BASIC DENSITY AND STRENGTH PROPERTIES OF *GREVILLEA ROBUSTA* CUNN. AND *CORDIA AFRICANA* LAM. GROWN IN AGROFORESTRY IN MOSHI, KILIMANJARO, TANZANIA.

BY

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ABSTRACT

Basic density and some strength properties of wood from *Grevillea robusta* Cunn. and *Cordia africana* Lam. grown in agroforestry in Moshi, Kilimanjaro region were studied with an overall objective of assessing the quality of these agroforestry tree species.

The specific objectives were to conduct survey of end uses of the wood from *G.robusta* and *C.africana* grown in agroforestry, to determine tree characters such as tree form, branching habit and crown size, basic density and its variation within and between these tree species, some strength properties (Modulus of elasticity, Modulus of rupture, Work to maximum load, Total work, compression, shear and cleavage) and their variation within and between these tree species and the relationship between basic density and the strength properties for the two species. Sampling and data collected were done using standard methods according to Lavers (1969). Data analysis were done using both qualitative statistics and computer statistical analysis programme (SAS).

The main results were as follows:

- the current end uses for these species were construction, furniture, fuelwood, shade for coffee, fodder, poles, tool handles, amenity, utensils and medicine.

- trees of *C. africana* had larger crown size and diameter at breast height (dbh) than *G. robusta.* Trees of *G. robusta* had longer and more straight bole (9.5 m) than that of the former (5.5 m).

- *G .robusta* also had slightly larger proportion of heartwood (65%) than *C. africana* (64%).

- Average basic density for *G. robusta* and *C. africana* were 0.48 g/cm^3 and 0.37 g/cm^3 respectively. Basic density showed significant difference between sites, species, trees and within trees.

- Average strength property values for *G .robusta* and *C. africana* were; Modulus of elasticity (4988.0 N/mm^2 and 4711.3 N/mm^2) Modulus of rupture (47.85 N/mm^2 and 47.46 N/mm^2), Work to maximum load 0.07 mmN/mm^3 and 0.06 mmN/mm^3, total work (0.11 mmN/mm^3 and 0.10 mmN/mm^3) respectively. Other strength properties were Compression (30.8 N/mm^2 and 27.11 N/mm^2), Shear (8.37 N/mm^2 and 7.34 N/mm^2) and Cleavage (16.29 N/mm and 12.35 N/mm) respectively.

- For all strength properties studied, there were significant differences between the two species, site, trees and within trees of the same species. *G. robusta* was found to be stronger than *C. africana.* For both species, trees from the lower

altitude zone were stronger than those at higher altitude zone.

It is recommended that, wood from *G. robusta* should be used where high strength is required. *C. africana* trees are suitable for shade due to their larger crown size. Denser and stronger timber should be selected from the low altitude zone.

DECLARATION

I, Simon John Mosha, do declare to the Senate of Sokoine university of Agriculture that this dissertation is my own original work and that it has not been submitted for a degree award in any other university.

Signature .....

Simon John Mosha.

Date 20th .May. 1998.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ABBREVIATIONS

ANOVA	-	Analysis of variance
Bd	-	Basic density
CLEAV	-	Cleavage strength
COMPRE	-	Compression strength
Cor	-	*Cordia africana*
DBH	-	Diameter at breast height (at 1.3m)
Fmax	-	maximum load
GR	-	*Greville robusta*
HA	-	High altitude
LA	-	Low altitude
MC	-	Moisture content
MOE	-	Modulus of elasticity
MOR	-	Modulus of rupture
SAS	-	Statistical analysis system
Twork	-	Total work to fracture
Wmax	-	Work to maximum load
a.o.	-	and others

CHAPTER ONE

1 INTRODUCTION

1.1 Background information.

Tanzania has a total land of approximately 89 mill ha of which 33.51 mill ha i.e. 37.7% is under forest cover (FAO 1997). Out of the 33.51 mill ha, 13 mill ha has been gazetted as forest reserves of which about 80 000 ha are under plantation and 1.6 mill ha are under water catchment forest (Kimaryo 1982; TFAP 1997).

Currently Tanzania is losing about 2% of her forest cover annually. This is due to among other factors inefficient utilization of wood, poverty, rapid population increase (3%) which in turn result into high demand for agricultural land, settlement, grazing land and forest products i.e. furniture, woodfuel and construction material (FAO 1981; Iddi and Nagoda 1992; TFAP 1997). Deforestation reduces the availability of forest product and has resulted in exposing much land to severe soil erosion which renders the land unfertile (FAO 1993).

In order to rehabilitate degraded land, to reduce pressure on natural forest, to sustain wood supply and to alleviate poverty the government started a national tree planting campaign in 1967 (Lulandala *et al.* 1989).

The campaign involved individuals, communities and organisations. Trees were planted in deforested lands as well as in farmlands. Agroforestry constituted an important component in the tree planting campaign.

Agroforestry is a collective name for land use systems and technologies in which woody perennial i.e. trees, shrubs, palms or bamboo are deliberately combined on the same land management with herbaceous crops and/or animals either in some form of spatial arrangement or temporal sequence (ICRAF 1988). This system has been practised in certain parts of Tanzania like Kilimanjaro, Kagera, Mbeya and Tanga region for long time.

The slopes of mount Kilimanjaro constitute major agricultural areas of Tanzania where agroforestry has been practised for many years to produce coffee, bananas, maize, potatoes, timber and other agricultural crops (O'Kting'ati 1984). The practice has resulted from tradition and land scarcity (O'Kting'ati and Monela 1991).

1.2 Problem statement and justification

Wood is the dominant basic material for construction and form of energy in most developing countries particularly in Africa (Kimaryo and Ngereza 1993; Ishengoma 1994). In Tanzania nearly all houses are constructed with wood as the base frame (Temu and Philip 1981). On the other hand, about 78% of walls and 72% of roofs in

traditional houses in Tanzania are constructed by poles. Ishengoma *et al.* (1992) stated that, today poles remain the most widely used building materials in rural Tanzania and to a lesser extent in urban areas. Further more, wood energy in Tanzania accounts for 90% or more of energy requirement (Openshaw 1978). In Kilimanjaro region timber and woodfuel accounts for about 95% of the total wood harvested. Natural forests in Tanzania however, can supply only 55.9% of wood consumed per annum (Ishengoma *et al.* 1992). This means that about 44.1% of wood is overcut annually.

Agroforestry systems have been introduced in rural areas including Kilimanjaro region, with the expectation that agroforestry grown trees would supply wood and hence relieve pressure on natural forests, rehabilitating the farms, supply fodder, fruits, shade and also to improve the living standard of the rural poor. Agroforestry systems contribute about 13.5% of the present requirement of wood (Ishengoma *et al.* 1992).

Although the agroforestry systems in Kilimanjaro region are endowed with over 53 tree species only 7.2% are used. Of these however, little is known about their wood qualities and potential end uses. A number of researches have been conducted to determine the right trees and agricultural crops combination (Lulandala *et al.* 1989), but ignored wood properties required for end uses. This situation resulted into poor marketing and inefficient utilization of agroforestry tree species.

Wood from tree species grown in agroforestry such as *Grevillea robusta, Cordia africana, Rauvolfia caffra* and *Persea americana* are already in use for construction and furniture in Kilimanjaro region. However their properties especially strength properties are not known. Using wood without knowing their strength properties may lead to safety hazards. The knowledge of strength properties of wood is also important for its efficient utilization.

Due to resource constraints it was not possible to study all properties. In this study therefore the most important properties were considered. These included basic density and some strength properties.

Basic density, which is the ratio of dry weight to green volume, has been found to be a much better guide of properties of wood than other cell characteristics (Zobel and van Buijtenen 1989). According to Siau (1984) of all the physical properties of wood, density is very important. Kollmann and Cote (1968) emphasized that, the quality of wood as a building material depends mainly on its density, or influence of density. Wood density has also an effect on the yield, strength and general quality of the product produced from wood (Zobel and van Buijtenen 1989).

1.3 Objective

1.3.1 Overall objective

The overall objective of this study was to assess the quality of wood from *Grevillea robusta* and *Cordia africana* grown in agroforestry in Moshi district, Kilimanjaro region.

1.3.2 Specific objectives

- To conduct survey of current end uses of the wood from *Grevillea robusta* and *Cordia africana* grown in agroforestry.

- To determine tree characters such as tree form, branching habit and crown size for each species.

- To determine basic density and its variation within and between the two species.

- To determine some strength properties (Modulus of elasticity (MOE), Modulus of rupture (MOR), Work to maximum load (Wmax), Total

work (Twork), compression strength (COMPRE), shear strength and cleavage (CLEAV) and their variation within and between the two species.

- To determine the relationship between basic density and the strength properties studied for each species.

1.4 Significance of the study.

In literature, there are no reported studies on wood quality of *Grevillea robusta* and *Cordia africana* grown in agroforestry trees in Tanzania. Findings from this study will therefore form a basis for recommendation on the efficient utilization of wood of *Grevillea robusta* and *Cordia africana* in Kilimanjaro and other areas with similar climate. This will in turn improve marketability of the wood hence improving living standards of the people. The findings will also form a basis for recommendations for further planting of the two species. Moreover they will form a basis for further research.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 The studied tree species

2.1.1 *Grevillea robusta* Cunn.

Grevillea robusta Cunn. belongs to the family *Proteceae.* It is native to Australia in coastal New South Wales and Queensland. The species has become well established in subtropical and tropical highland over the last century (Hardwood 1992). It is economically important in many countries, particular in Africa and South Asia. The first main use was as a shade tree for coffee plantations. This use has declined over the last few decades but still remains significant in some countries. The species is also a popular amenity plant in both rural and urban areas in many countries around the world. This is because of its attractive overall appearance, the foliage and its spectacular bright yellow flowers. In Africa however, farmers have developed a new role for it as a multipurpose tree for small mixed farms, where it is grown in rows and isolated trees on the farm boundary and within the farm.

In Tanzania, *G. robusta* has been planted since 1914 as a shade tree for coffee on the slopes of mount Meru, Kilimanjaro and Usambara. Milimo (1988) reported that, *G.*

robusta grown on small farms now makes a substantial contribution to national wood production in several African countries for example, Rwanda, Kenya and Tanzania.

2.1.1.1 Distribution

The natural range of *G. robusta* Cunn. extends in eastern Australia some 470 km, from 25°50'S to 30°10'S and from just above sea level near the coast to a maximum of 1100 m a.s.l. (Hardwood 1992). This tree species however, can be grown at a range from sea level to about 2500 m and in a variety of soils (Milimo 1988).

2.1.1.2 Yield

Annual growth rate of 2 m in height and 2 cm in diameter over the first five years are commonly achieved in a number of countries where climate and soil are suitable. The species grow well within the following conditions: Mean annual rainfall 600 - 1700 mm, 0 - 6 months dry season, mean maximum temperature of 25 - 31°C in hottest month, mean minimum temperature of 1 - 12°C in coldest month, mean annual temperature 13 - 20°C and absolute minimum temperature not lower than -10°C. The species can however persist in wide range of climates, but grows more slowly in less suitable environments. In all but the most favourable conditions, growth slows greatly after 10 - 15 years. At the age of 20 years and above, *G. robusta*'s growth rate slows down and may cease growing at the age of about 25 years (Kaumi 1983). Growth in

plantation monoculture is poorer than growth of trees planted singly in rows. It is recommended that, due to allelopathy effect *G. robusta* should not be grown in plantations (Kaumi 1983).

2.1.1.3 Uses

Grevillea robusta has been identified as an agroforestry tree species that can grow in harmony with intensive agriculture on semi-arid sites (Kaale 1984). The species produces wood that is used as timber and firewood. Milimo (1988) reported that timber from *G. robusta* dries fast and has reddish brown colour, attractive grain which makes it suitable for construction and furniture making. The sapwood however, is susceptible to *Lactase* borer (Kimweti 1992). The wood has also a tendency to warp and check during seasoning (Kaumi 1983).

2.1.1.4 *Grevillea robusta* in Agroforestry

Grevillea robusta can be planted in nearly all agroforestry systems both within the farm and along the farm. Kaumi (1983) suggested several agroforestry land use systems incorporating *G. robusta* as the tree component. The systems include intercropping with agricultural crops, intercropping with fodder systems, soil conservation structures, in boundaries and as windbreaks.

Grevillea robusta is popular with African farmers because the species provides economically viable products, it is easy to propagate and establish and it can grow in low-fertility soils. The species does not compete strongly with adjacent crops and it tolerates heavy pruning of its roots and branches (Hardwood and Both 1992).

2.1.2 *Cordia africana* Lam.

2.1.2.1 Distribution

Cordia africana Lam. belongs to the family *Boraginaceae* and is a native of Nigeria. It is a small to medium sized forest tree 4 m to 15 m and grows up to 30 m in height in the forest. It is heavily branched with a rounded crown. The species occurs at medium to low altitude in warm moist areas, in woodlands and bushland often along river banks (Dale and Greenway 1961; Kaale 1984; Drummond 1988; Rocheleau *et al.* 1988; Mbuya *et al.* 1994; Beentje 1994). In Tanzania *C. africana* is commonly found in pasturelands between 1200 m to 2000 m a.s.l. particularly in Arusha and Kilimanjaro (Kaale 1984; Mbuya *et al.* 1994).

The outer bark of the species is fibrous and pale brown in colour with white inner bark. Leaves are ovate to almost round with rounded to subconded base. Margins are entire or dentate. Flowers are white in axillary cymes with yellow or orange fruits and voids.

The heartwood is pinkish brown in colour and durable. Wood from *C. africana* can be worked easily and polishes well (Drummond 1988; Beentje 1994), however the heartwood can twist during seasoning (von Carlowitz 1986).

2.1.2.2 Yield

At the age between 30 and 35 years, *C. africana* grown in agroforestry can provide about 0.7 m^3 of lumber per tree. However, this will depend on growth rate of the tree species on that particular area.

2.1.2.3 Uses

Cordia africana is a useful shade tree for coffee. The timber is prized for furniture and roof shingles. It is also used for making beehives, grinding motors and utensils, as fuelwood and medicine, for soil conservation and as amenity planted along roads. Fruits are edible and fruit gum is used as glue (Beentje 1994). According to von Carlowitz (1986) *C. africana* produces very good mulch and is a nitrogen fixing tree species.

2.1.2.4 *Cordia africana* in Agroforestry

Like *G. robusta, Cordia africana* can be planted in nearly all agroforestry systems both within the farm and along the farm (Kaumi 1983; Sabuni *et al.* 1981). The species can be used for intercropping with agricultural crops, intercropping with fodder systems, soil conservation structures, in boundaries and as windbreaks.

2.2 The studied properties

The studied properties were basic density and some strength properties which includes Modulus of elasticity, Modulus of rupture, Work to maximum load, Total work, Compression strength, Shear strength and cleavage.

2.2.1 Basic density

Density of wood is defined as the mass per unit volume and is expressed as g/cm³ or kg/m³ (Kollmann and Cote 1968; Panshin and de Zeeuw 1980; Desch 1981). The weight of an oven dried volume of wood is generally an index of the amount of cell wall substance present and of the volume comprising air space. The amount of wood substance in a given piece of wood is a valuable indicator of its strength properties and to some extent of its working and finishing characteristics. The air space volume

indicates amount of free water it can absorb (Kollmann and Cote 1968).

2.2.1.1 Importance of wood density

Of all the physical properties of wood, density is very important and in most cases is the first to be investigated (Kollmann and Cote 1968). The amount of cell wall substance present in wood expressed as density is an important indicator of many physical properties. According to Desch (1981), physical properties of wood depends on the cellular structure and proportions of tissue that are present.

Wood density is very important because in most cases there is a strong relationship between wood density and strength properties. Desch (1981) found that there is positive correlation between wood density and strength properties and between wood density and pulp yield. By influencing basic properties, therefore, density influences the utility of wood.

2.2.1.2 Factors influencing wood density

Moisture content

Density is influenced to a large extent by the moisture content of the wood (Kollmann and Cote 1968). An increase in moisture content will increase the mass of the wood at

a greater rate than it does for volume. The increase occur at a greater rate above the fibre saturation point (Fsp) because swelling has ceased (Siau 1984).

Growth rate

Growth rate influences several characteristics of wood such as cell sizes and wall thickness, the ratio of earlywood to latewood, the amount of ray cells and the size of vessel elements. Although these factors are controlled genetically they can be manipulated by genetical selection and can also be altered by changing growing condition (Dinwoodie 1981).

Ring porous and diffuse porous hardwoods are affected differently by growth rate. Panshin *et al.* (1964) in Zobel and van Buijtenen (1989) state that, in ring porous hardwoods, ring width is directly related to the average density of the wood. The author further reported that, there is little relationship between wood density and ring width in diffuse porous hardwoods. Similar observation was reported by Kaumi (1983) for *Betula maximowiczian* and *Tilia japonica* which are also diffuse porous hardwoods.

For most species in which density and growth rate appear to be negatively correlated, wood of the desired type can be produced regardless of growth rate achieved because of the relative genetic independence of these two characteristics (Zobel and van Buijtenen 1989).

Porosity

The porosity of timber is defined as the fractional void volume (Dinwoodie 1981). Porosity determines the volume of liquid per unit volume of wood to be absorbed (Siau 1984). Thus by influencing wood volume, porosity influences the density of wood. Kellogg and Wangaard (1986) found that, the density of cell wall including microvoids was approximately 1.45 g/cm^3 while the one which exclude microvoids varied from 1.50 g/cm^3 to 1.53 g/cm^3. Siau (1984) concluded that, there is a negative correlation between wood porosity and wood density for extractive free wood.

2.2.1.3 Variation of basic density

A piece of perfectly dry wood consist of both the solid material comprising the cell walls and the cell cavities which contain air and small quantities of gum and other substances. The density of the solid material of the cell walls was found to be similar for all timbers 1.5 g/cm^3 (Kollman and Cote 1968; Panshin and de Zeeuw 1980; Desch 1981; Dinwoodie 1981; Siau 1984). Different timbers, however vary in density from about 0.04 g/cm^3 *Ochroma lagopus* to 1.4 g/cm^3 *Gaujacum officinales* (Desch 1981).

Variation in wood density is caused by among other factors differences in the ratio of cell wall to air space in different timbers (Kollman and Cote 1968; Hughes and Plumpter 1977). This ratio is controlled by both the relative proportions of the thinner-

walled vessels, parenchyma cells, the thicker walled fibres and the extent of development of the secondary walls of the fibre (Panshin and de Zeeuw 1980). Generally both factors operate to produce this wide range in density among timbers (Desch 1981). Variation in wood density is known to occur between different species, within species and within a given tree (Desch 1981; Zobel and van Buijtenen 1989; Ishengoma and Nagoda 1991).

Variation between species

Different wood species have different density values. As stated earlier, density from different wood species range from 0.04 g/m^3 to 1.48 g/m^3 (Ishengoma and Nagoda 1991). This variation is due to the differences in the amount of cell wall substance and the extraneous materials present per unit volume (Panshin and de Zeeuw 1980). According to Desch (1981), the range in densities of the softwood timbers is much lower than that of the hardwood timbers.

Variation within species

The subject that is studied widely in forestry with respect to wood is the variability of properties within and among trees. Wood from trees of the same species have some basic anatomical properties, but differences in inherent properties and growth conditions such as geographical distribution, elevation, air temperature, solar radiation,

humidity, precipitation, soil characteristics and growing space may result in wood of different quality (Zobel and van Buijtenen 1989)

It was reported for example that wood density varies from 0.402 g/cm^3 to 0.439 g/cm^3 for *Populous tremuloides,* from 0.433 g/cm^3 to 0.634 g/cm^3 for *Eucalyptus saligna* and from 0.470 to 0.570 g/cm^3. for *E. regians* (Zobel and van Buijtenen 1989). The differences in density among trees in some species for example *Eucalyptus spp* is sometimes more than 30% (Walker 1993).

Variation within a given tree

Variation within a tree is often greater than between trees of the same species grown under the same conditions (Zobel and van Buijtenen 1989; Hamza and Ringo 1991). There are several patterns of variability within a given tree that are of importance. These include within ring variations, radial variation and axial variation (Rydholm 1965; Hamza 1987; Zobel and van Buijtenen 1989; Ishengoma and Nagoda 1991; Klem 1996; Hamza *et al.* 1998).

Density variation within growth rings

Wood of trees grown under seasonal conditions consist of a series of concentric layers of tissue i.e. the growth rings. Wood variation within a growth ring is generally known

to occur in earlywood and latewood. Earlywood or springwood is characterized by cells having large cavities and thin walls. Latewood or summerwood have smaller cavities and thicker walls (Zobel and van Buijtenen 1989; Ishengoma and Nagoda 1991; Hamza and Iddi 1996). The densities of earlywood and latewood are different.

The greatest variability in wood density occurs within each annual ring. Zobel and Buijtenen (1989) reported a ratio of earlywood to latewood to be 1.0 to 2.8 for Sugi (*Cryptomeria japonica)* and that the ratio varies between species. According to Ishengoma and Nagoda (1991), latewood is approximately three times denser than early wood. Tajima, (1967) cited by Zobel and van Buijtenen (1989) put forward that the density of latewood is 2 to 2.5 times heavier than that of the earlywood.

Hardwoods can have greater differences in cell type and structure within an annual ring, therefore the density varies for both the earlywood and latewood themselves. Kollman and Cote (1968) however reported that, the difference in density between earlywood and latewood exist from pith to the bark and from butt to the top. Generally, latewood was found to be more variable than earlywood. While the density of earlywood decreases slightly from pith to bark or keeps at about the same level, the density of the latewood increases from pith to the bark. In axial variation the density of earlywood decreases from butt to the top. This is contrary to latewood whose density increases from butt to the top (Kollman and Cote 1968; Zobel and van Buijtenen 1989; Ishengoma and Nagoda 1991).

Variation in radial direction

The variations in density through a particular cross section of the stem are usually affected very much by the width of growth rings and the percentage of dense latewood (Desch 1981; Ishengoma and Nagoda 1991). The density variation from the pith towards the bark follows different patterns in different tree species (Panshin and de Zeeuw 1980; Zobel and van Buijtenen 1989). Walker (1993) reported the following four general patterns of density variation.

- density increases from the pith to bark,

- high density near the pith, followed by a decrease from the first few years and then increase to maximum at the bark,

- moderate increase of density for the first five years followed by a more or less plateau or sometimes a decrease in the last formed wood near the bark and

- gradual decrease in density from the pith to the bark.

In softwoods, wood of low density is often produced near the pith where wide growth rings are usually formed. On the other hand, the heaviest wood is found some distance

from the pith in sapwood where narrow growth rings are formed (Panshin and de Zeeuw 1980).

Hardwood however, show much less consistency in density patterns from the pith to the bark than softwoods (Zobel and van Buijtenen 1989). In ring porous hardwood the density usually decreases from the pith towards the bark (Ishengoma and Nagoda 1991). This change is influenced by the properties of latewood in the growth increments. The percentage of latewood tissue changes more than that for the earlywood. This change result into decreasing both fibre percentage and density from the pith to the bark (Panshin and de Zeeuw 1980).

In diffuse porous wood, density often increases in the growth rings near the pith then remains more or less constant, or sometimes it decreases in the last formed rings near the bark (Klem 1996; Ishengoma and Nagoda 1991).

Density variation in axial direction

Density changes along the length of the trunk is more pronounced in softwood than in hardwood. Panshin and de Zeeuw (1980) found that, axial variability of wood density in hardwood was difficult to describe since there is insufficient information and the trends appear to be much more complex. Panshin and de Zeeuw (1980) summarised the axial variation of hardwood density as follows:

- decreasing uniformly,

- decreasing in the lower trunk and increasing in the upper trunk and

- increasing in the stem from base to the top in non-uniform pattern.

Decrease in density from the base of the tree to the top is the most common trend found in softwoods. In hardwood density variation with height of the trunk shows very little consistency and no overall dominance of a single pattern (Panshin and de Zeeuw 1980). In hardwood, the heaviest wood is generally produced at the base of the tree i.e. at buttresses. Above the buttress density deceases in the lower portion of the trunk and then increases in the upper portion of the trunk (Zobel and van Buijtenen 1989; Ishengoma and Nagoda 1991).

The pattern of density variation from base of the tree to the top depends not only on species but also on environmental factors such as growth conditions and site quality (Kollman and Cote 1968). Panshin and de Zeeuw (1980) reported that, the density of *Liquidamba styraciflua* grown on poor site decreases from the butt to the crown. On the other hand the density of the same species grown on the better site increased uniformly from bottom to the top.

2.2.2 Strength properties

2.2.2.1 Studied strength properties

The term strength applied to a material such as wood refers to the ability of the material to resist external forces or load tending to change its size and alter its shape (Desch 1981). The strength property of wood is an expression of its behaviour under applied force (Panshin and de Zeeuw 1980). Many uses to which wood is put require the ability to resist load (Ishengoma and Nagoda 1991).

Wood has several types of strength, and a strong timber in one respect may be comparatively weak in another (Desch 1981). These include static bending, tensile strength, impact bending, hardness compressive strength, shear strength and cleavage (Lavers 1969).

Bending strength

Bending strength is the ability of the body to resist flexure or bending forces acting upon it (Panshin and de Zeeuw 1980).

The strength properties under static bending are modulus of rupture, modulus of elasticity, work to maximum load and total work. Modulus of rupture is the measure of

the ultimate strength of timber. Modulus of elasticity is an expression of the relationship between stress and strain and is of importance in determining the deflection of a beam under load. Work to maximum load is a measure of the toughness of timber under bending stress and Total work is also the measure of toughness to a point of complete failure (Lavers 1969; Panshin and de Zeeuw 1980; Dinwoodie 1981; Desch 1980; Ishengoma and Nagoda 1991; Ishengoma *et al.* 1988).

Compressive strength

This is the force that tends to shorten dimensions or reduces the volume of the body when acting on it. It is defined as total compression force divided by the cross sectional area of the piece being stressed (Lavers 1969; Panshin and de Zeeuw 1980).

Shear strength

Shear strength is the ability of the body to resist the force which tend to cause one portion of the body to move with respect to another in a direction parallel to their plane of contact. Shear strength is determined only in a direction parallel to grain, since wood is week in this axis (Panshin and de Zeeuw 1980). According to Lavers (1969), shear strength is very important when wood is used as pole for construction and for furniture making.

Cleavage strength

Cleavage is resistance against splitting. It is usually determined in radial and axial directions. The resistance against cleavage is important in structural work in respect to type of nails and their holding power. Timber with low cleavage resistance, has a little nail to wood contact. Such timber is not suitable for furniture and construction work. Low cleavage however, is a desirable property for woodfuel and other uses where splitting is necessary (Dinwoodie 1981; Ishengoma and Nagoda 1991).

2.2.2.2 Factors influencing strength properties of wood

Many variables that influence density of timber also influence the various strength properties of timber. These can be regarded as either material dependant or manifestations of the environment (Dinwoodie 1981). Among the factors are wood density, moisture content, knots, anisotropy and grain angle. Others are ring width, cell length, temperature, time under load, duration of load and fatique.

Density

The density of wood, which is a measure of the relative amount of solid cell wall material, is the best index that exist for predicting the strength properties of wood (Panshin and de Zeeuw 1980). According to Panshin and de Zeeuw (1980) and

Dinwoodie (1981) the relationship between basic density and strength properties irrespective of the kind of wood can be expressed by the equation:

$$S = k(g)^n$$

where S = any strength property

g = wood density

k = a proportionality constant for each strength property.

n = an exponent that defines the shape of the curve.

Over the range of density of most of the timber used commercially the relationship between density and strength properties can be assumed to be linear with the possible exception of shear and cleavage. Similarly within a single species the range is low and the relationship can again be treated as linear (Dinwoodie 1981).

Moisture content

Water in green timber (freshly felled timber) is present both in the cell cavities and within the cell walls, (Kollman and Cote 1968; Koch 1972; Desch 1981; Dinwoodie 1981). During the seasoning process, water is first removed from within the cell cavity. This holds true, down to moisture content of about 27 - 30%. Since water in the cell cavities is free (not chemically bounded to any part of the timber), its removal will have

no effect on the strength or dimensions of the timber (Desch 1981). However, Dinwoodie (1981) reported that, there is an increase in strength as the moisture content of the timber is reduced from about 27% to 2%. Below this range the strength of timber shows a slight decrease. Lavers (1969) found that, over 200 species tested, the strength properties for green timber was lower than for timber at 12% moisture content. The relationship can be expressed mathematically as:

$$\mathbf{Log_{10}\, H = Log_{10}\, 0f + k\,(uf - 11)}$$

Where H = the strength at 12% moisture content,

0f = the strength at fibre saturation point,

uf = the moisture content at f.s.p. and

k = a constant.

However, this relationship may not always apply when the timber contains defects (Dinwoodie 1981). Even in knot-free timber the relationship does not always hold true for impact resistance (Walker 1993).

Knots

Knots are associated with distortion of the rain. Since even slight deviation in grain angle reduces the strength of the timber appreciably, it follows that, knots will have a

marked influenced on strength of wood (Dinwoodie 1981; Klem and Ringo 1984; Ishengoma and Nagoda 1991; Walker 1993). The significance of knot however will depend on their size and distribution both along the length of a piece of timber and across its section (Klem 1996). Dinwoodie (1981) reported that, knots in cluster are more important than knots of a similar size which are evenly distributed while knots on the top or bottom edge are much more critical than small knots in the middle. Knot ratio, is one of the parameter used to relate the sum of the cross-sectional area of the knots at a cross section to the cross-sectional area of the piece of timber. There is a correlation between the strength of a timber and its knot ratio (Dinwoodie 1981; Walker 1993).

Anisotropy and grain angle

Strength of timber is directionally dependent. Irrespective of moisture content the highest degree of anisotropy is in tension. This reflects the fact that the highest strength of timber is in tension along the grain while the lowest is in tension perpendicular to the grain.

Anisotropy in strength is due in part to the cellular nature of timber and in part to the structure and orientation of the microfibril in the wall layer. (Dinwoodie 1981). Bonding along the direction of microfibrils is covalent whilst bonding between microfibrils is by hydrogen bonds; thus it will be easier to rupture the cell wall if the

load is applied perpendicular than if applied parallel to the fibre axis.

Since timber is an anisotropic material, it follows that the angle at which stress is applied relative to the longitudinal axis of the cell will determine the ultimate strength of the timber. Hankinson formula is used to obtain an approximate value of strength at any angle to the grain from the knowledge of corresponding values both parallel and perpendicular to the grain.

$$Q_o = \frac{Q_p}{Q_p \mathrm{Sin}^n s + Q_q \mathrm{Coss}}$$

Where Q_o = strength property at angle s from the fibre direction,

Q_p = strength parallel to the grain,

Q_q = strength perpendicular to grain and

n = an empirically determined constant.

In tension, n = 1.5 - 2, in compression n = 2 - 2.5; for stiffness test, n = 2 (Dinwoodie 1981).

Ring width

Density is influenced by the rate of growth of the tree. It follows that, variation in ring width will change the density of the timber and hence the strength. However, in the ring

porous timbers such as oak and ash, increasing growth rate (ring width) will consequently increase density and so will strength (Dinwoodie 1981).

Cell length

The cells overlap one another, therefore, there must be a minimum cell length below which there is insufficient overlap to permit the transfer of stress without failure in shear occurring. Some investigators have argued that there must be a high degree of correlation between the cell length and the strength of the cell wall material (Dinwoodie 1981; Walker 1993).

Temperature

In general most properties with exception of shock resistance, are affected by temperature changes (Lavers 1969). Reduction of strength of the wood occurs with a rise of temperature (Kollman and Cote 1969; Lavers 1969; Dinwoodie 1981). At temperatures ranging from -200°C to +200°C and at constant moisture content strength properties are linearly (or almost linearly) related to temperature.

At temperatures above 95°C or at temperatures above 65°C for very long periods of time there is an irreversible effect of temperature due to thermal degradation of the wood substance (Lavers 1969; Dinwoodie 1981).

The different mechanical properties are affected to different degrees. The compressive strength and the modulus of rupture are the most sensitive, and tensile strength parallel to the grain and modulus of elasticity the least (Ishengoma and Nagoda 1991; Walker 1993).

The effect of temperature is very dependent on moisture content, sensitivity of strength to temperature increasing appreciably as moisture content increases. The relationship between strength, moisture content and temperature appear to be linear over the range 6 to 20% moisture content and -20 to 60°C. However in case of toughness, at low moisture content it decreases with increasing temperature while in high moisture content it increases with increasing temperature (Waangard 1976; Dinwoodie 1981).

Time under load

Rate of loading

All strength properties of wood are time dependent. Time dependence is especially important for bending strength. In static bending test which takes few minutes to complete, the strength will be less when load is applied more slowly and it will be higher at higher rates of loading (Kollman and Cote 1968; Panshin and de Zeeuw 1981; Dinwoodie 1981).

Generally, higher values of strength are obtained for wood loaded at rapid rates and lower values are obtained for slower rates. For example, load required to produce failure in a piece of wood in one second is approximately 10% higher than that required in standard test (Lavers 1969).

Duration of stress

The time during which the force acts on a piece of wood has an important effect on the magnitude of the load which that piece can sustain. Strength is a function of duration of stress. Strength decreases about 8% for every ten-fold increase in duration of the load. The relationship is approximately linear and is expressed by the following regression: -

$$Q = 91.5 - 7\log_{10} t$$

where Q = the stress level (%)

t = effective duration of maximum load (hr)

The effect of duration can be described as creep and fatigue.

Creep

Creep is defined as time dependent deformation exhibited by material under constant load. When first loaded, a wood member deforms elastically, but if load is maintained additional time dependent deformation occurs i.e. creep. (Dinwoodie 1981).

Changes in climatic condition, increase the rate of creep and also shorten the duration during which a member can support a given load. For small dimension under large cyclic changes in temperature and relative humidity the effect can be substantial (Dinwoodie 1981; Ishengoma and Nagoda 1991).

Fatigue

Fatique refers to a progressive damage that occurs to a material subjected to cyclic loading. It is the ability of wood to sustain repeated, reversed or vibrational load without failure. When sufficiently high and repetitious enough, cyclic loading stress can result into fatigue failure (Panshin and de Zeeuw 1980; Ishengoma and Nagoda 1991).

2.3 Relationship between basic density and strength properties

There is a relationship between density and various strength properties of wood in both softwood and hardwoods. This relationship is usually based on the results of tests on small clear specimens (Kollmann and Côté 1968). The relationship between density and strength properties for most tree species is assumed to be linear. According to Dinwoodie (1981) this relationship is very important since density is easy to determine. By knowing basic density therefore, one can estimate the strength value of wood.

2.3.1 Relationship between different strength properties

Literature indicates that, there is a relationship among the strength properties of wood of both softwood and hardwood (Panshin and de Zeeuw 1980). Strong correlation is found to exist between impact bending and total work and also between Modulus of Elasticity and Modulus of Rupture (Dinwoodie 1981).

CHAPTER THREE

3 MATERIALS AND METHODS

3.1 Study area

The study was conducted in Moshi Rural District. Moshi rural is among the six districts of Kilimanjaro region. The region is located on the North eastern part of mainland Tanzania just South of equator. It borders Kenya to the North, Tanga region to the East and South and Arusha region to the West.

3.1.1 Geographical location and size

Moshi rural district is located in the southern slopes of mount Kilimanjaro with an area of 152 km^2. It lies between latitude 3°S to 3°30' S and longitude 37°30' E to 37°45' E. The altitude varies between 1000 m to 5895 m a.s.l. at the highest peak of mount Kilimanjaro. Figure 1 below shows a sketch map of Moshi rural district and the approximate location of study villages.

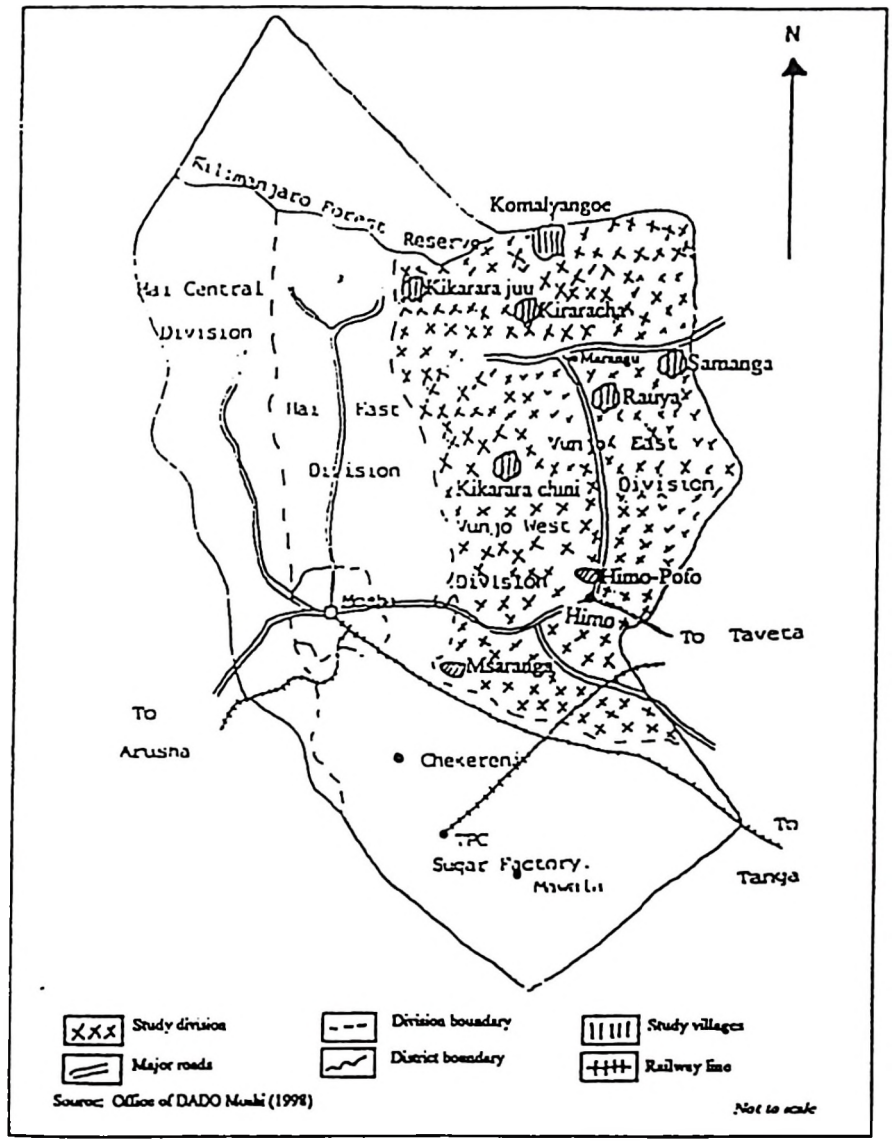

Figure 1 : The sketch map of Moshi District and approximate location of Komalyangoe, Kikarara juu, Kiraracha, Kikarara chini, Samanga, Rauya, Himo-Pofo and Msaranga study villages

3.1.2 Physical environment

3.1.2.1 Climate

Moshi rural district is characterized by a cool and wet climate. Annual mean temperature is 20°C. The area has a bimodal rainfall pattern with short rains from November to December and long rains from March to early June. The wettest areas are at the elevation from 1500 m to 2000 m a.s.l. where mean annual precipitation reaches 2000 mm. Below 1500 m a.s.l. rainfall decreases to about 700 mm on the low lying plain.

Based on this variation the agricultural land around mount Kilimanjaro has been divided into three altitudinal belts i.e. lowlands, midlands and highlands (Table 1). The studied villages were selected from lower and high zones. The two zones were selected because they differ in climatic condition and probably the soil quality. According to Kaale and Temu (1985) and Walker (1993), climate influences wood properties.

Table 1: Altitudinal belts of agricultural land around mount Kilimanjaro.

Zones	Altitude (m.a.s.l)	Rain (mm)	Temperature °C
High zone (highlands)	1100 - 2000	1250 - 2000	15 – 25
Middle zone (midlands)	900 - 1100	800 - 1250	25 – 30
Low Zone (lowlands)	Up to 900	up to 800	over 30

Source: Makundi (1996)

3.1.2.2 Soils

Soils on the slopes of mount Kilimanjaro have been formed by volcanic activities of mount Kilimanjaro. These soils show great variations because they have developed from volcanic materials of different ages (Deckers *et al.* 1990). The following four major groups of soils can be identified in Moshi rural district.

- humic notasols and associated humic andosols.
- chromic cambisols and associated eutric cambisols.
- orchid andosols and associated chromic cambisols and vitric andosols and associated eutric nitosols and
- mollic andosols and associated eutric nitosols.

In general, these volcanic soils are supposed to be fertile with a high base saturation and cation-exchange capacity (Fernandes *et al.* 1984). However, continuous use of the land has resulted into nutrient depletion (Makundi 1996). In order to maintain high agricultural production substantial erosion control is necessary. In other areas arability is limited by slope, stoniness or by shallow petrocalcic horizon (O'kting'ati and Kessy 1991).

3.1.3. Vegetation belts

The vegetation in Moshi rural district changes with altitude. Mwasaga (1991) identified five types of vegetation cover in Moshi rural district. These include:

- woodland and bushland belt which occurs between 900 m to 1500 m a.s.l. This belt is characterized by Mosaic and *Acacia spp.*, thorn bushland and *Combretum/ Terminalia* woodland. The belt is also susceptible to fire;
- Cultivated belt between 1500 m to 1900 m a.s.l. The cultivated belt completely encircles the mountain with the exception of a narrow (8 km) corridor of native vegetation on the northwest slope,
- Montane forest between 1900 m to 2500 m a.s.l.
- Ericaceous belt between 2500 m to 3000 m a.s.l. and
- alpine belt above 3000 m a.s.l.

3.1.4 Socio-economic characteristics

3.1.4.1 Population

In 1988 the population of Moshi rural district was 342 553 people. According to population projections the population has increased to about 411 106 people by 1997. The population density is 224 person per km^2. Actual densities are as high as 700 people per square km in the middle climatic zone between 1100m - 1800m a.s.l. where the majority of the population is settled. In Moshi urban, population is as high as 3 339 people per km^2 (URT 1994)

3.1.4.2 Crops and cropping pattern

A wide variety of crops are grown is Moshi rural district. The main crops are perennial crops such as coffee and banana. Popular cereals are maize, sorghum beans and finger-millet. The finger-millet is used mostly for local beer ("mbege") brewing. Others are sweet potatoes, Irish potatoes and yams. Common vegetables are cabbages, spinach and tomatoes. Fruits such as mangoes, plums, avocados, guavas and peaches are widely consumed in the peak period. Beans are the dominantly eaten legumes.

3.1.4.3 Farming system

Agroforestry in Moshi rural district are characterised by an intensive integration of numerous multipurpose trees and shrubs, with food crops and animals, simultaneously on the same unit of land. The coffee/banana farming is practised by the farmer resident in the uplands and midlands between 1100 m to 1900 m a.s.l. The main distinguishing factor of these farmers is the production of coffee, banana, keeping of diary cattle and trees in the uplands. Diary cattle, provides milk, meat and manure. Coffee is mainly used as a cash crop, trees and shrubs are deliberately retained in the homegardens to provide shade for coffee, fodder, mulch, live fence, fuelwood, timber, fruits and local medicines. These trees and shrubs among others, include *Cordia africana, Grevillea robusta, Persia americana* and *Rauvolfia caffra*. A wide species diversity provides both subsistence and cash crop. This enables farmers to keep their management options open thus provide insurance against drought, pest and economic risks.

3.2 Tree characters and some physical characteristics

Tree characters and some physical characteristics of the studied species were described according to Smith *et al.* (1994). Tree characters studied include tree form, height, dbh, branching habit, bole length and crown height. Physical characteristics such as heartwood proportion, bark width, heartwood colour, figure and texture were also studied.

3.3 Survey of current end uses

A survey was conducted in the study area to determine the current end uses of wood from *Cordia africana* and *Grevillea robusta.* Structured questionnaire was used to interview farmers, pit sawyers, carpenters and timber sellers (Appendix 1).

3.4 Tree sampling

The study area was sub-divided into two zones according to altitude: lower altitude below 900 m a.s.l. and higher altitude between 1100 m to 2000 m a.s.l. From each zone five trees of good form and free from any visible defect for each species were randomly selected. The selected trees were aged 26 years for *Grevillea robusta* and between 30 to 35 years for *Cordia africana.* Before felling dbh for each sample tree was measured and North side marked.

Trees were felled by using two man cross-cut saws. From each sample tree three disks measuring 5 cm thick were cut at 1.3 m, 45% and 75% of the total tree height. The disks were labelled to indicate species, tree number and position in the stem. The disks were for basic density determination.

A sample log measuring 1m long was cut above 1.3 m. for strength properties determination and basic density for correlation with strength properties. A centre plank

measuring 65 mm thick including the pith was sawn in the east west direction from each log. The planks were labelled to indicate species and tree number.

The disks and planks were air dried and then transported to Sokoine University of Agriculture, where laboratory tests were carried out.

3.5 Sample preparation

3.5.1 Basic density

Radial strips extending from pith to bark were cut from each disks. Then four samples were cut from each strip at 1%, 33% 66% and 100% starting at the pith.

3.5.2 Strength properties

Strength properties were determined in accordance with Lavers (1969). Scantlings measuring 30 x 65 x 1000 mm were radially sawn from each one metre plank and labelled from pith to bark for the two sides east and west. The scantlings were air dried and then planed and labelled serially from pith to bark. Each scantling provided a number of samples depend on the width of scantling for each sample plank. The size of the samples for each test were as follows:

- 20*20*300 mm for static bending,
- 20*20*60 mm for compression parallel to grain,
- 20*20*20 mm for shear parallel to grain and
- 20*20*45 mm for cleavage perpendicular to grain.

3.6 Laboratory procedures

3.6.1 Basic density

Determination of basic density was done by using the maximum moisture content (Olesen 1971). According to Olesen (1971) green volume and oven dry weight for each specimen should be determined.

3.6.1.1 Green volume determination

Green volume in cubic centimetres for each specimen was obtained by water displacement method. Before measuring, all specimens were soaked in distilled water until green volume was attained. A beaker of water was then placed on a balance and set to zero reading. Each specimen was then suspended by needle clamped on a stand and lowered into the beaker while being in no contact with the sides or bottom of the beaker. The weight in grams of water displaced was recorded. According to Archimedes principle, the weight in grams of water displaced is equal to the volume in

cubic centimetre of the specimen.

3.6.1.2 Oven dry weight determination

After measuring the green volume, the specimens were then oven dried in the oven at temperature of 102±3 °C until a constant weight was attained. This was followed by cooling the specimen in a descator and reweighed. The weight of each specimen in grams was recorded.

3.6.1.3 Calculations of basic density

Basic density (g/cm^3) was calculated by using the following formula:

$$Bd = \frac{\textbf{oven dry weight}}{\textbf{green volume.}}$$

Where: Bd = basic density.

3.6.2 Strength properties

All test specimens were tested in accordance with Lavers (1969). A Monsato Tensiometer machine was used. Strength values for each specimen at moisture content m were obtained. Calculations for strength properties was done depending on the type

of strength property.

3.6.2.1 Static bending

The specimen were loaded in the machine until it failed to support 1/10 of the maximum load. While the specimen was loaded, the stress/strain deflection curve were plotted. The area under the curve was measured by using a planimeter. From this test modulus of elasticity (MOE), modulus of rupture (MOR), work to maximum load and total work to fracture were determined.

Modulus of elasticity in N/mm^2 of each test specimen was calculated by the following formula:

$$\mathbf{MOE = Fmax*L^3/2*d*h^2}$$

Where: Fmax = maximum load (N).

L = span length equal to 280 mm.

d = actual deflection to the elastic limit (mm).

h = thickness of the specimen equal to 20 mm.

The values obtained were then multiplied by the following factor:

$$\mathbf{MOE = Fmax * 34.3\ N/mm^2}$$

Modulus of rupture in N/mm^2 for each specimen was obtained by the following formula:

$$\mathbf{MOR = 3*Fmax*L/2*U*d\ N/mm^2}$$

Where: Fmax = maximum load (N).

L = span length equal to 280 mm.

U = width of the specimen equal to 20 mm.

d = thickness of the specimen equal to 20 mm.

Then values obtained were multiplied by the following factor:

$$\mathbf{MOR = Fmax*0.0525\ N/mm^2}$$

Work to maximum load (Wmax) for each specimen was obtained by the formula:

$$\mathbf{Wmax = A_1*Q/V\ N/mm^2}$$

Where: A_1 = area under the curve to maximum load (mm^2).

Q = work equivalent to 1 mm on the load deflection curve.

V = volume of the specimen equal to 280*20*20 = (112 000 mm^3).

The following formula were used to calculate total work to fracture (Twork) in N/mm^2 for each specimen:

$$\mathbf{Twork = A_2 * Q/V\ N/mm^2}$$

Where: A_2 = area under the curve to total fracture (mm^2).

Q = work equivalent to 1 mm on the load deflection curve.

V = the volume of the specimen equal to $280*20*20 = 112000\ mm^3$.

All the tests were carried out at room temperature and relative humidity in accordance with Lavers (1969). The specimens were weighed before testing for strength properties and the weight at test was recorded. Then the specimens were allowed to dry to constant weight in oven at a temperature of $102 \pm 3^{\circ}C$. The specimens were re-weighed and oven dry weight for each specimen was recorded. The difference in moisture content (n) at test from 12% for each specimen were calculated and recorded. The moisture content (MC) in percentage of each specimen at test were calculated as follows:

$$\mathbf{MC(\%) = \frac{weight\ at\ test - oven\ dry\ weight}{Oven\ dry\ weight} X\ 100}$$

The strength were then adjusted to 12% moisture content by the formula:

$$Y_{12} = Y_w (1 + z)^n$$

Where Y_{12} = strength value at 12% MC

Y_w = strength value at test

z = constant (0.02, 0.04, -0.01, for MOE, MOR and Wmax respectively)

n = difference in moisture content at test from 12%.

3.6.2.2 Compression parallel to grain

Ultimate compression parallel to grain (COMPRE) in N/mm^2 was calculated by using the formula:

$$\mathbf{COMPRE = Fmax/a.b\ N/mm^2}$$

Where; Fmax = the maximum load (N)

a and b = cross-sectional dimensions (mm)

Compression strength were adjusted to 12% moisture content (MC) by the formula:

$$Y_{12} = Y_w (1 + z)^n$$

Where Y_{12} = compression strength value at 12% MC

Y_w = strength value at test

z = correlation factor equals to -0.01

n = difference in moisture content at test from 12%.

3.6.2.3 Shear parallel to grain

Maximum shear strength parallel to grain in N/mm^2 was calculated by the formula:

$$\textbf{Shear} = \textbf{Fmax/WL}$$

Where: Pmax = breaking load.

W = specimen thickness in mm.

L = length of shearing surface (mm).

Shear strength were then adjusted to 12% moisture content by the formula

$$Y_{12} = Y_w (1 + z)^n$$

where: Y_{12} = Shear strength at 12% MC

Y_w = Shear strength at test.

z = correlation factor (0.02).

n = difference in moisture content at test from 12%.

3.6.2.4 Cleavage

The splitting force was applied to the specimens then maximum load causing failure was measured. The maximum load in N/mm² necessary to split a specimen into two sections at the point of application of load (Cleavage) perpendicular to grain was calculated by the formula:

$$\textbf{Cleavage} = \textbf{Pmax/b N/mm}$$

Where: Pmax = the maximum load (N) and

b = the specimen width (mm).

Cleavage strength value were adjusted to 12% moisture content by the formula:

$$Y_{12} = Y_w(1+Z)^n$$

Where: Y_{12} = the strength value at 12% moisture content.

Y_w = the strength value at test

Z = the correlation factor equal to 0.02

n = the difference in moisture content at test from 12% (Desch 1981).

3.7 Data analysis

3.7.1 Current end uses, tree form, crown size and branching habit.

The quantitative statistics were used. Means and frequencies in percentages of current end uses, tree form, crown size and branching habit were calculated and results presented in form of tables.

3.7.2 Tree character and some physical characteristics

Descriptive method was used in the analysis of tree character and some physical characteristics in accordance with Smith *et al.* (1994).

3.7.3 Basic density

Data analysis for basic density was done by computer using statistical analysis system programme (SAS).

3.7.3.1 Average basic density

Average basic density for the two studied species was determined by use of simple statistical procedures. Means and standard deviations were determined.

3.7.3.2 Variation of basic density

Analysis of Variance (ANOVA) and Duncan grouping were done in the analysis of variations of basic densities between and within tree species. Statistical model for ANOVA were

$$Y_{ij} = r + X_i + e_{ij}$$

Where: Y_{ij} = Basic density at a given tree height or position from pith to bark.

X_i = height or position at which basic density was determined. X_i's are fixed.

r = General effect.

e_{ij} = error term, normally distributed with mean 0, and variance δ^2.

3.7.4 Strength properties

3.7.4.1 Average strength properties

Average strength properties for the two studied species was determined by simple statistical procedure. Mean value of each sample for each studied strength property was determined. Variances and standard deviation were also determined. This was done for high and low altitude zones.

3.7.4.2 Variation of strength properties

Variations of strength properties between and within tree for the two studied species were analyzed by using SAS computer program. The analysis of Variance (ANOVA) and Duncan grouping were done. Statistical model for ANOVA involved were:

$$Y_{ij} = r + X_i + e_{ij}$$

Where: Y_{ij} = strength property at a given tree height or position from pith to bark.

X_I = height or position at which strength property was determined. X_i's are fixed.

r = General effect.

e_{ij} = error term, normally distributed with mean 0, and variance δ^2.

3.7.5 Relationship between basic density and strength properties

Relationship between strength properties and basic density were determined by correlation coefficient analysis. Statistical model for Regression was:

$$Y_i = m + ax_i + e_i$$

Where: Y_i = dependent variable, i.e. strength properties at a given tree height or position from pith to bark.

a = random variables.

x_i = independent variable, i.e. basic density at a given tree height or radial position, X_i's are fixed.

m = general effect.

e_i = error term, normally distributed with mean 0 and variance δ^2 (Johnson and Bhattacharya 1992).

CHAPTER FOUR

4 RESULTS AND DISCUSSION

4.1 Current end uses of *Grevillea robusta* and *Cordia africana*

Table 2 shows the summary of the current end use of two studied species. It can be noted in the table that wood from this two species is mainly used for construction, furniture production and fuelwood although levels of utilization differ between the two species. While construction purposes is the most important use (38%) for *G. robusta*, furniture production ranks high with 42% for *C. africana*. Wood from *G. robusta* is most used for school furniture production and coffin making and that of *C. africana* mostly for home and office furniture production. Compared to the wood of *G. robusta*, wood of *C. africana* was used less in construction. The reasons for this among others might be the limited sizes especially lengths and its properties which appeal much for furniture production. These species have also some other end uses as indicated in the table. These include shade for coffee, fodder, poles and tool handles. They are further used as ornamental or for decoration, utensils and as medicine.

Table 2: Current end uses for *G. robusta* and *C. africana* and their respective percentage.

End uses	Corresponding percentages	
	G. robusta	*C. africana*
Construction	38.0	19.0
Furniture	32.0	42.0
Fuelwood	21.0	12.0
Shade for coffee	4.0	8.0
Fodder	1.0	7.0
Poles	1.0	5.0
Tool handles	1.0	4.0
Decoration/ ornamental	2.0	1.0
Utensils	0.0	1.5
Medicine	0.0	0.5
TOTAL	100.0	100.0

4.2 Tree characteristics and some physical properties

4.2.1 Tree characteristics

Average values for tree characteristics and some physical properties for *Grevillea robusta* and *Cordia africana* are presented in table 3. It is evident from the table that, *C. africana* had large crown both in width and height as compared to *G. robusta*. This means that *C. africana* is more suitable for shade. It was found that *G. robusta* had straight round bole with about 9.5 m in length, while *C. africana* had bole length of about 5.5 m. However, for *C. africana* the straight portion was only 3.4 m of the bole length. The implication is that, timber from *C. africana* is limited by bole length.

4.2.2 Some physical properties

Values of some physical properties for the studied species are summarized in table 3. It is indicated in table 5 that, the percentage of heartwood was 63.8 and 64.5 for *G. robusta* and *C. africana* respectively. There is no any documented work in the literature showing the percentage of heartwood for *G. robusta* and *C. africana* grown in agroforestry systems or in plantations. However the values are within the range reported by Hamza *et al.* (1998) for *Tectona grandis* which were 61.7% and 72% at age 32 and 35 respectively.

Table 3: Values of tree characteristics and some physical properties for *Grevillea robusta* and *Cordia africana*

Characteristics	Species	
	G. robusta	*C. africana*
DBH (cm)	36.6	50.6
Tree height (m)	17.1	14.7
Bole length (m)	9.5	5.5
Crown width (m)	6.0	9.1
Crown height	7.1	9.2
Heartwood percentage	63.8%	64.5%
Bark thickness (mm)	7.6	8.2
Sapwood width (cm)	2.5	3.8
Tree form	straight	straight up to 3.4 m
Grain	straight	straight
Heartwood colour	reddish brown	pinkish red

The heartwood proportion has great influence in terms of density, colour (for decorative work) and probably the woods natural durability (Iddi and Nagoda 1992). Extractives in heartwood influence density and also give wood the distinctive colour and probably durability (Dinwoodie 1981; Zobel and van Buijtenen 1989). Heartwood is also important in timber grading and pricing. Since valuable and durable wood is obtained from heartwood portion, trees with high proportion of heartwood should be selected and used for breeding.

Wood colour is very useful where decoration or appearance is of prime importance. According to Ishengoma and Nagoda (1991), the price of wood does not always depend only on its hardness, or other strength properties but also its colour when used for decorative work. Coloured wood like *Dalbegia melanoxylon*, the red Opepe wood and the green African walnut in different parts of the world are always highly prized due to colour for decorative work (Dinwoodie 1981).

The result has also shown that bark thickness were 7.6 mm and 8.2 mm for *G. robusta* and *C. africana* respectively. *C. africana* found to have thicker bark than *G. robusta*. Thick bark is important in protection of inner delicate parts of the tree such as cambium and conserving water and nutrients. Cambium is very important in translocation of nutrients within a tree. For some species bark can store food that is used during stress period.

4.3 Basic density

4.3.1 Average basic density

Average basic density was found to be 0.481 g/cm^3 and 0.371 g/cm^3 with standard deviation 0.05 and 0.06 for *G. robusta* and *C. africana* respectively. *G. robusta* was found to be more dense than *C. africana* by 23%. The value for *G. robusta* is higher than that reported by Forest Division department (1962) for the same species which

was 0.33 g/cm^3 at age of 16 years. This variation may be due to age difference. Basic density for the two studied species are lower compared to those reported by Bryce (1967) for common hardwood timbers in Tanzania. These include *Olea welwitschii, Afzelia quanzensis, Milicia excelsa, Pterocarpus angolensis* and *Ocotea usambarensis* with basic density of 0.736 g/cm^3, 0.832 g/cm^3, 0.657 g/cm^3, 0.657 g/cm^3 and 0.736 g/cm^3 respectively.

4.3.2 Variation of basic density

4.3.2.1 Variation between the studied species

As already reported, basic density for *G. robusta* and *C. africana* were 0.481 g/cm^3 and 0.371 g/cm^3 respectively. The difference was significant at 99% significance level (Appendix 2).

R-square was found to be 0.49. This indicates that 49% of the total variation in basic density is due to species. Kollman and Cote (1968) reported that, variation in density between tree species is due to genetical differences which results into complex differences in wood structure. Since density is an indicator of wood strength, wood with high density should be selected where strength is required.

4.3.2.2 Variation within a species

Variation between sites

The overall mean basic density values for each species in each site together with duncan grouping are given in Table 4. The result indicated that density of these tree species differs between the two zones. Basic density for *G. robusta* and *C. africana* at low altitude were 0.50 g/cm^3 and 0.39 g/cm^3 respectively, while at high altitude the densities were 0.46 g/cm^3 for *G. robusta and* 0.35 g/cm^3 for *C. africana* respectively. It is evident from the table that basic density was higher at low altitude for both species.

The observed differences in basic density between low altitude and high altitude zones might be caused by differences in growth conditions. As indicated in table 3, usually low altitude zone received low annual rainfall compared to high altitude zone. These results are in agreement with observation by Zobel and van Buijtenen (1989) that growth condition such as climate and soil type may significantly influences the density of the tree. Basic density for the studied species between the two zones is significantly different ($P < 0.05$) (appendices 3a,b).

R-Square for zones obtained for *G. robusta* and *C. africana* were 0.5 and 0.53 respectively. This indicates that the contribution of the difference in zones were 50% and 53% of total variations in basic density for *G. robusta* and *C. africana* respectively.

The results suggest that low rainfall in low altitude zone resulted into low tree growth rate. According to Desch (1981) low growth rate influences the density of wood.

Table 4. Mean basic density for *G. robusta* and *C. africana* at different altitudinal zones.

Species:	Zone	Basic density $g.cm^3$	Duncan grouping
C. africana	LA	0.39	A
	HA	0.35	B
G. robusta	LA	0.50	A
	HA	0.46	B

Means for the same species with the same letter are not significantly different.

LA = Low altitude zone

HA = High altitude zone

Variation between trees

Mean basic densities for each tree for *G. robusta* and *C. africana* are summarized in table 5. The result showed difference in basic density between trees of the same species

at the same zone (table 5). Basic density varied from 0.434 to 0.491 g/cm^3 and from 0.475 to 0.520 g/cm^3 for *G. robusta,* at high altitude and low altitude respectively. Basic density of *C. africana* also varied from 0.327 to 0.375 g/cm^3 at high altitude and from 0.367 to 0.413 g/cm^3 at low altitude. The difference is significant ($p < 0.05$). ANOVA for each tree species are shown in appendices (4 and 5). The findings are similar to those reported by Zobel and van Buijtenen (1989) for *Eucalyptus robusta* where basic density varies from 0.331 to 0.869 g/cm^3 and for 12 stems of *Populus tremuloides* where basic density varies from 0.402 to 0.438 g/cm^3.

This variation in basic density might be due to differences in site quality and /or genetical factor as reported by Zobel and van Buijtenen (1989) that, variation in basic density between trees of the same species is genetically controlled. Hereditary tendencies, physiological and environmental factors also affect the wood structure and therefore basic density.

4.3.2.3 Variation within a stem

Variation in radial direction

The pattern of variation from pith to bark for the two studied species is shown in figure 2a. *G. robusta* density decreases uniformly from the pith to the bark while for *C. africana* the density increases sharply from the pith to the first few growth rings then

Table 5. Variation in basic density between trees for *G. robusta* and *C. africana* in the low and high altitude zones.

Tree	Number	1	2	3	4	5
Zone	Species	Basic density (g/cm^3)				
	Grevillea robusta	0.44	0.43	0.47	0.47	0.49
High altitude	Duncan	C	BC	ABC	AB	A
	Cordia africana	0.36	0.37	0.33	0.34	0.36
	Duncan	A	A	B	B	A
	Grevillea robusta	0.52	0.47	0.50	0.52	0.49
Low altitude	Duncan	A	B	BA	A	BA
	Cordia africana	0.38	0.37	0.41	0.41	0.39
	Duncan	AC	C	A	A	BA

NB: Means for the same species with the same letter are not significantly different

increases slowly reaching a maximum at the middle of the diameter, followed by a slow decrease towards the bark. The patterns are in agreement with type I and type III described by Panshin and de Zeeuw (1980) in chapter two for *G. robusta* and *C. africana* respectively. The trend for *C. africana* is also in agreement with that reported by Zobel and van Buijtenen (1989) for *Liriodendron tulipifera*. Basic density of the species increased rapidly from pith to 25% of radial length followed by slightly increase to about 45% and then decreased slowly to the bark.

The pattern of variation for *Cordia africana* differs from that of *G. robusta*, though they are both ring-porous hardwood. According to Panshin and de Zeeuw (1980), the pattern of variation differs among different species. The pooled mean densities for the radial sample for *G. robusta* varies from 0.415 g/cm^3 to 0.491 g/cm^3. The difference is statistically significant at 99% level of significance (Appendices 4 and 5).

At high altitude, density variation in radial position for *G. robusta* decreases uniformly from the pith to the bark. At low altitude site, density decreases from the pith to the bark in a non-uniform manner.

Radial basic density variation for *C. africana* ranges from 0.268 g/cm^3 to 0.389 g/cm^3. The difference is statistically significant ($p < 0.01$) (appendices 4 and 5). For this species the pattern seemed uniform for low and high altitude. As stated earlier in chapter two there is no single pattern dominant in hardwood variation. The difference

in pattern for the two species is due to differences in genetical constituents.

Axial variation

Axial basic density variation for the two species is shown in figure 2b. It can be seen from figure 2b that, basic density for the two species decreased from breast height i.e. 1.3m reaching minimum value at about 45% of total tree height. From there the density increased with increasing height in the tree reaching maximum value at about 75% of the tree height. The trend is in agreement with result reported by Hamza *et al.* (1998) for *Tectona grandis* of different ages.

Axial variation in basic density for both species were significant ($p < 0.05$) (Appendices 4 and 5). This might be caused by growth condition and/or site characteristics. Panshin and de Zeeuw (1980) found that the density for *Nyassa aquatic* grown on swampy site was very low in the butt log, but increases upward in the trunk. On the other hand, the same species grown on upland site showed the maximum values for density in the base of the trunk. The study of axial variation is important for log grading and log sorting. Since high density wood is found at the butt end and upper part of the bole just below the branches, logs with high density could be cut at the butt and just below the branches.

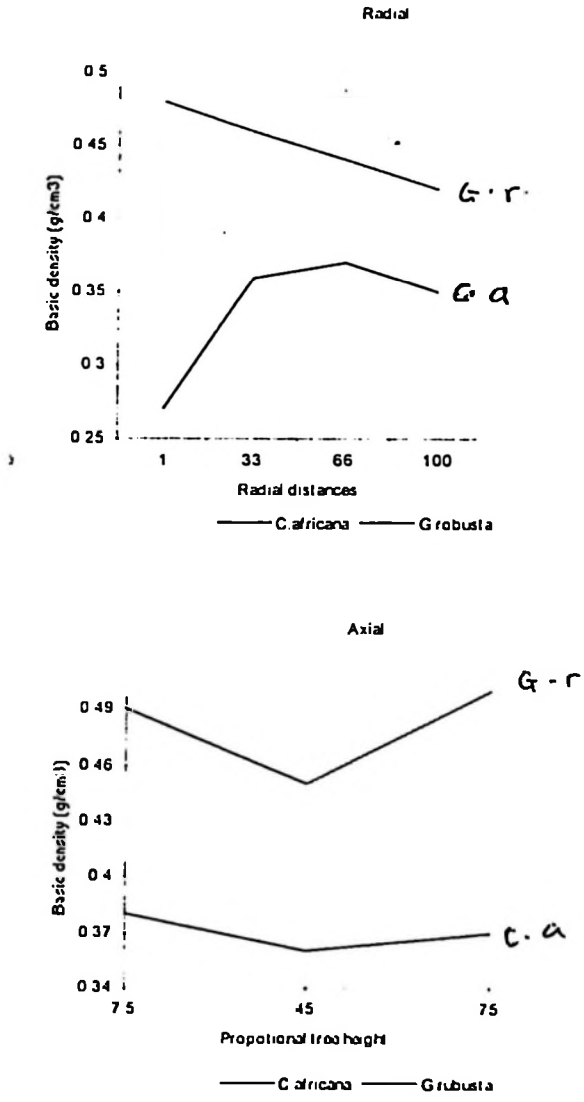

Figure 2. Radial and axial variation in basic density for *Cordia africana* and *Grevillea robusta*

4 .4 Strength properties

4.4.1 Mean values

Mean values for the studied strength properties for each species are presented in table 6a. The studied strength properties values for both species are within the range reported by Kollman and Cote (1968). Some values were in agreement with those reported by Forest Division (1962) for *Olea welwitschii, Afzelia quanzensis* and by Bryce (1967) for *Milicia exelsa, Pterocarpus angolensis* and *Ocotea usambarensis* (table 6b). The observed values in this study were lower for Modulus of Elasticity, Modulus of Rupture, Compression strength, Shear strength and Cleavage for both species. Work to maximum load for *G. robusta* was similar to that of *O. welwitschii, M. exelsa* and *O. usambarensis*. The values for total work for *G.robusta* were also similar to that of *O. usambarensis*. On the other hand *C. africana* showed total work similar to that of *O. welwitschii.*

Compared to the strength properties reported in table 2 for *O. welwitschii, A. quanzensis, M. exelsa, P. angolensis* and *O. usambarensis*, the values for *G. robusta* and *C. africana* in table 8 were generally lower. For example, bending strength of *G. robusta* was found to be 49%, 59%, 46%, 42% and 52% lower than those of *O. welwitschii, A. quanzensis, M. excelsa, P. angolensis* and *O. usambarensis* respectively.

The capacity to store energy before failure (Wmax) of *G. robusta* was found to be equal to that for *M. excelsa* and *O. usambarensis*, but lower than that of *O. welwitschii, A. quanzensis*, and *P. angolensis* by 6%, 47% and 22% respectively. Total work was found to be lower than that of *O. welwitschii, A. quanzensis, M. excelsa* and *P. angolensis* 5%, 46%, 26%, and 56% respectively, but similar to that of *O. usambarensis*. Similarly *G. robusta* has lower crushing strength than the five species by 48%, 56% 9%, 18% and 34% respectively. Shear strength of *G. robusta* was lower than that of *O. welwetschi, A. quanzensis, M. excelsa, P. angolensis, O. usambarensis* by 45%, 56%, 8%, 23% and 22% respectively. Splitting strength of *G. robusta* was also found to follow a similar pattern by 87%, 82%, 75%, 82% and 67% respectively.

Comparison also showed that *C. africana* possesses lower strength properties than the five species except Wmax which was similar to that of *M. excelsa* and *O. usambarensis*. Modulus of Rupture in bending strength of *C. africana* was found to be 49%, 59%, 33%, 41% and 36% lower than those of *O. welwitschii, A. quanzensis, M. excelsa, P. angolensis* and *O. usambarensis* respectively. Also modulus of elasticity (MOE) was found to be 57%, 55%, 46%, 42% and 52% lower than those for *O. welwitschii, A. quanzensis, M. excelsa, P. angolensis* and *O. usambarensis* respectively.

Cordia africana in this study had lower capacity to store energy before failure (Wmax) than *O. welwitschii, A. quanzensis, M. excelsa, P. angolensis* and *O. usambarensis* by 14%, 55%, 14%, 33% and 14% respectively. Similarly its capacity to continue

supporting loads after failure (Twork) was less by 5%, 45%, 33%, 60% and 9% respectively. Crushing strength was lower than *O. welwitschii, A. quanzensis, M. excelsa* and *P. angolensis* by 55%, 61%, 20%, 30% and 42% respectively. Shear strength for *C. african* was lower than that of *O. welwitschii, A. quanzensis, M. excelsa, P. angolensis* and *O. usambarensis* by 52%, 62%, 19%, 33% and 31% respectively, similarly splitting strength of *C. africana* followed a similar pattern. The practical implication of these low strength values for the two species is that, they can not be assigned to end uses where higher strength values are required.

Low strength values for *G. robusta* and *C. africana* are probably attributed to their low density values compared to those for the species presented in table 2 because density positively influences strength properties of wood. Panshin and de Zeeuw (1980), Desch (1981) and Ishengoma and Nagoda (1991) reported that density of the timber is a major factor in determining its strength. By knowing the strength values for these two species, one can utilize wood efficiently. For example where bending strength is needed, wood with high values of MOE and MOR should be selected. *G. robusta* will therefore be preferred to *C. africana*

Table 6a. Summary of mean values for the studied strength properties.

	G. robusta	*C.africana*
MOE(N/mm^2)	4988.0 (1337)	4711.30 (1043)
MOR (N/mm^2)	47.85 (10.05)	47.46 (13.6)
Wmax(mmN/mm^3)	0.069 (0.02)	0.06 (0.03)
Twork(mmN/mm^3)	0.105 (0.04)	0.10 (0.04)
Compre (N/mm^2)	30.800 (6.26)	27.11 (6.36)
Shear (N/mm^2)	8.373 (1.26)	7.34 (1.07)
Cleav (N/mm)	16.289 (3.11)	12.35 (2.69)

Figures in brackets are standard deviations.

Table 6b. Values of some strength properties of *Olea welwitschii, Afzelia quanzensis, Milicia excelsa, Pterocarpus angolensis* and *Ocotea usambarensis*

Property	*Olea welwits*	*Afzelia quanzen*	*Milicia Excelsa*	*Pterocarpus angolensis*	*Ocotea usambaren*
MOR (N/mm^2)	93.36	116.98	70.35	80.69	75.17
MOE (N/mm^2)	11037.10	10615.30	8827.59	8137.93	9931.04
Wmax (mmN/mm^2)	0.07	0.13	0.07	0.09	0.07
Twork (mmN/mm^2)	0.10	0.18	0.15	0.25	0.11
COMP//grain(N/mm^3)	60.32	70.51	34.00	38.97	46.83
SHEAR//grain (N/mm^2)	15.40	19.40	9.10	10.97	10.69
CLEAV (N/m)	100.02	92.16	68.30	91.07	49.04

Source: Bryce (1967).

4.4.2 Variation of strength properties

4.4.2.1 Variation between species

The results of mean values for low and high altitude zones for each species are summarized in Table 7. It is apparent from the table that, the two species showed variation in almost all strength properties. This is confirmed by the subsequent analysis of variance in appendix 6. The study has also shown that *G. robusta* bears higher values for all strength properties studied than *C. africana*. This may be attributed to its high density that positively influences strength properties (Desch 1981).

The difference for Modulus of Elasticity, Modulus of Rupture, Work to maximum load and Total work were not significant, however, Compression, Shear and Cleavage were significant ($p < 0.05$). As indicated in table 8 the mean values for modulus of rupture, work to maximum load and total work for *G. robusta* and *C. africana* were almost similar. This suggest that, the two species can be used for the same purpose if the above strength properties are of importance. Variation in strength properties is very important in selection of wood species for several end uses such as construction and furniture making.

4.4.2.2 Variation within a species

Variation between zones

The mean results for all tested strength properties in each zone are shown in table 7. It is evident from the table that values for strength properties at the low altitude zone for both species are higher than that at high altitude zone. Analysis of variance showed that there is significant difference between the zones for some strength properties except for Modulus of Rupture and Total work (appendix 7a and 7b). Both species showed higher values at low altitude than at high altitude (table 7). The differences are statistically significant ($p < 0.05$). Analysis of variance is presented in appendix 7. The study has also shown that there were significant difference between zones for Modulus of Rupture and Compression for *C. africana*, but no significant difference for shear, Work to maximum load and Total work ($p < 0.05$). Cleavage showed higher value at high altitude. The variation in strength properties between zones should be expected since the same trend has been observed for density that has a direct relationship with strength properties.

Like for basic density, variation in strength properties between zones might be influenced by management practices. Management practices such as silvicultural practise influences the wood quality. Good silvicultural practises normally produce optimum wood quality (Lema 1996). However abnormal silvicultural operations such

Table 7: Strength properties for *G. robusta* and *C. africana* grown at high and low altitude zones.

	G. robusta		*C.africana*	
	Low altitude	high altitude	low altitude	high altitude
MOE (N/mm^2)	5875.9	4100.0	5235.0	4187.6
MOR (N/mm^2)	50.28	45.41	50.75	44.18
Wmax (mmN/mm^3)	0.07	0.06	0.07	0.05
Twork(mmN/mm^3)	0.11	0.10	0.11	0.10
Compre(N/mm^2)	32.98	28.62	28.91	25.31
Shear (N/mm^2)	8.73	8.02	7.59	7.10
Cleav (N/mm)	17.24	15.33	13.03	11.67

as excessive initial spacing, over crowding, excessive application of fertilizers, severe pruning or poor thinning regime will increase the variability of the wood structure and so will strength. Thinning for example, tends to increase ring width in the lower part of the stem, and is associated with a number of wood qualities such as increase in proportion of juvenile wood. Large proportion of juvenile wood in a stem results in reduction of wood density (Klem 1996). In the other hand, increase in rotation age

leads into increase in proportion of mature wood and so do density. Topping, trimming and pruning of the trees are the practices usually done in agroforestry trees for fodder, firewood and poles especially for trees such as *G. robusta* and *C. africana*. Such practices influence the quality of wood as well as tree structure (Zobel and van Buijtenen 1989). Since density has high correlation with strength properties of wood, management practice which affect density will therefore influence the strength properties of wood. It is important to understand that trees of the same species and age may have different strength values due to difference in site quality. This idea is very important in selection for several end uses and for timber grading.

Variation between trees

Average values of studied strength properties of each tree for the two studied species together with Duncan grouping are summarised in tables 8a and 8b. It is evident from the table 8a and 8b that the average strength properties differ between trees of the same species. For example, modulus of elasticity varies from 3589.3 to 4596.1 (N/mm^2) and from 3440.6 to 4528.9 (N/mm^2) for *G. robusta* and *C. africana* respectively. Modulus of Rupture varies from 38.80 to 50.64 for *G. robusta* and 34.65 to 53.18 for *C. africana*. While work to maximum load varies from 0.05 to 0.06 (mmN/mm^3) and from 0.03 to 0.07 (mmN/mm^3), total work varies from 0.09 to 0.12 (mmN/mm^3) and from 0.06 to 0.13 (mmN/mm^3) for *G. robusta* and *C. africana* respectively.

Table 8a. Variation in strength properties between trees of *G.robusta* and Duncan grouping.

	Tree number				
Property	1	2	3	4	5
MOE(N/mm^2)	4596.1	4415.7	4221.3	3679.8	3589.3
Duncan	A	A	A	A	A
MOR(N/mm^2)	50.64	48.76	45.0	43.79	38.80
Duncan	A	BA	BA	BA	B
Wmax(mmN/mm^3)	0.07	0.06	0.06	0.06	0.05
Duncan	A	A	BA	BA	B
Twork(mmN/mm^3)	0.12	0.12	0.103	0.092	0.09
Duncan	A	BA	BAC	BC	C
Comp(N/mm^2)	32.98	30.50	30.28	26.00	23.31
Duncan	A	BA	BA	BC	C
Shear(N/mm^2)	8.68	8.29	8.22	7.63	7.25
Duncan	A	BA	BA	BC	C
Cleav(N/mm^2)	19.99	15.32	15.22	14.86	13.78
Duncan	A	A	A	A	A

For each properties figures with same latter are not significant different.

Table 8b. Variation in strength properties between trees of *C. africana* and Duncan grouping

	Tree number				
Property	1	2	3	4	5
MOE(N/mm^2)	4528.9	4470.5	4256.6	4241.5	3440.6
Duncan	A	A	A	B	B
MOR(N/mm^2)	53.18	49.37	48.33	35.35	34.65
Duncan	A	A	A	B	B
Wmax(mmN/mm^3)	0.07	0.06	0.06	0.05	0.03
Duncan	A	BA	BC	DC	D
Twork(mmN/mm^3)	0.13	0.11	0.10	0.10	0.06
Duncan	A	BA	B	B	C
Comp(N/mm^2)	29.69	28.56	27.62	25.48	15.64
Duncan	A	A	BA	B	C
Shear(N/mm^2)	7.57	7.57	7.02	6.88	6.83
Duncan	A	A	BA	BA	B
Cleav(N/mm^2)	16.33	13.81	13.81	10.87	10.31
Duncan	A	B	B	C	C

For each property figures with same latter are not significant different.

Compression strength, Shear strength and cleavage also showed variation between trees with mean values ranging from 23.31 to 32.98 (N/mm^2) and 15.64 to 29.69 (N/mm^2), from 7.25 to 8.69 (N/mm^2) and 6.83 to 7.57 (N/mm^2), from 19.99 to 13.78 (N/mm) and 10.31 to 16.33 (N/mm) for *G. robusta* and *C. africana* respectively.

With exceptions of Modulus of Elasticity and Cleavage for *G. robusta* all other studied strength properties showed significant difference at 95% level of significance (Appendix 8). These results are in agreement with observation by Zobel and van Buijtenen (1989) that, tree to tree variation is large, and is common for almost tree species. Variation between trees of the same species is mainly genetically controlled (Panshin and de Zeeuw 1980; Zobel and van Buijtenen 1989). Differences in management practices also contribute to variation between trees of the same species (Lema 1996).

4.4.2.3 Variation within a tree

Radial variation

Variation in strength property in the stem from pith to bark for the two studied species is illustrated in figures 3a and b, 4a and b. While figure 3a and b illustrates the trend for radial variation in strength properties for *G. robusta*, figure 4a and b shows the trend for *C. africana*.

The figures indicate that average values of the studied strength properties varied from pith to bark. For *G. robusta* all studied strength properties except cleavage, decreased uniformly from the pith outwards. Cleavage increased from the pith to about 20% of radial length then decreased slowly to 40%, followed by sharp decrease towards the bark.

Cordia africana showed different trends of radial variation of strength properties. Modulus of elasticity, work to maximum load, total work, Compression and shear increased rapidly from the pith to about 20%, then decreased slowly outwards the bark. Modulus of rupture increase rapid from the pith to about 20%, followed by slow increase to 40%, then decreased slowly towards the bark. Cleavage increase rapidly from the pith to about 20%, followed by slow decrease to 60%, then sharp increase to the bark for low altitude and slow decrease outwards to the bark for high altitude. With exception of cleavage, other studied strength properties for the two species followed similar trend as that for basic density, probably because basic density is an indicator for strength properties of wood (Kollman and Cote 1968; Ishengoma and Nagoda 1991).

Cleavage did not follow similar trend as that for other strength properties. These results are similar to observation reported by Zobel and van Buijtenen (1989) that wood density shows no defined relationship with cleavage. Variation in strength properties in radial direction is important in log sawing,lumber sorting and grading.

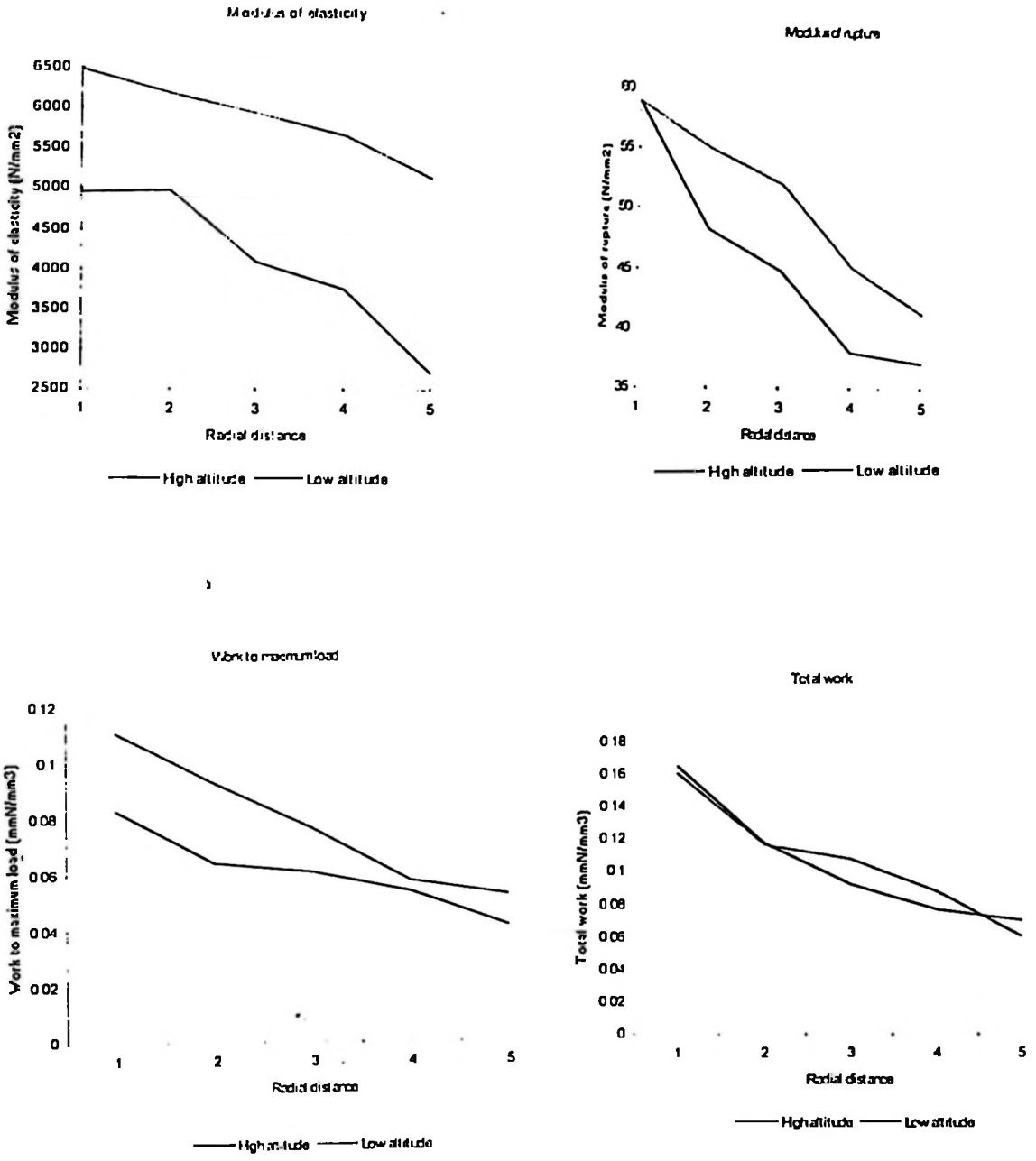

Figure 3a: Radial variation in modulus of elasticity, modulus of rupture, work to maximum load and total work in stems of *Grevillea robusta* for high and low altitudes.

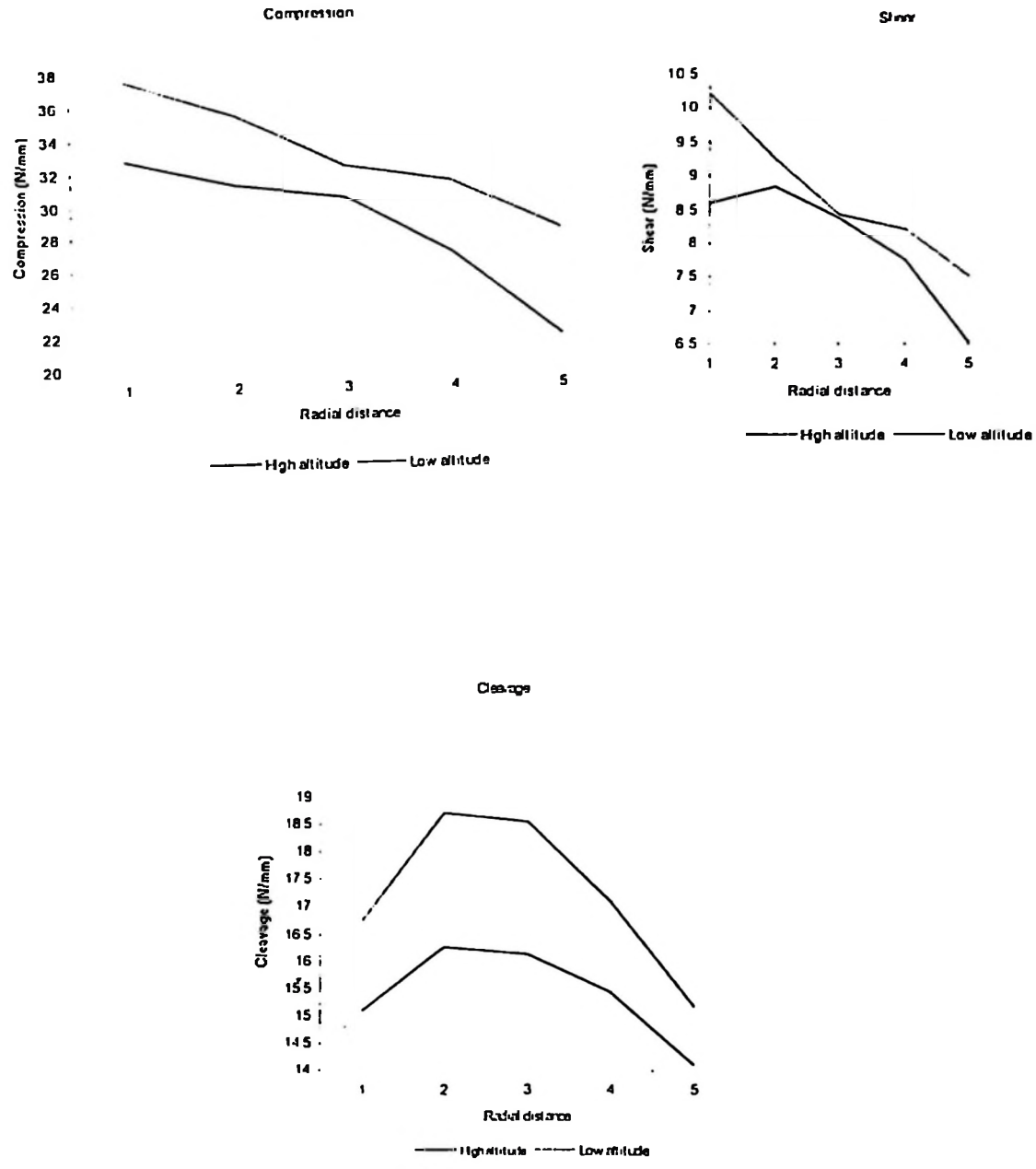

Figure 3b: Radial variation in compression strength, shear strength and cleavage in stems of *Grevillea robusta* for high and low altitudes.

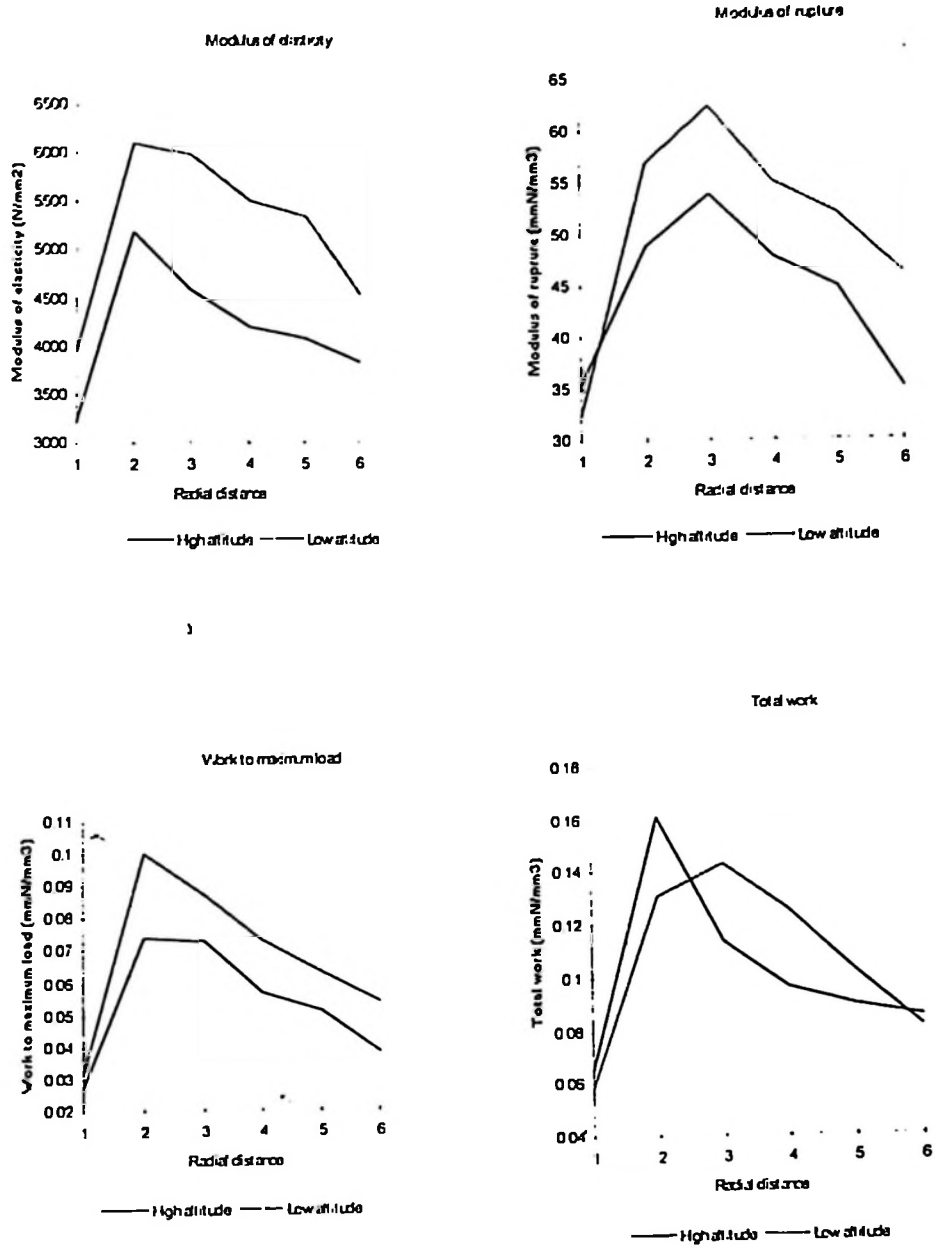

Figure 4a: Radial variation in modulus of elasticity, modulus of rupture, work to maximum load and total work for stems of *Cordia africana* for high and low altitudes.

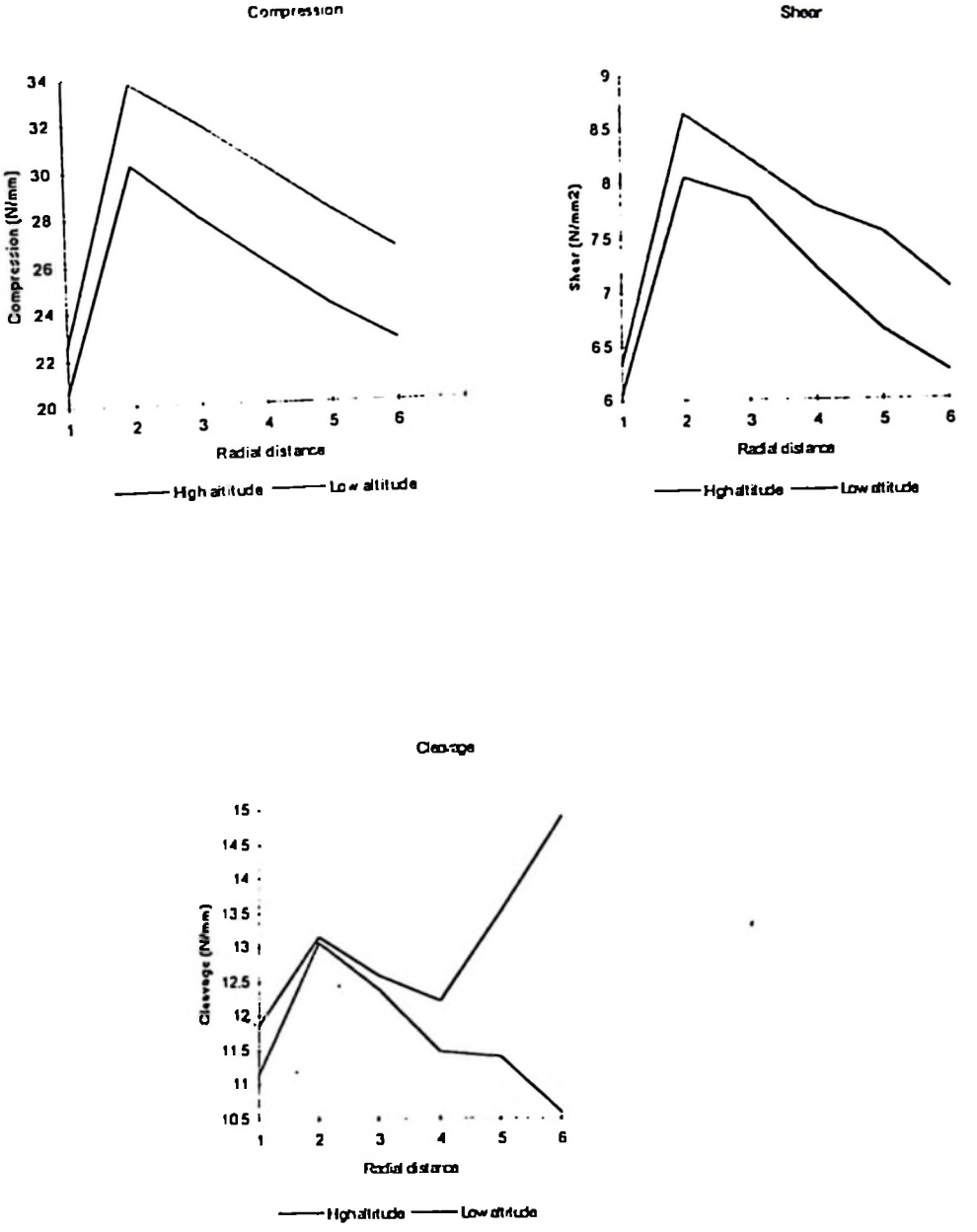

Figure 4b: Radial variation in compression strength, shear strength and cleavage in stems of *Cordia africana* for high and low altitudes.

4.5 Relationship between basic density and studied strength properties

The relationship between basic density and studied strength properties are shown in tables 9 and 10. Positive regression coefficients were found between basic density and strength properties for all studied strength properties for the two species. This indicates that, as density increases strength properties also increase.

Modulus of elasticity for *G. robusta* showed higher correlation with basic density than the other studied properties with correlation coefficient (r^2) of 0.85. This followed by Work to maximum load, Modulus of Rupture, Total work, Shear and Compression with correlation coefficients of 0.72, 0.71, 0.64, 0.56 and 0.55 respectively. The correlation between basic density and cleavage was the least with correlation coefficients of 0.06.

Similarly for *C. africana* Modulus of Elasticity showed higher correlation with basic density than the other properties, with correlation coefficient (r^2) of 0.83. This was followed by Modulus of Rupture, Shear strength, Compression strength, Work to maximum load and Total work with correlation coefficients of 0.71, 0.66, 0.56, 0.35 and 0.35 respectively. The correlation between basic density and Cleavage were the least with correlation coefficients of 0.06.

Table 9: Regression equations and coefficient of correlation (r^2) for relationship between basic density and some strength properties of *G. robusta*.

Strength property (at 12%MC)	Regression (Y = a + bx)	r^2 value
MOE	Y = 15384X - 2411.693	0.85
MOR	Y = 105.128X - 2.718	0.71
Wmax	Y = 0.348X - 0.098	0.72
Twork	Y = 0.159X + 0.024	0.64
COMPRE	Y = 88.583X - 11.809	0.55
SHEAR	Y = 18.271X - 0.415	0.56
CLEAV	Y = 13.699X + 9.699	0.06

y = strength value

a = y-intercept

b = regression coefficient

x = basic density

Table 10: Regression equations and coefficient of correlation (r^2) for relationship between basic density and some strength properties for *C. africana*.

Strength property (at 12%MC)	Regression (y = a + bx)	r^2 value
MOE	MOE = 12844X - 51.593	0.83
MOR	MOR = 145.558X - 6.513	0.71
Wmax	Wmax = 0.340X - 0.066	0.35
Twork	Twork = 0.083X + 0.072	0.35
COMPRE	COMPRE = 54.551X + 7.213	0.56
SHEAR	SHEAR = 12.938X + 2.546	0.66
CLEAV	CLEAV = 9.161X + 8.954	0.06

y = strength value
a = y-intercept
b = regression coefficient
x = basic density

The observed trends in this study are similar to the reported relationship by Zobel and van Buijtenen (1989) for *Eucalyptus spp.* These results indicate that basic density of wood is a reliable indicator of its strength. Therefore one can estimate strength value of the wood by just knowing its density.

CHAPTER FIVE

5 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The study had the following findings:

5.1.1 Current end uses of *G. robusta* and *C. africana*

The current end uses for the two studied species are for construction, for furniture making and as fuelwood. Other uses includes shade for coffee, fodder, poles, tool handles and as amenity along the road side. *C. africana* can also be used as medicine and for making utensils.

5.1.2 Tree characteristics and some physical properties

5.1.2.1 Tree characteristics

A bole of *G. robusta* at age 26 is straight, rounded with dbh of about 36.6 cm. The stem had a mean total height of 17.1 m and bole length of about 9.4 m. The crown of *G. robusta* was a medium size with height and width of about 7.2 m and 6.0 m

respectively.

A bole of *C. africana* at age of between 30 - 35 years is straight from the bottom to about 3.4m. The average dbh of the species is 50.6 cm while mean total tree height is 14.7 m. The bole length is about 5.5m. The stem has large crown size with 9.2m height and 9.1m width.

5.1.2.2 Some physical properties

The heartwood proportion for *G. robusta* and *C. africana* are 63.8% and 64.5% respectively. The heartwood colour is reddish brown for *G. robusta* and pinkish red for *C. africana*. Both species have straight grains, however the rays of *G.robusta* are distinct thus gives it an attractive figure. Wood texture is medium and fine for *G. robusta* and *C. africana* respectively.

5.1.3 Basic density

5.1.3.1 Mean basic density

Mean densities are 0.48 g/cm^3 and 0.37 g/cm^3 for *G. robusta* and *C. africana* respectively. Tree grown on low altitude has higher density than that grown on high altitude. The two studied species have low density and they can be characterized as

light timber species.

5.1.3.2 Variation in basic density

The studied species differ in basic density. Higher altitude zone has low basic density values for both species comepared to low altitude zone. Basic density also varies between trees of the same species. Basic density is higher at the butt, followed by slight decrease in the middle of the stem then increase towards the top for both species.

5.1.4 Strength properties

- Mean MOE in this study are 4988.00 and 4711.3 N/mm^2 for *G. robusta* and *C. africana* respectively.
- Mean MOR for *G. robusta* and *C. africana* are 47.85 and 47.46 N/mm^2 respectively.
- Mean Wmax are 0.07 and 0.06 mmN/mm^3 for *G. robusta* and *C. africana* respectively.
- Mean Twork are 0.11 and 0.10 mmN/mm^3 for *G. robusta* and *C. africana* respectively.
- Mean compression parallel to grain for *G. robusta* and *C. africana* are 30.80 and 27.11 N/mm^2 respectively.

- Mean shear parallel to grain are 8.37 and 7.34 N/mm^2 for *G. robusta* and *C. africana* respectively.
- Mean cleavage perpendicular to grain is 16.29 and 12.35 N/m for *G. robusta* and *C. africana* respectively.

5.1.4.1 Variation in strength properties

With exception of cleavage, all the studied strength properties for *G. robusta* are high near the pith, followed by a uniform decrease outwards toward the bark. For *C. africana* the strength properties were low near the pith, followed by increase for the first few growth rings, then slight decrease outward towards the bark. Cleavage did not show a defined pattern.

5.1.3 Correlation between basic density and strength properties

With exception of cleavage strength properties are positively correlated with basic density, for both species. For *G. robusta* shear strength correlate strongly with basic density, while for *C. africana* MOE has higher correlation. Also correlation between MOE and MOR for the two species is positive.

5.2 Recommendations

The study has the following recommendations : -

- Since *C. africana* tree has large crown size, it is suitable for shade.

- The two species were described as light timber, they can be used for light construction, furniture, utensils, decoration and fuelwood. These species therefore should not be used for heavy construction works.

- At age 26 and between 30 to 35 years for *G. robusta* and *C. africana* respectively, heartwood percentages for both species were high. Further studies should be carried to determine whether the heartwood are durable.

- Trees from low altitudinal zone showed higher basic density and strength properties values for both species, thus high quality timber should be selected from this zone.

- Both species have indicated high basic density values at butt end and the upper part of the trunk, hence saw logs should be selected from these portions.

- *G. robusta* showed high basic density and strength properties near the pith while for *C. africana* high values were found between the pith and the bark. It is suggested that, live sawing should be employed for the former and quarter sawing for the later species.

- Since high density and strong wood is found in lower zone, thus for establishment and further expansion of the two species lower zone should be given first priority.

- The two species were found to have suitable agroforestry characteristics and high quality timber. Therefore, effort should be made to establish more agroforestry land and also to promote and expand the utilization of these species so as to reduce pressure on remaining natural forests.

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APPENDICES

Appendix 1: Questionnaire form

Village name:

Date:

1 **General questionnaires**

1.1 What kinds of house are currently built.

1.2 In what percent wood account as buildings materials.

1.3 Which type of tree species are mostly used for construction.

1.4 Which type of tree species are mostly used for furniture

1.5 Where do this wood come from

- Natural forests
- Plantation
- Village woodlot
- personal farmland

1.6 Are their any timber outside the region used. Why?

If yes, which tree species. .....

1.7 What are the uses of *G. robusta and C africana* tree species

2 **Questionnaires for farmers**

2.1 Name of the tree owners .....

Education .....

2.2 Do you have trees in your farm ? Yes/No

If yes, which species do you plant

1 .....

2.....

3 .....etc.

Where are they planted

- on the farm boundary

- in the farm

- on wood lot etc

2.3 Why do you plant trees

3 Building material information.

3.1 What type of houses do you build?

3.2 What are building materials dominantly used?

(i) Poles

(ii) Timbers

(iii) Others

3.3 Poles or Timbers in (3.2) above, where do you get these materials?

(a) Natural forestry

(b) Farmlands

(c) Plantations

(d) Village woodlot

(e) Others (specify)

3.4. What tree species do you prefer?

3.5. Do you have *G.robusta* or *c.africana* in your farm(s)/plantation(s)?

3.6. What are their main uses:

(a).....

(b).....

(c).....

(d)..... others

3.7 Do you have any problem regarding the planting or use of trees/tree produced from *G.robusta* and *C.africana*? No/Yes.

If yes, outline them

(a).....

(b).....

(c)..... others

4 Questionnaires for pitsawyers

4.1 Which type of two tree species is mostly sawn?

(a).....

(b).....

(c).....

(d)..... others

4.2 Which one between *G.robusta* and *C.africana* is mostly used/utilized ?

4.3 Which size of the two species do you often saw?

(a) 2"x2"

(b) 2"x3"

(c) 2"x4"

(d) 2"x6"

(e) 1"x10"

(f) other(specify)

4.4 From 4.3 above, what are the end uses of the two species?

5 Questionnaires for timber traders.

5.1 Which timber species do you oftenly sell?

5.2 Who supplies you these timbers?

5.3 At what price is each timber species sold?

5.4 Do you have timber from *G.robusta* and *C.africana*? Yes/No.

If yes why?

5.5 If yes in 5.4 above. how do you compare them with others?

(a). sells more (give reasons)

(b). sells less (give reasons)

5.6 What the end uses for *G.robusta* and *C.africana* timber do you know?

(a).....

(b)..... others

6 Forest official workers questionnaires.

6.1 (a) How do people in your area participate in tree planting?

(b) What species do they prefer?

(c) How do your people accept planting *G.robusta* and *C.africana*?

Appendix 2. Anova table for overall basic density showing species variation for *Cordia africana* and *Grevillea robusta*

Source	DF	Anova SS	Mean Square	F Value	Pr > F	Sig level
SPP	1	0.33	0.33	104.43	0.0001	**
Error	108	0.34	0.003			
Total	109	0.67				

R-Square = 0.49

Appendix 3a. Anova table showing basic density variation between sites for *Grevillea robusta.*

Source	DF	Anova SS	Mean Square	F Value	Pr>F	Sig level
SITE	1	0.01	0.01	8.49	0.0054	**
Error	48	0.11	0.002			
Total	49	0.13				

R-Square = 0.50

Appendix 3b. Anova table showing basic density variation between sites for *Cordia africana.*

Source	DF	Anova SS	Mean Square	F Value	Pr > F	Sig level
SITE	1	0.02	0.02	8.89	0.0042	**
Error	58	0.18	0.003			
Total	59	0.21				

R-Square = 0.53

Appendix 4a. Anova table showing variation in basic density between and within trees of the same species for *Grevillea robusta* at high altitude zone.

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F	Sig level
TREENO	4	0.01	0.0026	4.84	0.0094	**
RPOSI	4	0.03	0.0097	17.63	0.0001	**
VPOSI	2	0.03	0.012	6.78	0.0013	**
Error	16	0.008	0.0005			
Total	24	0.05				

R-Square = 0.84

NS = not significant
* = significant at 95% level of significance
** = significant at 99% level of significance
RPOSI = radial position
VPOSI = vertical position

Appendix 4b. Anova table showing variation in basic density between and within trees of the same species for *Grevillea robusta* at low altitude zone.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Sig level
TREENO	4	0.01	0.001	2.35	0.0980	NS
RPOSI	4	0.03	0.008	11.88	0.0001	**
VPOSI	2	0.008	0.004	4.34	0.0142	*
Error	16	0.01	0.0007			
Total	24	0.05				

R-Square = 0.78

Appendix 5a. Anova table showing variation in basic density between and within trees of the same species for *C. africana* at high altitude zone.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Sig level
TREENO	4	0.01	0.003	8.46	0.0004	**
RPOSI	5	0.07	0.015	38.34	0.0001	**
VPOSI	2	0.008	0.004	1.85	0.0159	*
Error	20	0.01	0.0004			
Total	29	0.09				

R-Square = 0.84

Appendix 5b. Anova table showing variation in basic density between and within the trees of the same species for *Cordia africana* at low altitude zone.

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F	Sig level
TREENO	4	0.01	0.002	6.20	0.0021	**
RPOSI	5	0.06	0.013	32.84	0.0001	**
VPOSI	2	0.02	0.013	6.10	0.0026	*
Error	20	0.007	0.0003			
Total	29	0.08				

R-Square = 0.79

NS = not significant
* = significant at 95% level of significance
** = significant at 99% level of significance
RPOSI = radial position
VPOSI = vertical position

Appendix 6. ANOVA table showing variation in strength properties between species

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F	Sig level
Dependent Variable: MOE						
SPP	1	2087278.98	2087278.98	1.49	0.2255	NS
Error	108	151675564.04	1404403.37			
Total	109	153762843.02				
R-Square =		0.013575				
Dependent Variable: MOR						
SPP	1	1.49	1.49	0.01	0.9199	NS
Error	108	15865.49	146.90			
Total	109	15866.99				
R-Square		0.34				
Dependent Variable: WMAX						
SPP	1	0.005	0.005	6.73	0.0108	*
Error	108	0.08	0.0008			
Total	109	0.09				
R-Square		0.05				
Dependent Variable: TWORK						
SPP	1	0.00002	0.00002	0.01	0.9121	NS
Error	108	0.20	0.002			
Total	109	0.20				
R-Square =		0.0001				
Dependent Variable: COMPRE						
SPP	1	371.41	371.41	8.51	0.0043	**
Error	108	4711.37	43.62			
Total	109	5082.78				
R-Square		0 .07				
Dependent Variable: SHEAR						
SPP	1	28.90	28.91	21.52	0.0001	**
Error	108	145.07	1.34			
Total	109	173.97				
R-Square =		0.66				
Dependent Variable: CLEAV						
SPP	1	422.84	422.84	50.55	0.0001	**
Error	108	903.313	8.36			
Total	109	1326.15				
R-Square =		0.31				

NS = not significant
* = significant at 95% level of significance
** = significant at 99% level of significance

Appendix 7a. Summary of ANOVA for some strength properties of *G. robusta* showing variations between sites.

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F	Sig level
Dependent Variable: MOE						
SITE	1	39421410.45	39421410.45	39.33	0.0001	**
Error	48	48109664.69	1002284.68			
Total	49	87531075.14				
R-Square =		0.45				
Dependent Variable: MOR						
SITE	1	315.25	315.25	3.26	0.0771	NS
Error	48	4636.91	96.60			
Total	49	4952.17				
R-Square =		0.63				
Dependent Variable: WMAX						
SITE	1	0.002	0.002	4.71	0.0350	*
Error	48	0.02	0.0005			
Total	49	0.02				
R-Square =		0.48				
Dependent Variable: TWORK						
SITE	1	0.00006	0.00006	0.03	0.8569	NS
Error	48	0.09	0.002			
Total	49	0.09				
R-Square =		0.68				
Dependent Variable: COMPRE						
SITE	1	238.36	238.36	6.81	0.0120	**
Error	48	1679.42	34.98			
Total	49	1917.78				
R-Square =		0.42				
Dependent Variable: SHEAR						
SITE	1	6.34	6.34	4.29	0.0438	*
Error	48	70.99	1.47			
Total	49	77.33				
R-Square =		0.71				
Dependent Variable: CLEAV						
SITE	1	45.39	45.39	5.08	0.0287	*
Error	48	428.52	8.92			
Total	49	473.92				
R-Square =		0.59				

NS = not significant
* = significant at 95% level of significance
** = significant at 99% level of significance

Appendix 7b. Summary of ANOVA for some strength properties of and *C. africana* showing variations between sites and between species.

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F	Sig level
Dendent Variable: MOE						
SITE	1	16455303.39	16455303.39	20.01	0.0001	**
Error	58	47689185.51	822227.34			
Total	59	64147348.90				
R-Square =		0.56				
Dependent Variable: MOR						
SITE	1	609.60	609.60	3.43	0.0691	NS
Error	58	10303.71	177.65			
Total	59	10913.32				
R-Square =		0.56				
Dependent Variable: WMAX						
SITE	1	0.002	0.003	2.97	0.0902	NS
Error	58	0.06	0.009			
Total	59	0.06				
R-Square =		0.48				
Dependent Variable: TWORK						
SITE	1	0.0003	0.0004	0.19	0.6672	NS
Error	58	0.11	0.001			
Total	59	0.11				
R-Square =		0.32				
Dependent Variable: COMPRE						
SITE	1	194.58	194.58	4.34	0.0416	*
Error	58	2599.01	44.81			
Total	59	2793.59				
R-Square =		0.69				
Dependent Variable: SHEAR						
SITE	1	3.66	3.66	3.32	0 .0737	NS
Error	58	64.07	1.10			
Total	59	67.73				
R-Square =		0.54				
Dependent Variable: CLEAV						
SITE	1	27.60	27.60	3.99	0.0506	*
Error	58	401.79	6.92			
Total	59	429.39				
R-Square =		0.64				

NS = not significant
* = significant at 95% level of significance
** = significant at 99% level of significance

Appendix 8a. ANOVA table showing strength properties variation within and between trees of *G. robusta* (high altitude).

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F	Sig level
Dependent Variable: MOE						
TREENO	4	3999728.74	999932.18	1.48	0.2538	NS
SNO	4	17973943.30	4493485.83	6.66	0.0023	*
Error	16	10787641.16	674227.57			
Total	24	32761313.20				
R-Square		0.670720				
Dependent Variable: MOR						
TREENO	4	363.54	90.88	1.94	0.15	NS
SNO	4	1863.68	465.92	9.95	0.0003	*
Error	16	749.52	46.84			
Total	24	2976.75				
R-Square		0.74				
Dependent Variable: WMAX						
TREENO	4	0.001	0.0001	3.41	0.0336	*
SNO	4	0.004	0.001	19.02	0.0001	**
Error	16	0.001	0.00005			
Total	24	0.005				
R-Square		0.84				
Dependent Variable: TWORK						
TREENO	4	0.004	0.0010	3.27	0.0385	*
SNO	4	0.029	0.0074	22.57	0.0001	**
Error	16	0.005	0.0003			
Total	24	0.033				
R-Square		0.861				
Dependent Variable: COMPRE						
TREENO	4	302.22	75.55	5.02	0.0082	*
SNO	4	379.28	94.82	6.30	0.0031	*
Error	16	240.88	15.05			
Total	24	922.40				
R-Square		0.73				
Dependent Variable: SHEAR						
TREENO	4	6.53	1.63	4.53	0.0123	*
SNO	4	16.84	4.21	11.67	0.0001	**
Error	16	5.77	0.35			
Total	24	29.15				
R-Square	=	0.80				
Dependent Variable: CLEAV						
TREENO	4	28.07	7.01	0.80	0.5404	NS
SNO	4	13.21	3.30	0.38	0.8206	NS
Error	16	139.68	8.73			
Total	24	180.97				
R-Square		0.58				

NS = not significant
* = significant at 95% level of significance
** = significant at 99% level of significance

Appendix 8b. ANOVA table showing strength properties variation within and between trees of *G. robusta* (low altitude).

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F	Sig level
Dependent Variable: MOE						
TREENO	4	9514760.943	2378690.246	58.24	0.0001	**
SNO	4	5180073.915	1295018.49	31.71	0.0001	**
Error	16	653516.63	40844.79			
Total	24	15348351.48				
R-Square		0.95				
Dependent Variable: MOR						
TREENO	4	534.97	133.74	13.66	0.0001	**
SNO	4	968.53	242.13	24.73	0.0001	**
Error	16	156.65	9.79			
Total	24	1660.16				
R-Square		0.90				
Dependent Variable: WMAX						
TREENO	4	0.009	0.002	15.66	0.0001	**
SNO	4	0.007	0.001	11.12	0.0002	**
Error	16	0.002	0.0001			
Total	24	0.01				
R-Square		0.87				
Dependent Variable: TWORK						
TREENO	4	0.01	0.003	4.82	0.0096	*
SNO	4	0.02	0.007	9.88	0.0003	*
Error	16	0.01	0.001			
Total	24	0.05				
R-Square		0.78				
Dependent Variable: COMPRE						
TREENO	4	126.60	31.65	2.00	0.1431	NS
SNO	4	377.16	94.29	5.96	0.0039	*
Error	16	253.25	15.82			
Total	24	757.02				
R-Square		0.66				
Dependent Variable: SHEAR						
TREENO	4	9.12	2.28	3.38	0.0347	*
SNO	4	21.93	5.48	8.13	0.0009	**
Error	16	10.78	0.67			
Total	24	41.83				
R-Square		0.74				
Dependent Variable: CLEAV						
TREENO	4	70.17	17.54	2.07	0.1327	NS
SNO	4	41.70	10.42	1.23	0.3376	NS
Error	16	135.67	8.47			
Total	24	247.55				
R-Square		0.45				

NS = not significant
* = significant at 95% level of significance
** = significant at 99% level of significance

Appendix 9a. ANOVA table showing strength properties variation within and between trees of *C. africana* (high altitude).

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F	Sig level
Dependent Variable: MOE						
TREENO	4	4573331.12	1143332.78	6.62	0.0015	*
SNO	5	11172302.05	2234460.41	12.95	0.0001	**
Error	20	3452171.04	172608.55			
Total	29	19197804.21				
R-Square		0.82				
Dependent Variable: MOR						
TREENO	4	1732.63	433.15	10.87	0.0001	**
SNO	5	1457.91	291.58	7.32	0.0005	*
Error	20	797.20	39.86			
Total	29	3987.74				
R-Square		0.80				
Dependent Variable: WMAX						
TREENO	4	0.01	0.001	11.28	0.0001	**
SNO	5	0.01	0.002	11.17	0.0001	**
Error	20	0.003	0.0001			
Total	29	0.02				
R-Square		0.83				
Dependent Variable: TWORK						
TREENO	4	0.01	0.004	15.11	0.0001	**
SNO	5	0.02	0.005	19.19	0.0001	**
Error	20	0.01	0.0002			
Total	29	0.04				
R-Square		0.88				
Dependent Variable: COMPRE						
TREENO	4	759.724	89.93	43.40	0.0001	**
SNO	5	314.052	62.81	14.35	0.0001	**
Error	20	87.52	4.37			
Total	29	1161.29				
R-Square		0.92				
Dependent Variable: SHEAR						
TREENO	4	5.72	1.43	2.71	0.0593	*
SNO	5	23.73	4.74	9.00	0.0001	**
Error	20	10.55	0.52			
Total	29	40.01				
R-Square		0.73				
Dependent Variable: CLEAV						
TREENO	4	145.21	36.30	9.89	0.0001	**
SNO	5	29.53	5.90	1.61	0.2031	*
Error	20	73.37	3.66			
Total	29	248.12				
R-Square		0.70				

NS = not significant
* = significant at 95% level of significance
** = significant at 99% level of significance

Appendix 9b. ANOVA table showing strength properties variation within and between trees of *C. africana* (low altitude).

Source	DF	Sum of Squares	Mean Square	F Value	P>F	Sig level
Dependent Variable: MOE						
TREENO	4	4204036.04	1051009.01	3.17	0.036	*
SNO	5	17647623.54	3529524.71	10.63	0.0001	**
Error	20	6639721.72	331986.09			
Total	29	28491381.30				
R-Square		0.77				
Dependent Variable: MOR						
TREENO	4	1552.223	388.05	3.87	0.0173	*
SNO	5	2759.73	551.94	5.51	0.0024	*
Error	20	2004.01	100.20			
Total	29	6315.97				
R-Square		0.68				
Dependent Variable: WMAX						
TREENO	4	0.01	0.003	6.29	0.0019	*
SNO	5	0.01	0.003	5.74	0.0019	*
Error	20	0.01	0.001			
Total	29	0.04				
R-Square		0.73				
Dependent Variable: TWORK						
TREENO	4	0.02	0.005	8.34	0.0004	*
SNO	5	0.03	0.005	7.44	0.0004	*
Error	20	0.02	0.001			
Total	29	0.06				
R-Square		0.78				
Dependent Variable: COMPRE						
TREENO	4	930.60	232.65	45.90	0.0001	**
SNO	5	405.74	81.14	16.01	0.0001	**
Error	20	101.36	5.07			
Total	29	1437.71				
R-Square		0.92				
Dependent Variable: SHEAR						
TREENO	4	1.12	0.28	1.00	0.4306	NS
SNO	5	17.36	3.47	12.44	0.0001	**
Error	20	5.58	0.27			
Total	29	24.06				
R-Square		0.76				
Dependent Variable: CLEAV						
TREENO	4	58.55	14.64	3.91	0.0167	*
SNO	5	20.27	4.05	1.08	0.3994	NS
Error	20	74.83	3.74			
Total	29	153.66				
R-Square		0.51				

NS = not significant
* = significant at 95% level of significance
** = significant at 99% level of significance

Appendix 10a. Correlation analysis between wood properties for *G. robusta*.

8 'VAR' Variables: BD COMPRE SHEAR CLEAV MOE MOR WMAX TWORK

Simple Statistics

Variable	N	Mean	Std Dev	Sum
BD	50	0.48	0.05	24.04
COMPRE	50	30.79	6.25	1540.00
SHEAR	50	8.37	1.25	418.65
CLEAV	50	16.28	3.10	814.46
MOE	50	4988.00	1337.00	249398.00
MOR	50	47.33	10.05	2367.00
WMAX	50	0.04	0.02	2.34
TWORK	50	0.10	0.04	5.25

Variable	Minimum	Maximum
BD	0.33	0.64
COMPRE	10.07	51.93
SHEAR	4.52	12.20
CLEAV	9.35	27.27
MOE	1020	7585
MOR	23.88	69.25
WMAX	0.01	0.13
TWORK	0.03	0.21

appendix 10a continued

	BD	COMPRE	SHEAR	CLEAV
BD	1.00	0.73	0.75	0.22
	0.00	0.0001	0.0001	0.10
COMPRE	0.73	1.00	0.85	0.29
	0.0001	0.00	0.0001	0.04
SHEAR	0.75	0.85	1.00	0.41
	0.0001	0.0001	0.00	0.003
CLEAV	0.23	0.29	0.41	1.00
	0.11	0.04	0.003	0.00
MOE	0.59	0.60	0.67	0.37
	0.0001	0.0001	0.0001	0.007
MOR	0.58	0.56	0.65	0.31
	0.0001	0.0001	0.0001	0.03
WMAX	0.62	0.66	0.68	0.41
	0.0001	0.0001	0.0001	0.0024
TWORK	0.61	0.46	0.49	0.07
	0.0001	0.0008	0.0003	0.61

	MOE	MOR	WMAX	TWORK
BD	0.58	0.58	0.62	0.60
	0.0001	0.0001	0.0001	0.0001
COMPRE	0.61	0.56	0.66	0.46
	0.0001	0.0001	0.0001	0.0008
SHEAR	0.67321	0.65829	0.68	0.49
	0.0001	0.0001	0.0001	0.0003
CLEAV	0.37	0.30	0.41	0.07
	0.0077	0.0290	0.002	0.61
MOE	1.00	0.73	0.55	0.44
	0.00	0.0001	0.0001	0.001
MOR	0.72	1.00	0.73	0.73
	0.0001	0.00	0.0001	0.0001
WMAX	0.55	0.73	1.00	0.67
	0.0001	0.0001	0.0	0.0001
TWORK	0.44	0.73	0.67	1.00
	0.0012	0.0001	0.0001	0.0

Appendix 10b. Correlation analysis between wood properties for *C. africana.*

8 'VAR' Variables: BD COMPRE SHEAR CLEAV MOE MOR WMAX TWORK

Simple Statistics

Variable	N	Mean	Std Dev	Sum
BD	60	0.37084	0.05963	22.25050
COMPRE	60	27.44283	6.35789	1647
SHEAR	60	7.34350	1.07149	440.61000
CLEAV	60	12.35167	2.69777	741.10000
MOE	60	4711	1043	282679
MOR	60	47.56450	13.60043	2854
WMAX	60	0.06101	0.03184	3.66080
TWORK	60	0.10409	0.04370	6.24510

Variable	Minimum	Maximum
BD	0.20930	0.49360
COMPRE	11.82000	43.22000
SHEAR	5.08000	9.54000
CLEAV	7.86000	18.10000
MOE	3005	7092
MOR	18.46000	89.62000
WMAX	0.00670	0.18160
TWORK	0.01160	0.24470

appendix 10b continued

	BD	COMPRE	SHEAR	CLEAV
BD	1.00	0.51	0.72	0.20
	0.0	0.0001	0.00	0.12
COMPRE	0.51	1.00	0.44	-0.13
	0.00	0.0	0.0004	0.31
SHEAR	0.72	0.44	1.00	0.07
	0.0001	0.0004	0.0	0.58
CLEAV	0.20	-0.13	0.07	1.00
	0.12	0.31	0.58	0.0
MOE	0.73	0.48	0.74	0.07
	0.0001	0.0001	0.0001	0.58
MOR	0.63	0.42	0.59	0.28
	0.0001	0.0008	0.0001	0.02
WMAX	0.62	0.40	0.52	0.24
	0.0001	0.0014	0.0001	0.0628
TWORK	0.59	0.50	0.69	0.25
	0.0001	0.0001	0.0001	0.0475

	MOE	MOR	WMAX	TWORK
BD	0.73	0.63	0.62	0.59
	0.0001	0.0001	0.0001	0.0001
COMPRE	0.48	0.42	0.40	0.50
	0.0001	0.0008	0.0014	0.0001
SHEAR	0.74	0.59	0.52	0.69
	0.0001	0.0001	0.0001	0.0001
CLEAV	0.07	0.28	0.24	0.25
	0.58	0.02	0.06	0.04
MOE	1.00	0.67	0.67	0.57
	0.0	0.0001	0.0001	0.0001
MOR	0.67	1.00	0.78	0.68
	0.0001	0.0	0.0001	0.0001
WMAX	0.67	0.78	1.00	0.65
	0.0001	0.0001	0.0	0.0001
TWORK	0.57	0.68	0.65	1.00
	0.0001	0.0001	0.0001	0.0