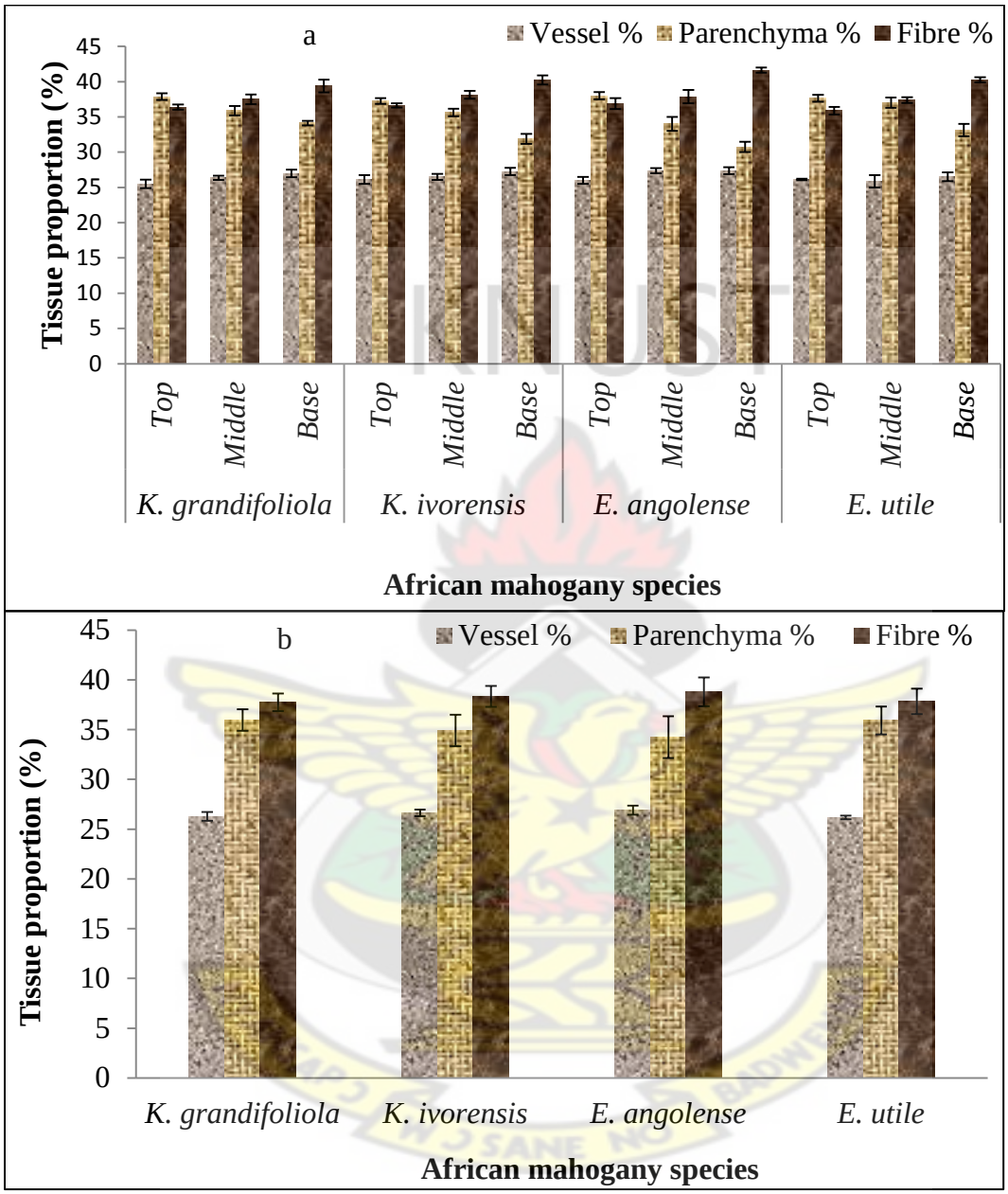
Appendix 19: Effect of age of stock-plant on: number of roots per cutting and root length (a) and rooting percentage (b). Error bars = ± SE



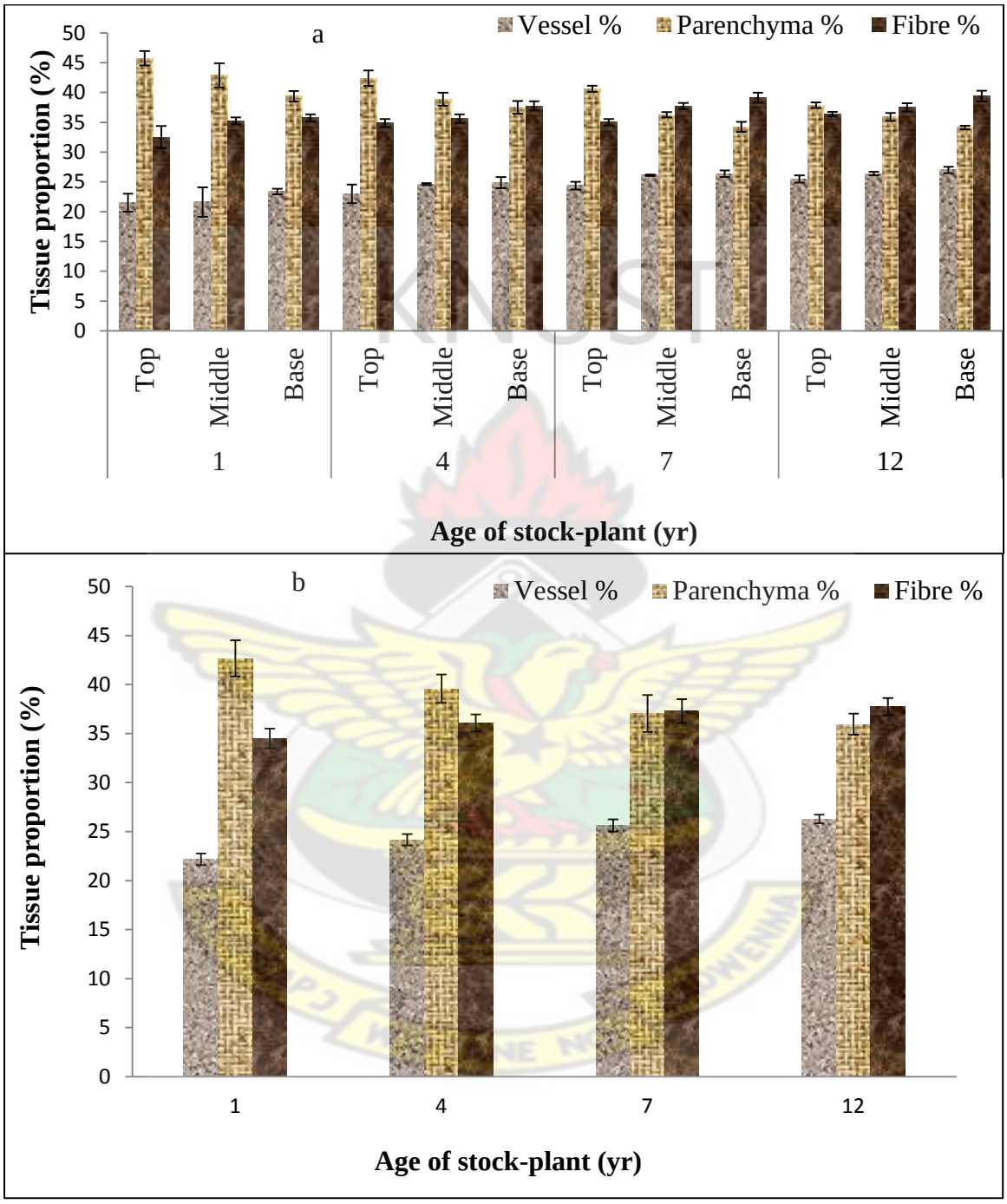
Appendix 20: Effect of cutting position on shoot on the rooting ability of cuttings from shoots from different aged stock-plants of *K. grandifoliola*; number of roots per cutting (a), root length (b) and rooting percentage (c). Error bars = ± SE



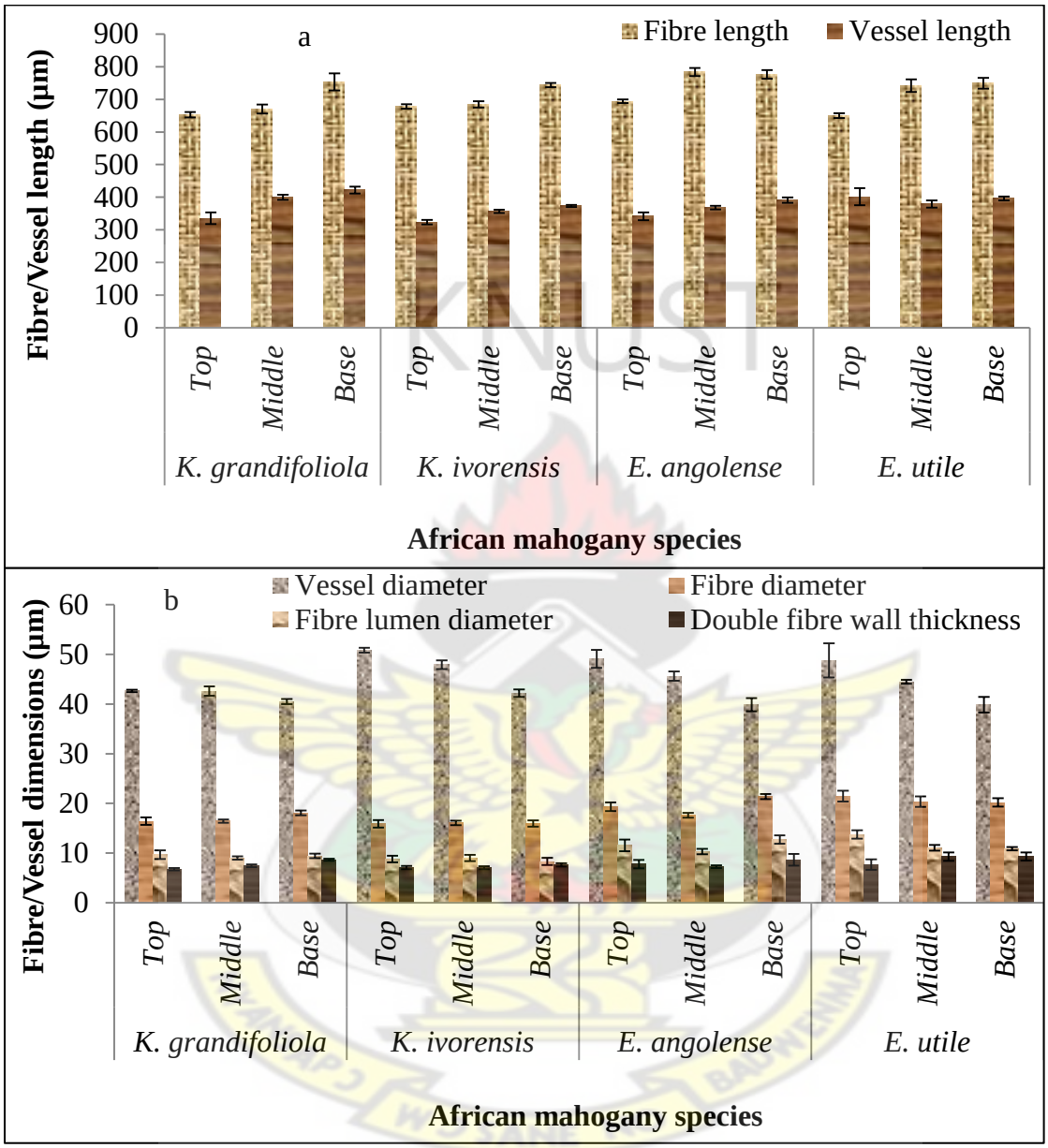
Appendix 21: Effects of: internode position on shoot (a) and species (b) on tissue proportions of shoots from four african mahogany species. Error bars = ± SE



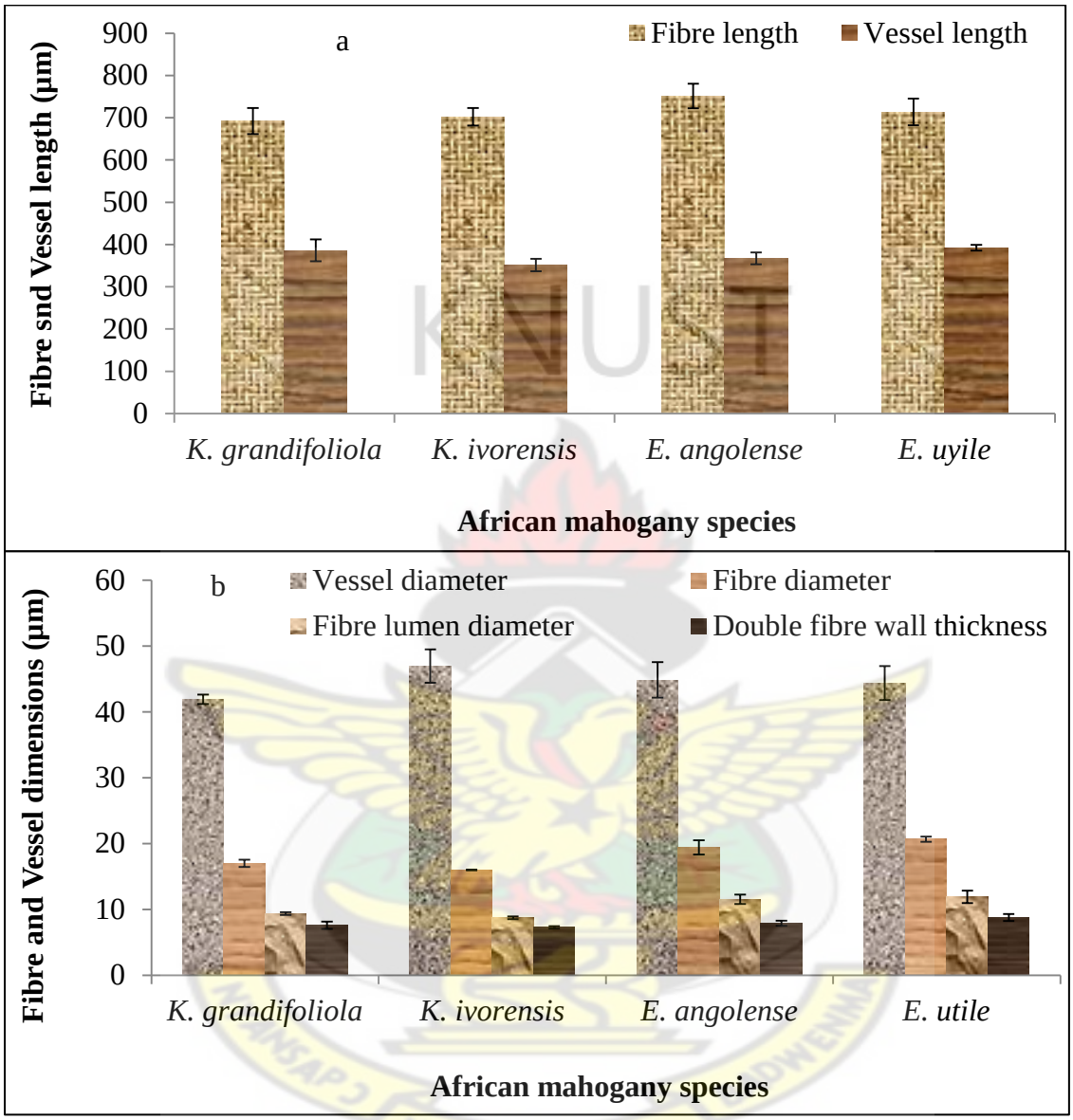
Appendix 22: Effects of: internode position on shoot (a) and age of stock-plant (b) on tissue proportions of shoots of *K. grandifoliola*. Error bars = ± SE



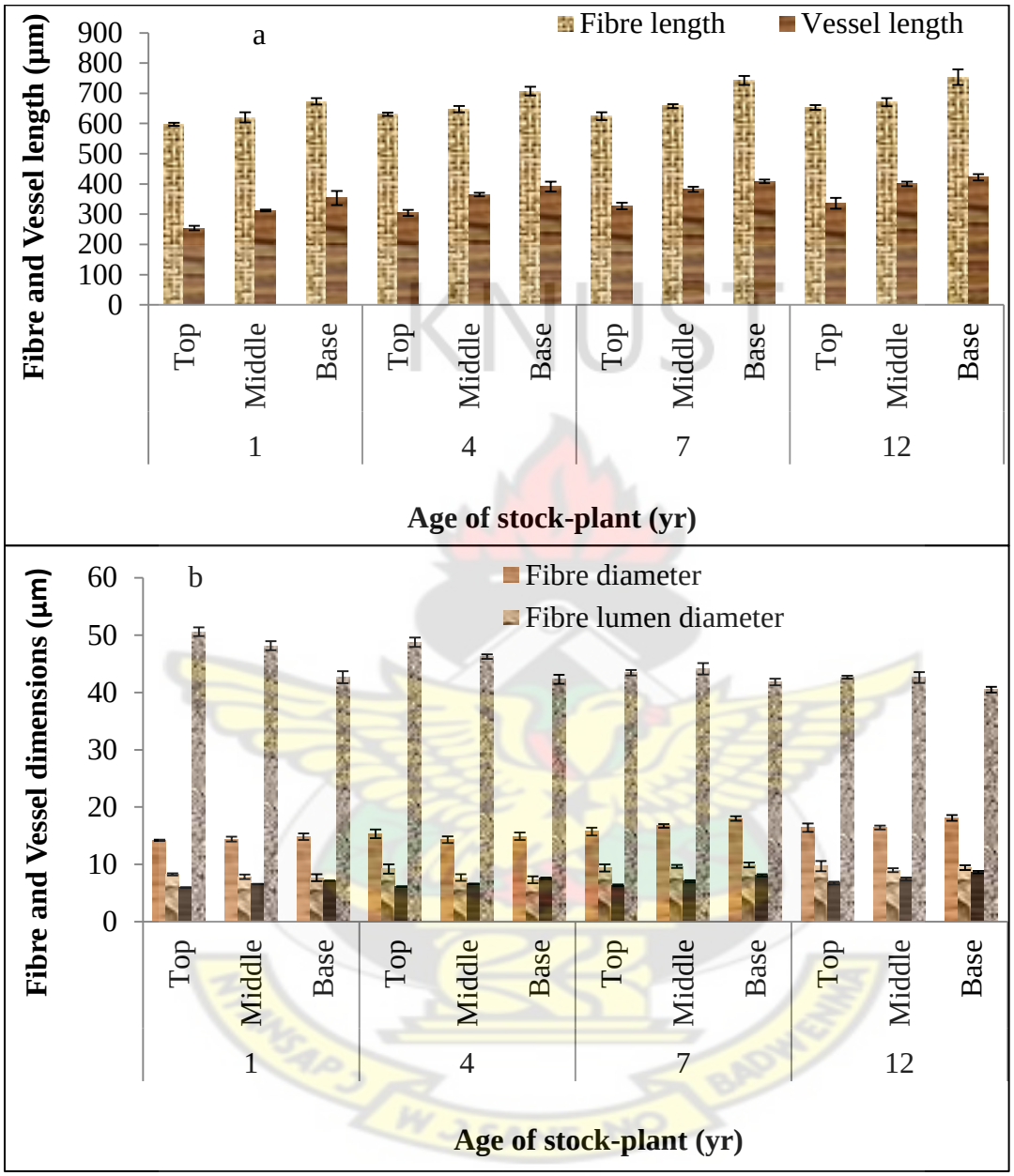
Appendix 23: Fibre and vessel dimensions from different positions on shoots from four African mahogany species. Error bars = ± SE



Appendix 24: Fibre and vessel dimensions of shoots from four African mahogany species. Error bars = ± SE



Appendix 25: Fibre and vessel dimensions of portions of shoots from four different aged stock-plants of K. grandifoliola. Error bars = ± SE



Appendix 26: Fibre and vessel dimensions of shoots from four different aged stock-plants of K. grandifoliola. Error bars = ± SE