PHYSICAL AND MECHANICAL PROPERTIES OF SELECTEDHYBRID EUCALYPTS GROWN IN UGANDA

HAROLD TURINAWE BAMWOYA

2007/HD07/8931U

A DISSERTATION SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE DEGREE IN FORESTRY OF MAKERERE UNIVERSITY

JUNE 2011

DECLARATION

I Harold Turinawe, hereby declare that the work in this report is original and of my own effort, where references have been made authors have been duly acknowledged. I declare that this work has never been submitted to any higher institution of learning for academic credit.

Signed.. Date 08/07/2011

Harold B. Turinawe

This special project has been submitted to school of graduate studies Makerere University with approval from the university supervisors.

Signed.. Date 08/07/2011

Dr. Paul Mugabi

Department of forestry, Biodiversity and Tourism

Signed.. Date..........................

Associate Professor MnasonTweheyo

Department of forestry, Biodiversity and Tourism

DEDICATION

This work is dedicated to the almighty God who givesme life;

My parents who brought me into this world;

and

My friends and relatives who added meaning to my life.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to all those who made it possible to complete this thesis. I would like to register my appreciation to the Director National Forestry Resources Research Institute (NaFORRI) Mr. J.F.O.Esegu and the senior research staff at the institute who allowed me unlimited access to research plots and the institute data on colonal forestry.

I thank the UK Government's Department for International Development (DfID) for extending research support through Development Partnerships in Higher Education (DelPHE). I am particularly indebted to Professor Joseph Obua through whom I accessed partial funding from DelPHE. I am grateful for the support from the Sawlog Production Grant Scheme (SPGS) that bridged the funding gap for the success of this study.

I am deeply indebted to my supervisors Dr. Paul Mugabi and Professor Mnason Tweheyo from the Faculty of Forestry and Nature Conservation, Makerere University whose stimulating suggestions and encouragement guided me during research and writing up of this thesis.

My former colleagues at the university supported me in my research work. I am especially obliged to thank Moreen Uwimbabazi, Leo Twinomuhangi, Concy Acen Oulanya and Martin Bogere for all their support, interest and valuable comments. Special thanks to all technicians and scientists who assisted me during sample collection, preparation and setting up of experiments. Messr's Katongole (Department of Animal Science), Basoga and Akope (NaFORRI), Nakimesi and Sseremba (Forest Products Engineering) and Matovu (KAVA International) deserve specific mention.

I am especially indebted to my parents John and Evas Bamwoya who have always been there to offer support, comfort and prayers and have always been there to celebrate every moment of my life. I further thank my friend Hon. David Bahati for his support, encouragement and ever presence when needed. Finally, I would like to give my special thanks to my friend and wife Laura whose unequalled support and encouragement enabled me to complete this work and tothe almighty God from whom all blessings flow.

TABLE OF CONTENTS

DECLARATION ii
DEDICATION iii
ACKNOWLEDGEMENTS iv
TABLE OF CONTENTS v
LIST OF TABLES vii
LIST OF FIGURES vii
ABSTRACT viii
CHAPTER ONE: INTRODUCTION 1
1.1 Background to the study 1
1.2 Statement of the Problem 3
1.3 General objective 3
1.3.1 Specific Objectives 3
1.4 Research questions 4
1.5 Hypotheses 5
1.6 Justification 5
CHAPTER TWO: LITERATURE REVIEW 7
2.1 Wood properties 7
2.1.1 Introduction 7
2.1.2 Physical Properties of wood 8
2.1.3 Mechanical Properties 13
2.2. Wood properties and current uses of parent materials for the study clones 17
2.2.1 *E. grandis* 18
2.2.2 E. camaldulensis 19
2.2.3 E. urophylla 19
CHAPTER THREE: MATERIALS AND METHODS 21
3.1. Selection of sample trees 21
3.2. Location and characteristics of agro-ecological zones (AEZ) sampled 21
3.3. Preparation of test pieces 22
3.4. Laboratory procedures 24
3.5. Comparison of wood properties for clonal eucalypts and parent material 30
3.6. Data Analysis 30
CHAPTER FOUR: RESULTS 32
4.1 Overall means and tolerance intervals of properties 32

4.2 Variations in wood properties 33
4.2.1 Variation due to growing site 33
4.2.2 Variation in properties a long tree height 34
4.2.3 Variation in properties across the stem 35
4.3 Comparison of wood properties of clones and parent materials 38
CHAPTER FIVE: DISCUSSION 42
5.1. Variation in properties 42
5.2. Comparison of properties and prediction of potential end use of clonal timber 43
CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS 46
6.1 Conclusions 46
6.2 Recommendations 47
REFERENCES 48

LIST OF TABLES

Table 3.1: The dimensions for specimen used for property assessment 24
Table 4.1: Overall mean properties of clonal eucalypts 32
Table 4.2: Two-sided tolerance interval for the test clone for each test property 33
Table 4.3: Comparison of wood properties of clones with properties of parent materials at utilisable age (Mean values) 40
Table 4.4: Comparison of wood properties of clones with properties parent materials at utilisable age (tolerance interval values) 41

LIST OF FIGURES

Figure 3.1: Scheme used to obtain samples for the study 23
Figure 3.2: Set up for the three point bending test (BS 373: 1957) 27
Figure 3.3 Set Up for compression strength parallel to the grain test (BS 373: 1957) 28
Figure 3.4: The loading set up for shear stress parallel to the grain (BS 373: 1957) 29
Figure 3.5: Loading set up for cleavage resistance parallel to the grain (BS 373: 1957) 30
Figure 4.1: Influence of growing site on BD, MSS, CLR, MOE, MOR and Wmax 36
Figure 4.2: Variation of BD, MCS, MSS, CLR, MOE and MOR along tree height 37
Figure 4.3: Variation of MCS, MSS, MOE and MOR across stem 38

ABSTRACT

This study was aimed primarily at providing information on physical and mechanical properties of selected eucalypts clones GU7, GU8, GC540, GC550 and GC796; assess the variations of these properties across growing sites, along tree height and from pith to bark; and compare these properties with those of their parent materials; i.e. *Eucalyptus grandis, Eucalyptus cammaldulensis,* and *Eucalyptus urophylla.* The physical properties assessed were basic density (BD) and calorific value (CV) while the mechanical properties included static bending strength (MOE, MOR, Wmax), maximum compressive strength parallel to the grain (MCS), ultimate shear strength parallel to the grain (MSS) and cleavage strength (CLR). The test samples were collected between December 2008 and March 2009 from clonal trials in Kifu and Ikulwe located in Lake Victoria Crescent and South and Eastern Lake Kyoga Basin Agro ecological zones (AEZ), respectively. Five well-formed trees were selected for each clone per site, felled and sectioned into three billets of 1.2m long obtained at breast height (1.3m), 45% and 75% of the merchantable tree height. The test samples were seasoned to 28 % MC and machined to the final size of 800 x 20 x 20 mm from which the test pieces were obtained. Test methods were adopted from British Standard (BS 373:1957) for all properties except for calorific value test where standard test methods for analysis of wood fuels according to the American Society for Testing and Materials [ASTM E870-82(2006)] were used. Results showed that clones GC540 and GU7 had higher mean values for basic density, CLR and CV which are the basic properties for structural timber and fuel wood production. GC540 and GC796 had higher values for MCS, MOR and CRL compared to other clones tested and parent materials indicating a potential for use as structural timber and poles with good workability especially with joints. However, MOE values of all clones tested was lower than that of parent materials. The site × property relationship was significant for properties BD, MSS, CRL, MOE, MOR and Wmax and this was most expressed in clones GC540 and GC796. Position along the tree × property relationship was significant for BD and MCS and was more pronounced in GU7 and GU8 clones. MCS, MSS, MOE and MOR varied significantly in radial direction while BD and CV did not. It was concluded that, clonal eucalypts wood at 6-7 years can be used for fuel wood, furniture, posts, and poles while for construction and other structural uses, advice of registered structural engineers should be sought. It is recommended that a wider study of wood properties including microfibril angle, fibre length, kappa number and chemical properties be carried out on all clones from all agro ecological zones and at higher rotations so as to fully assess the suitability of clones.

LIST OF ACRONYMS AND ABBREVIATIONS

AEZ	:	Agro Ecological Zone
ASTM	:	American Society for Testing and Materials
BD	:	Basic Density
BS	:	British Standards
CLR	:	Cleavage resistance
DBH	:	Diameter at Breast Height
EMC	:	Equilibrium moisture content
FSSD	:	Forest Sector Support Department
GC	:	*Grandis* x *Camaldulensis*
GU	:	*Grandis* x *Urophylla*
MC	:	Moisture Content
MCS	:	Maximum compression strength parallel to the grain
MOE	:	Moment of Elasticity
MOR	:	Moment of Rapture
MSS	:	Maximum shear stress parallel to the grain
NaFORRI	:	National Forestry Resources Research Institute
NFA	:	National Forestry Authority
SPGS	:	Saw log Production Grant Scheme
TBP-U	:	Tree Biotechnology Project-Uganda
USDA	:	Unites States Department of Agriculture
Wmax	:	Work to maximum load
PROTA	:	Plant Resources of Tropical Africa
PROSEA	:	Plant Resources of South East Asia

CHAPTER ONE

INTRODUCTION

1.1 Background to the study

Eucalyptus species are widely planted throughout the tropics and semi-tropics because of their rapid growth and ability to adapt to different climates (Kauman *et al.,* 1995). They originated from Australia and were introduced to Uganda from South Africa in 1912 for fuel wood, poles and posts. Currently *Eucalyptus* species dominate private forest plantations in Uganda, some of the most common being *E. camaldulensis. E. grandis* and *E. Saligina* (SPGS, 2007; Ruyooka, 1999).

Until recently, *Eucalyptus* species have been used locally for poles, posts and fuel wood and to a lesser extent for timber. *Eucalyptus* species are increasingly being used for sawn timber in response to Uganda's growing construction industry and the associated high demand for timber. In addition, the natural forest timber resources are dwindling (Kityo and Plumptre, 1997) and plantations are, therefore, poised to become a major source of sawn timber in the foreseeable future (SPGS, 2008). A supply gap of saw logs after the year 2010 was predicted by Tugumisirize (2001) and this partly prompted the Sawlog Production Grant Scheme (SPGS), National Forestry Authority (NFA), Forest Sector Support Division (FSSD) and the civil society in Uganda to promote the fast growing and well-formed clonal eucalypts.

Clonal eucalypts were introduced in Uganda in 2002 by the National Forest Resources Research Institute (NaFORRI) from Mondi owned forest plantations in South Africa under the Tree Biotechnology Project-Uganda. The project was aimed at introducing, testing, and demonstrating clonal forestry and producing suitable clones for public utilisation. Thirteen trials were made in the main agro-ecological zones of Uganda in 2002 and 2003 on 12clonal eucalypts including 5 hybrids of *Grandis* ×*Urophylla* (GUs), 6 hybrids of *Grandis*×*Camaldulensis* (GCs) and one pure *E. Grandis* hybrid (Epila-Otara, 2004). The silvicultural assessment results from the trials by NaFORRI were good, with some of the clones showing very good growth rates. For example, all the clones attained basal diameter of marketable class 1 poles (> 7 cm) at 15 months (Epila-Otara, 2004). On this basis, at least 800,000 plantlets were released to commercial growers by the end of 2009 (Gatsby Trust, 2009). It was envisaged that their fast growth rate could meet the future wood demand in a shorter time compared to the conventional tree varieties (Oballa *et al.*, 2005). At the time of introduction, it was estimated that a 4-6 year old stand of clonal eucalypts would provide building and transmission poles while a rotation of 7-8 years would be adequate for the trees to be harvested for timber (SPGS, 2007; Epila-Otara, 2004).

At the time of this study, continuous assessment and monitoring of clone performance by NaFORRI was still on-going in the established sites. The performance assessment parameters considered include volume, height, diameter at breast height (DBH) and root collar diameter. Preliminary assessment results showed that GC796, GC550 and GC540 had the best performance countrywide while GU7 and GU8 performed better in the Lake Victoria crescent, Lake Albert crescent and Southern and Eastern Lake Kyoga Basin agro ecological zones (Epila-Otara and Ndhokero, 2009). Due to the already high demand for planting material, the preliminary first rotation trial results have been used as the basis to recommend particular clones for different agro-ecological zones.

The results and recommendations of this study will guide stakeholders and other partners on large-scale promotion of clonal eucalypts. Further, the results will strengthen embracing of clonal trees for superior growth rate and form and will maximize the current gains by screening the best clones for different sites and end uses.

1.2 Statement of the Problem

The problem addressed by this study is the information gap on wood properties of the clonal eucalypts grown in Uganda. Several studies aimed at characterising Uganda's timber for end use based on critical wood properties have focussed to a large extent on indigenous and *Pinus* species (Zziwa *et al.*, 2006; Mugabi *et al.*, 2005; Odokonyero, 1998). However, limited work has been carried out on the properties of clonal eucalypts yet they are being promoted for commercial plantation development for sawlog production. The fact that clonal eucalypts were initially developed in South Africa for superior growth and pulping characteristics and were introduced by NaFORRI mainly for fire wood and poles (Epila-Otara, 2004) strengthens the need to carry out studies on their wood properties to ascertain their suitable uses in the Ugandan context.

1.3 General objective

To investigate selected physical and mechanical properties of selected clonal eucalypts grown in Lake Victoria Crescent and Southern and Eastern Lake Kyoga Basin agro ecological zones (AEZ).

1.3.1 Specific Objectives

i) To assess basic density (BD) and calorific value (CV) of selected clonal eucalypts.

ii) To assess static bending strength (MOE, MOR, Wmax), maximum compressive strength parallel to the grain (MCS), ultimate shear strength parallel to the grain (MSS) and cleavage strength (CLR).

iii) Determine the influence of growing site, height and girth on the selected physical and mechanical properties

iv) To compare properties of clonal eucalypts from this study with properties of parent material established from literature.

1.4 Research questions

i) What are the basic densities and calorific values for GU7, GU8, GC540, GC550 and GC796 clonal eucalypts?

ii) What are the values for compression strength parallel to the grain for the selected clonal eucalypts?

iii) What are the cleavage resistance values parallel to the grain for the selected clones?

iv) What are the values for shear strength parallel to the grain for these clones?

v) What are the mean values for bending strength parameters (MOE, MOR and Wmax) for the clones?

vi) How does growing site and within tree attributes such as girth and height influence mechanical and physical properties of clones?

vii) How do properties of clones compare with those of parent materials; *E.grandis, E. cammaldulensis,* and *E. urophylla*?

1.5 Hypotheses

i) There is no difference in BD, CV, MCS, MSS, MOE, MOR and Wmax for eucalyptus hybrids GU7, GU8, GC540, GC550 and GC796 between samples from Kifu and Ikulwe trials.

ii) There is no difference in BD, CV, MCS, MSS, MOE, MOR and Wmax for eucalyptus hybrids GU7, GU8, GC540, GC550 and GC796 along bole height.

iii) There is no difference in BD, CV, MCS, MSS, MOE, MOR and Wmax for eucalyptus hybrids GU7, GU8, GC540, GC550 and GC796 across the stem.

1.6 Justification

The strength properties of wood define its performance under load (Loung, 2004). The strength properties of wood reflect its fitness and ability to resist applied external forces which tend to alter its size, shape or deform it in any manner (Dinwoodie, 2000; Ishengoma, 1986). Ishengoma and Nagoda (1991) reported that the results of strength properties tests can be widely applied in the selection of wood as a construction material. According to Kityo and Plumptre (1997), selection of timber for structural purposes should be based on 'jobs for timber approach' a process which involves matching timber properties with the end uses cognizant of structural design requirements. Therefore, large scale promotion and adoption of clonal eucalypts especially for sawlog production would largely depend on empirical information on their wood properties not withstanding their high growth and yield per unit.

It is envisaged that knowledge of mechanical and physical properties of these eucalypts hybrids will guide decision making on large-scale promotion and commercialisation of the clonal eucalypts, provide firm recommendations on end uses of clonal eucalypts wood and contribute towards efficient utilization of plantation forestry in Uganda.

CHAPTER TWO

LITERATURE REVIEW

2.1 Wood properties

2.1.1 Introduction

Wood properties include all wood characteristics that determine its quality and also affect the serviceability of its end products. The properties are usually categorized as physical, mechanical i.e. strength related and machining properties (Desch and Dinwoodie, 1996). Choice and suitability of timber for particular tasks is an output of appropriately matching wood properties with task requirements.

The properties of wood vary both within and between species. This is because wood is a natural material and trees are subjected to constantly changing conditions such as moisture and growing space (FPL, 1999). The properties also vary in the different fibre orientations i.e. radial, tangential and longitudinal and it is for this very reason that strength properties of wood are usually referred to as "parallel to the grain" or "perpendicular to the grain" in structural design (Ishengoma and Nagoda, 1991). Three orders of structural variation have been recognised in wood as macroscopic, microscopic and ultra-scopic, and have all been observed to have a bearing on mechanical and physical properties of wood (Dinwoodie, 2000). Due to this variation in properties of wood, timber cannot be manufactured to a particular specification like some other materials used in construction. Instead the best has to be made of the material already produced naturally through selection (Dinwoodie, 2000). Despite this fact, the ubiquitous material, wood has been used for protection against wind, rain and cold throughout history (Thelandersson, 2003).

2.1.2 Physical Properties of wood

Physical properties of wood are characteristics associated with its nature that determine the quality of wood and influence its behavior in service (Thelandersson, 2003; FPL, 2000; Desch and Dinwoodie, 1996). They influence other wood properties such as strength, durability and resistance to fungal attack. The principle physical properties of wood that influence choice of wood for task and the consequential general performance in service include appearance, density and MC (Desch and Dinwoodie, 1996). Other properties such as thermal, electric, coefficient of friction and nuclear radiation are of secondary importance in general timber applications but important in specialized areas (FPL, 2000).

The versatility of wood is demonstrated by a wide variety of its products and is a result of a spectrum of desirable physical characteristics of many species of wood. For example, to select a wood species for a product, the value of appearance-type properties, such as texture, grain pattern, or color, may be evaluated against the influence of characteristics such as machinability, dimensional stability, or decay resistance (FPL, 2000). Some of the physical properties of wood include the following:

a) Appearance of wood

A lot of timber is used to make products such as furniture, wall panelling and certain sports goods on the basis of its aesthetic appeal only. The decorative appearance of many timbers is due to texture, figure, colour and lustre of wood or the combination of all four of these characteristics (Desch and Dinwoodie, 1996). The texture of wood depends on the size of the cells and or their arrangement. Wood can be referred to as fine textured, or coarse textured, even textured and uneven. Figure is defined as the ‘ornamental markings seen on the cut surface of timber, formed by the structural features of the wood (FPL, 2000). The four most important structural features inducing figure are grain, growth rings, rays and knots (Dinwoodie, 1979). The Colour of wood is largely due to various extractives present in the cell wall of the heart wood and may change with exposure to light while lustre depends on the ability of the cell walls to reflect light (Desch and Dinwoodie, 1996).

The appearance of wood is significant in surface finishing of wood products since at this stage the main attribute considered is aesthetic value of the product. The decorative value will depend upon colour, texture, figure, lustre and most importantly the way in which it bleaches, or takes fillers, stains and transparent paint finishes (FPL, 2000). Some would be defects in a strict sense such as knots, pinholes, bird pecks, decay in isolated pockets, mineral streaks and in grown bark are strikingly decorative in appearance and with carefully selection, can be utilized for particular architectural treatment properties such as decorative furniture (FPL, 2000).

However, it must be noted that often more than one property of wood is important for any given task. Therefore, selection of a timber for its appearance characteristics must be evaluated against other properties such as machinability, stability or decay resistance (FPL, 2000).

b) Moisture Content

Moisture content (MC) of wood is defined as the weight of water in wood expressed a percentage of the oven dry weight of wood (BS 373: 1957). Several attributes of wood including weight, shrinkage and strength are influenced by its MC. In trees, MC can range from about 30% to more than 200% of the weight of wood substance. In softwoods, the MC of sapwood is usually greater than that of heartwood. However, in hardwoods, the difference in MC between heartwood and sapwood depends on the species (FPL, 2000).

Wood is a hygroscopic material which readily adsorbs water from the surrounding air depending on the temperature and humidity of the atmosphere and duration of exposure (Dinwoodie, 1979). This means, the MC of wood is different under different conditions of weather. The amount of water present in wood influences its strength, stiffness and mode of failure, but also affects dimensions, its susceptibility to degrading fungi, its workability as well as ability to accept adhesives and finishes (Desch and Dinwoodie, 1996). Normally the strength is low when moisture is high, for example, the strength properties of wood especially compression parallel to the grain increase with decrease in MC (Ranta-Maunus, 2003; Ishengoma and Nagoda, 1991; Dinwoodie, 1979). However, this increment is pronounced below fiber saturation point and the relationship between strength and MC may not apply when timber contains defects.

Density (green basis) of wood increases by approximately 0.5% for every 1.0% increase in MC up to 30 per cent (Desch and Dinwoodie, 1996). Rapid changes in moisture cause moisture gradients in wood which induce stresses perpendicular to the grain and may cause splitting of wood (Ranta-Maunus, 2003). The moisture induced stresses develop due to constrained shrinkage or swelling during fast drying or wetting. The above influence is significant in seasoning of timber and also influences durability and choice of protection for wood in service.

There are several methods of measurement of MC in timber most of which follow the basic gravitational technique. The basic method is described in BS 373 (1957) i.e. the oven dry method which involves weighing the samples, drying them in the oven until constant weight and recording the weight loss. The recorded weight loss is expressed as the percentage of the final oven dry weight and is taken as the samples' MC. For timber containing volatile extractives that would result in erroneous reading of MC using oven drying method, a method that includes provisions for distillation in presence of a water-immiscible solvents is employed. Where time is a constraint and fast results are preferred over extreme accuracy, MC is measured using electric moisture meters (Dinwoodie, 1979).

Wood performs well, with its MC reduced to equilibrium moisture content (EMC) of the area of intended use (FPL, 2000). EMC is defined as that MC at which the wood is neither gaining nor losing moisture from the environment (Dinwoodie, 1979). According to Desh and Dinwoodie (1996), MC must be reduced to a level corresponding to at least 12 percent of its oven-dry mass for better results.

c) Basic Density

Density is defined as the ratio of mass to volume and is expressed in such terms as grams per cubic centimeter or, Kilograms per cubic meter (Ishengoma and Nagoda, 1991). According toDesch and Dinwoodie (1996), density of wood is the most important single property controlling performance of wood. Moisture makes up part of the weight of each product in use and the MC in wood increases the mass of wood as well as the volume. The density of wood must reflect this fact and thus to obtain an accurate measure of density, mass and volume must be carried out at the same MC and if not as in the case of measurement of basic density it must be stated (FPL, 2000; Desch and Dinwoodie, 1996). This is why in practice wood density is referred to as green density, basic density and oven dry density.

In the laboratory, green density is determined using both wet mass and wet volume of freshly felled trees, oven dry density is determined using both mass and volume at zero MC, while for basic density green volume and oven dry mass are used. The methods and procedure for determination of wood density at different moisture levels are described in BS 373 (1957) and ASTM D 143-94 (2000).

In practice, density is required at 12% MC, the point at which most timbers are in equilibrium with the relative humidity in the atmosphere i.e. 65% (FPL, 2000). According to Desch and Dinwoodie (1996), determination of density should be carried out at 12% moisture, or corrections to 12% MC equivalents can be made using standardized calculations to account for the changes in mass and volume at higher MCs. However, the above correction may not give accurate estimates for timbers with extractives and resins since density is determined not only by the amount of wood substance present but also by the presence of both extractives and MC (Ishengoma, 1986).

The calculated density of wood is usually considered as an approximation due to the natural variations in the anatomy, MC and heart wood to sapwood ratio (FPL, 2000). However, for practical reasons, the estimated values are sufficient to permit proper utilization of wood where weight is important such as estimation of structural loads and calculation of shipment weight (FPL, 2000).

d) Calorific Value

Calorific value of wood is defined as the number of heat units that are liberated when a unit weight of wood is burned in oxygen (Allaby, 2004; Isaacs, 2004). Calorific value is also known as the heat of combustion or heat value for the fuel (Desch and Dinwoodie, 1996). Calorific value is one of the most important thermal properties in the evaluation of materials as potential fuels and the only one factor considered in assessing overall efficacy. Regular combustion and low ash content are also important but are usually difficult to quantify (Desch and Dinwoodie, 1996).

The heat value of wood varies from species to species even when expressed in terms of oven dry mass of wood. According to Desch and Dinwoodie (1996), the fuel value of timber depends largely on the amount of wood substance in a given volume i.e. on the density, the chemical composition of the wood substance and the state of dryness of the wood. In general, the denser the wood, the higher it's potential for fuel, but this may be affected by the presence of substances such as resin. Calorific value of wood can be obtained directly as gross energy or heat of combustion using calorimetric procedure according to ASTM E870-82 (2006).

2.1.3 Mechanical Properties

Mechanical properties of wood are an expression of its behaviour under applied or incidental forces (Ishengoma and Nagoda 1991). Mechanical properties most commonly measured and represented as "strength properties" for design include static bending properties (modulus of rupture, modulus of elasticity and work to maximum load), maximum stress in compression parallel to grain, compression stress perpendicular to grain, and shear strength parallel to grain. Other mechanical properties often measured include; work to maximum load in bending, impact bending strength, tensile strength perpendicular to grain, and hardness (FPL. 1999). Mechanical properties of wood vary considerably within and between species (Metten, 1986). Assessment of mechanical properties can be carried out using two approaches, one of which is based on smaller clear specimen, while the other employs actual structural grade timber. Although the use of structural-sized timber is desirable for derivation of actual working stresses, the use of small clear specimen remains valid for characterizing new timbers and for strict academic comparison of wood from different tree species (Deschand Dinwoodie, 1996; Lavers, 1983). Mechanical properties include the following;

a) Static bending strength

Static bending is a measure of the strength of a material as a beam. There are many examples where timber is used as a beam, of which the most common are floor, ceiling joists, roof truss members, tables and chair bottoms. Test specimens can be of size 300 x 20 x 20 mm (BS 373: 1957) or 410 x 25 x 25 according to ASTM D 143-94 (2000). The sample is prepared in such a way that the growth rings are parallel to one edge and is tested with growth ring direction parallel to the direction of loading (BS 373:1957). Modulus of rupture (MOR), Modulus of Elasticity (MOE) and Work to Maximum load (Wmax) can then be computed using equations (1), (2) and (3) respectively (adopted from BS 373:1957).

$$MOR_w = \frac{3\,F_{max}L}{2bd^2} \qquad \text{(1)}$$

where:

$MORw$ is the Modulus of Rapture in N/mm^2 at w% MC

$F_{max}$is the maximum load (Newtons),

$L$is the span length (mm)

$b$is the width of sample (mm)

$d$is the depth of sample (mm)

$$MOE_w = \frac{P_{max}L^3}{4ybd^3} \qquad \text{(2)}$$

where:

MOE_w is the Modulus of Elasticity in N/mm^2 at w% MC

$P_{max}$is the load to the limit of proportionality,

$L$is span length (mm)

$b$is width of sample (mm)

$d$is the depth of the sample (mm) and

y is the deflection in mm at mid length to limit of proportionality

$$W_{max} = \frac{AQ}{V} \quad (3)$$

where:

W_{max} is work to maximum load in Joules/mm^3 at w% MC

$A$is the area under the curve to maximum load

$Q$is the work equivalent of 1 mm^2 on the load deflection curves

$V$is the volume of the test piece equal in mm^3

b) Compression strength parallel to the grain

This property determines the ability of timber to be used as columns, props and chair legs. High longitudinal compression strength is required of timber used as columns, props and chair legs. Test specimen can be of size 60 x 20 x 20 mm (BS 373: 1957) or 100 x 25 x 25 according to ASTM D 143-94 (2000). Care must be taken to ensure that the specimen does not buckle i.e. subjecting it to a bending rather than compression strength. Compression strength is obtained by dividing the load to failure by the cross-section area of specimen (equation 4) (Desh and Dinwoodie 1996; BS 373: 1957).

$$MCS_w = \frac{P_{max}}{ab} \quad (4)$$

where;

MCS_w is the maximum compression strength parallel to the grain in N/mm^2 at w% MC

P_{max} is maximum load in Newtons

a and b are cross sectional dimensional dimensions of the test specimen in millimetres

c) Ultimate shear parallel to the grain

This is the most important property in structural timber in reference to joints (Desch and Dinwoodie, 1996). The areas surrounding the mortise or bolt holes usually experience high longitudinal shear stresses. The test is done on a 20 mm cube (BS 373:1957) or 63 x 50 x 50 mm with a rebated notch (ASTM D 143-94 (2000). The specimen is placed in the shear test rig such that when the cube is loaded at constant load, shear will occur along the grain.

The maximum shear stress parallel to the grain, $\tau_w =$ in N/mm^2, for each test piece, at MC w at the time of test, can be calculated from the relationship in equation 5:

$$\tau_w = \frac{P_{max}}{bL} \quad (5)$$

where;

$\tau_w =$ is the maximum shear force in N/mm^2,

b is the thickness of test piece in mm, and

L is the length of the shearing surface in mm

d) Cleavage resistance

This property is an indicator of how easily wood would split, it is advantageous in the production of hand split shingles, barrels and firewood, though a distinct disadvantage when considered against nail or screw holding (Desch and Dinwoodie, 1996). The test is performed on a specimen of 45 x 20 x 20 mm (BS 373:1957) or 89 x 50 x 50 mm (ASTM D 143-94 (2000). A notch is made in the cross-section to accommodate the grip. The splitting force is applied at a constant rate specified in the standards and the cleavage resistance is measured and expressed in force per unit width (Equation 6). Cleavage resistance for each test piece (σ) in N/mm is calculated as follows:

$$\sigma = \frac{P_{max}}{b} \qquad \text{.........(6)}$$

where;

$P_{max}$is the maximum cleavage load in Newtons and

$b$is the specimen width in millimetres.

2.2. Wood properties and current uses of parent materials for the study clones

The study clones i.e. GU7, GU8, GC540, GC550 and GC796, are hybrids of parent eucalypts land races of *E.grandis, E. Camaldulensis* and *E.urophyla* which have known properties and uses. The properties and uses of the parent materials form a baseline for breeding and therefore, can provide a basis for prediction of properties and uses of the resulting hybrids. Harding & Copley (2000) noted that wood properties of the hybrids grown on the same site with their parents, tend to be intermediate between parental means and that in practical terms, interspecific hybrids usually have better wood properties than the parental species.

2.2.1 *E. grandis*

The colour of the heartwood ranges from almost white to pink or dark red while the sapwood is paler. The grain is straight or interlocked and the texture is medium to coarse (Nyunai, 2008). The wood density is 540–775 kg/m^3 at 12% MC (Nyunai, 2008; Zziwa, *et al.*, 2006). At the same MC, MOR, MOE and compression parallel to grain are 80–129(–172) N/mm^2, 9900–15,800 N/mm^2 and 31–68 N/mm^2 respectively while compression perpendicular to grain, shear and cleavage strength are 4–6 N/mm^2, 7–11 N/mm^2 and 15–21 N/mm respectively. The wood has energy value of 18,100–19,400 KJ/kg. The rates of shrinkage from green to oven dry are 4.0–7.7% radial and 7.5–12.7% tangential (Nyunai, 2008).

The wood is usually not stable in service. It is somewhat difficult to dry, but checking can be minimised by careful control of the conditions during the early stages of drying (Mugabi, *et al.*, 2009). The wood works well with machine and hand tools but the surface may be woolly and the wood has a tendency to splinter. It saws cleanly, planes excellently and takes all kinds of finish well. Nail and screw holding properties are good, but the wood tends to split on nailing. The gluing properties are good. It is moderately durable at best, and untreated wood is not suitable for use in contact with the ground (Nyunai, 2008; Kityo and Plumptre 1997).

E. grandis wood is used for construction, flooring, joinery, panelling, shingles, boat building, wheels, poles, posts, furniture, boxes, crates, mine props, veneer and plywood. It is also suitable for handles and ladders, agricultural implements, sporting goods, toys, novelties, turnery, railway sleepers, hardboard, particle board and wood-wool. It is used as fuelwood for domestic purposes and for curing tobacco, especially in Uganda, and also for charcoal production (Nyunai, 2008). It is an important source of pulp for the production of printing, writing, specialty and tissue papers.

2.2.2 E. camaldulensis

The wood is moderately heavy, with a density of 680–980 kg/m³ at 12% MC. At the same MC, the values for MOR, MOE, compression parallel to grain, shear strength and Cleavage are 101–192 N/mm², 10,500–14,700 N/mm², 49–72 N/mm², 5–15 N/mm² and 16-33 N/mm respectively. The energy value of the *E. Camaldulensis* wood is 17,700–21,000 KJ/kg. The wood is easy to saw despite its high density, but splitting may occur due to the release of growth stresses. The wood is difficult to work and should be pre-bored before nailing, but gluing properties are good and the wood polishes well. It is suitable for steam-bending (Doran &Wongkaew, 2008).

The wood is used mainly for firewood, charcoal, poles, posts, tools and paper pulp. Other uses include construction (especially bridges and wharves), flooring, ship building, railway sleepers, mine timber, furniture and packing cases. It is also used for veneer, plywood, turnery, hardboard, fibreboard and particleboard (Doran &Wongkaew, 2008).

2.2.3 E. urophylla

*E. urophylla*is very similar to *E. alba.* The heartwood is pinkish-brown to red-brown, and contains little gum. The basic density is in the range of 540—570 kg/m^3, which is comparatively light compared to other *Eucalyptus* species (Turnbull & Doran, 1997). The wood is fairly easy to saw and is moderately durable. Fibres are relatively short, 0.7—1 mm, and the wood is suitable for bleached chemical pulp and has a good pulp yield of about 50%.

E. urophylla is increasingly used in reforestation programmes and is economically important for wood production. It makes satisfactory fuelwood and charcoal (Turnbull & Doran, 1997).

In Timor, the wood is used for heavy construction and bridging. It is also used for flooring. Round wood is used for building poles and fence posts. It is particularly suitable as a source of mid-density to low-density eucalypt fibre for pulp and paper production (Turnbull & Doran, 1997).

CHAPTER THREE

MATERIALS AND METHODS

3.1. Selection of sample trees

Sample trees were selected from two ecological zones; Lake Victoria Crescent and Southern and Eastern Lake Kyoga Basin. The selected sites were Kifu in Mukono District and Ikulwe in Mayuge district representing Lake Victoria Crescent and Southern and Eastern Lake Kyoga basin agro ecological zones, respectively. The sites were specifically selected based on the recorded acreage of clonal eucalypts planted in the different ecological zones at the time of study. The selected trials, Kifu and Ikulwe were of the same age established between April and May 2002 (Epila-Otara and Ndhokero, 2009). For each of the study clone, 5 well-formed individual trees were randomly selected from each of the above trials. The selected trees were felled, sectioned into three billets of 1.2m long obtained at breast height (1.3m), 45% and 75% of the total tree height and labelled appropriately.

3.2. Location and characteristics of agro-ecological zones (AEZ) sampled

a) Lake Crescent AEZ

This is a large, extensive agricultural area that could be treated as three sub zones; west of the Nile, east of the Nile and the eastern section that falls in Bugiri, Busia and Tororo districts (Wortmann and Eledu, 1999).This AEZ is located at an altitude of 1174m and receives mean annual rain fall of above 1200mm.

The Kifu clonal trial is located in the west of Nile sub zone. The west of the Nile landscape is an old surface marked by ridges or lateric capped hills, long slopes and wide, often swampy valleys. The soils are variable but often have high clay content; sandy clay loam soils are common. Soils are often acidic and low in potassium but with moderate levels of organic matter (Wortmann and Eledu, 1999).

b) Southern and Eastern Lake Kyoga Basin AEZ

This AEZ is located at an altitude 1075 m above sea level and receives an annual rainfall average higher than 1200mm. Ikulwe clonal trial is located in the south eastern part of this zone. The soils are occasionally acidic and often have low organic matter and low nutrient supply. Soil erodibility is low and rainfall erosivity is moderate (Wortmann and Eledu, 1999).

3.3. Preparation of test pieces

Each of the 1.2 m billets from the sample trees was sawn using the through and through method to produce centre planks of 150 mm thickness.(Lavers, 1983). The centre pieces were machined to 80 mm thickness for easier seasoning and labelled to indicate particular clone, position in the tree and ecological zone of origin. The pieces were air seasoned for 30 days and reduced in size to 800 x 60 x 30 mm. The specimens were dried to 28 % MC and then machined further to the final size of 800 x 20 x 20 mm from which the test pieces were obtained (Figure 3.1). The test specimens were then prepared to the final dimensions specified by relevant standards as indicated in Table 3.1.

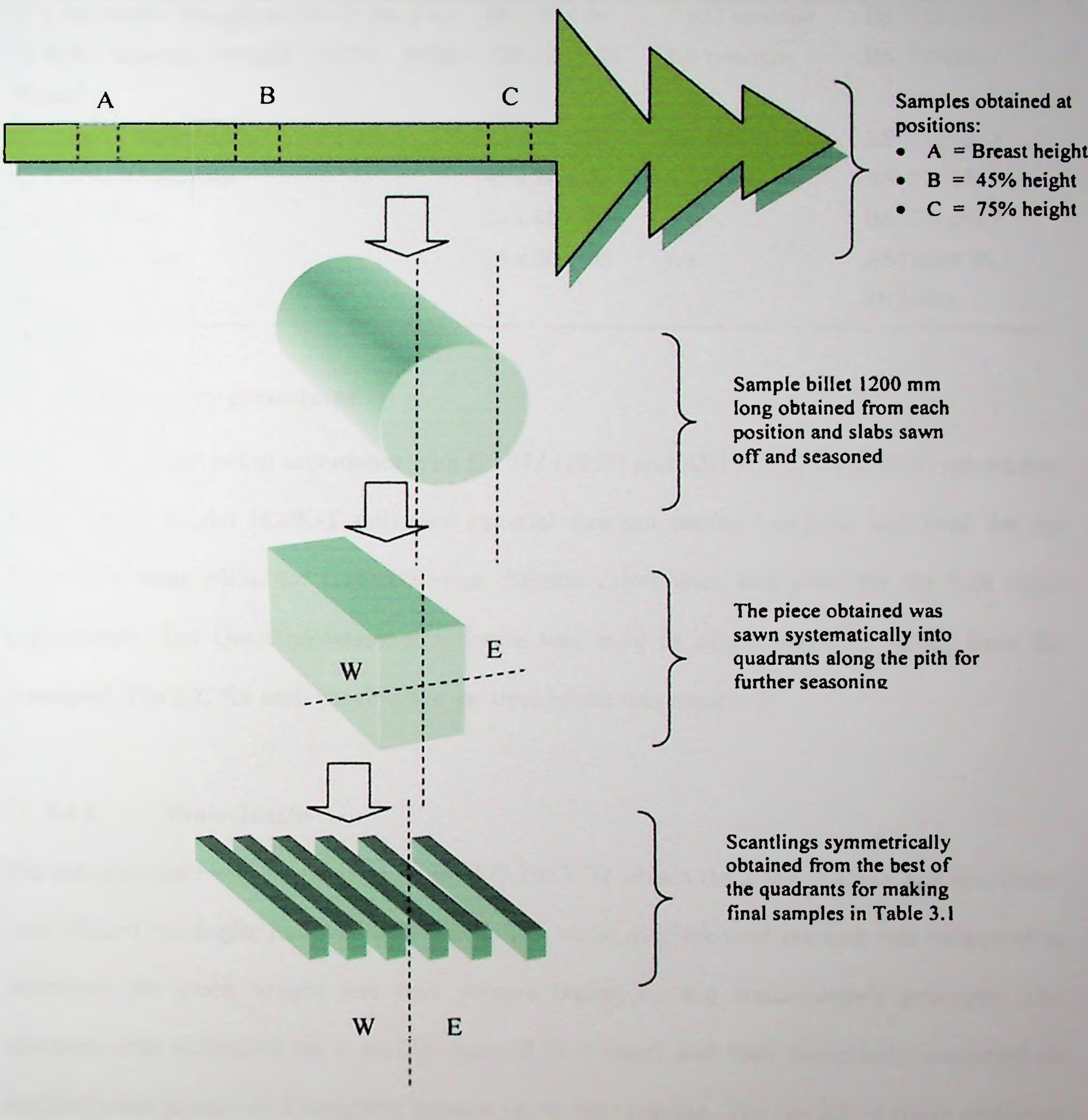

Figure 3.1: Scheme used to obtain samples for the study

Table 3.1: The dimensions for specimen used for property assessment

Property	Size of test specimen (mm)	Loading Rate/ speed of testing	Standard of Reference
a) Compression strength parallel to the grain	60 x 20 x 20	0.635 mm/min	BS 373:1957
b) Static bending strength (MOR, MOE, Wmax)	300 x 20 x 20	6.6 mm/min	BS 373:1957
c) Shear Strength parallel to the grain	20 x 20 x 20	0.4 mm/min	BS 373:1957
d) Cleavage resistance	45 x 20 x 20	2.54 mm/min	BS 373:1957
e) Basic density	20 x 20 x 20	n/a/	BS 373:1957
f) Calorific value	20 x 20 x 20	n/a	ASTME870-82(2006).

3.4. Laboratory procedures

Tests were carried out in accordance with BS 373 (1957) and ASTM E870-82(2006) procedures. Tinius Olsen Model H50K-T universal material strength testing machine was used for the mechanical tests while the Gallen Kampa diabatic calorimeter was used for the heat value experiments. The Qmat professional software was used to obtain strength values from the crosshead. The MC for each specimen at the time of test was recorded.

3.4.1 Basic density

The test procedure was as specified by BS 373:1957. To obtain the green volume, test specimens were soaked overnight, removed and wiped. The water displacement method was then used to determine the green weight and thus volume basing on the Archimedes's principle. The specimen was suspended by a needle clamped in a stand and then completely immersed in distilled water placed on a weighing balance set to zero reading. The weight of water displaced for each test specimen, which is equal to the green volume of the test piece was recorded. The test specimen was then oven dried at a temperature of 103 $\pm$ 2°C until constant weight (in grams), the specimen was re-weighed to obtain oven dry weight. Basic density in Kg/m^3 was calculated from relationship in equation 7.

$$BD = \frac{W_d}{V_g} \times 1000 \quad \text{...}(7)$$

where;

W_d *Oven dry weight of specimen (g)*

V_g *Green volume of specimen (cc)*

3.4.2 Calorific Value

The calorific value of wood was obtained directly from calorimetric tests using the Gallen Kamp adiabatic calorimeter. The procedure used was adopted from ASTM E870-82(2006); only the samples obtained at breast height of the tree were used for this test. This was on assumption that samples obtained at breast height will have higher density values and therefore higher calorific values (Desch and Dinwoodie, 1996) and thus give better values at that age for comparisons with mature parent material. The specimens were mechanically broken down to wood meal and packaged into well indexed dispensing envelopes. From each envelope, 0.5-1.0 grams of wood meal was weighed and placed in the stainless steel combustion capsule. The combustion capsule containing the sample was then lowered in the wire bomb head while the bomb head was on its support. A ten centimetre long fuse wire was firmly fixed to the electrodes to facilitate complete combustion. Then 1 ml of water was added to the bomb cylinder and the sealing ring of the bomb head was moistened. The bomb was carefully lowered into the cylinder and tightly closed with the sealing ring. To facilitate complete combustion, 30 atmospheres of oxygen was introduced into the combustion cylinder. The bomb cylinder was then lowered into the calorimeter bucket. The calorimeter cover was carefully placed and the thermometer bracket lowered. The power was then switched on to start the auto temperature adjustment and the stirring motor. The initial temperature was recorded after equilibrium was attained i.e. after 5 minutes. The bomb content was then fired using the ignition switch. The bucket temperature i.e. final temperature was recorded after it had stabilised i.e. after 5 minutes. The unburned fuse wire was straightened and its new length measured. The difference between the original length and the new length was multiplied by 2.3 to obtain the number of calories liberated by combustion of the fuse (fuse wire correction). For every sample, gross energy (calorific value) in Kcal/gm was calculated using the following equation:

$$\text{Gross energy} = \frac{\text{Temperature rise} \times 2206.24 - \text{fuse wire correction}}{\text{sample weight} \times 1000} \quad \ldots\ldots\ldots\ldots(8)$$

Where:

2206.24 is the energy equivalent of the system that was used for the experiment.

3.4.3 Static Bending

Modulus of Elasticity (MOE), Modulus of Rapture (MOR), and Work to Maximum load (Wmax) were determined following BS 373 (1957) procedures. The central (three point) loading method was employed as shown in Figure 3.2. The specimen size for the test was20mm x 20mm x 300mm as specified in BS 373 (1957). The load was applied centrally to the radial face at a speed of 6.6 mm/min of the specimen supported over a span of 280 mm. For each test piece, stress-strain curves as well as MOR and Wmax readings were automatically generated using the Qmat software (Tinius Olsen, 2003). MOE values were calculated from the stress strain graphs plotted by the software. This was because the result from the cross head would be inaccurate owing to the small displacements in deflection. MC for each individual test specimen was recorded and values were adjusted to their 12% EMC equivalents in accordance to Desch (1981).

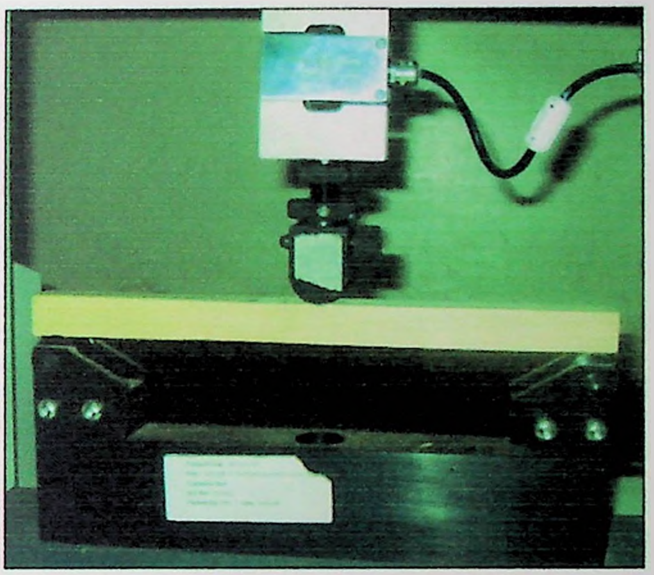

Figure 3.2: Set up for the three point bending test (BS 373: 1957)

3.4.4 Compression Parallel to the Grain

Conditions of loading used were in accordance with BS 373: 1957 standard procedures. The test specimen of 20mm x 20mm x 60mm was loaded at a speed of 0.635 mm/min as specified in the standards. The maximum crushing load, P_{max} for every specimen was obtained from the crosshead using the Qmat software. The loading set up was as shown in Figure 3.3. Moisture content for each individual test specimen at the time of the test was recorded and test results adjusted to 12% EMC equivalents in accordance to Desch (1981).

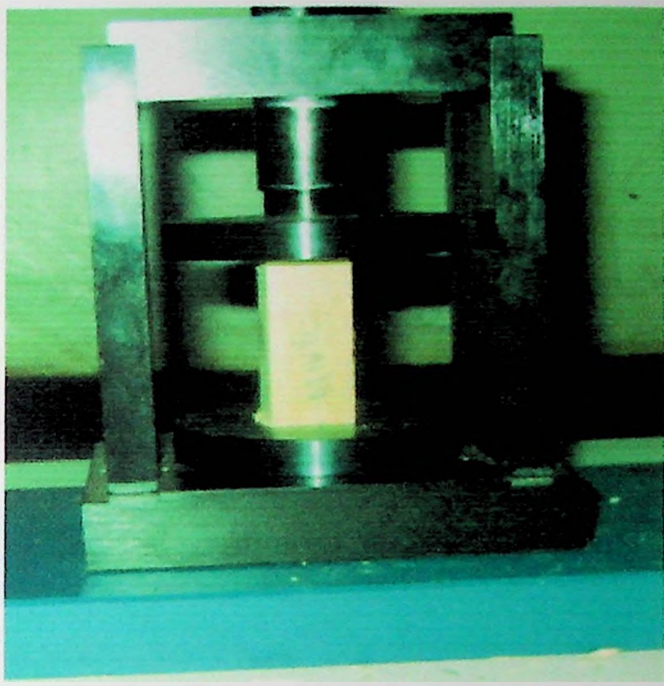

Figure 3.3 Set Up for compression strength parallel to the grain test (BS 373: 1957)

3.4.5 Ultimate Shear Strength Parallel to the grain

The BS 373:1957 standard procedures were used for this experiment. Each test piece measuring 20mm x 20mm x 20mm was loaded at a constant cross head speed of 0.4mm/min. The maximum (breaking) load, P_{max} was directly recorded by Qmat professional software from the cross head. The set up was as illustrated in Figure 3.4. The test specimens were at 12±3 % average MC at the time of the test.

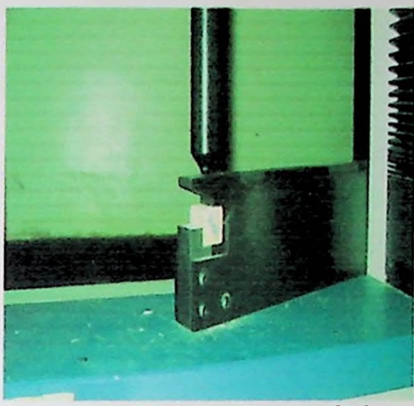

Figure 3.4: The loading set up for shear stress parallel to the grain (BS 373: 1957)

3.4.6 Cleavage resistance parallel to the grain

Cleavage tests were carried out at constant loading rates and conditions in reference to BS 373:1957. Each test piece measuring 20mm x 20mm x 45mm was loaded at a constant cross head speed of 2.54mm/min according to the standard. The shear stress in N/mm^2 was directly recorded by Qmat professional software from the cross head. The load cell set up was as illustrated in Figure 3.5. The test specimens were at 12±3% average MC at the time of the test.

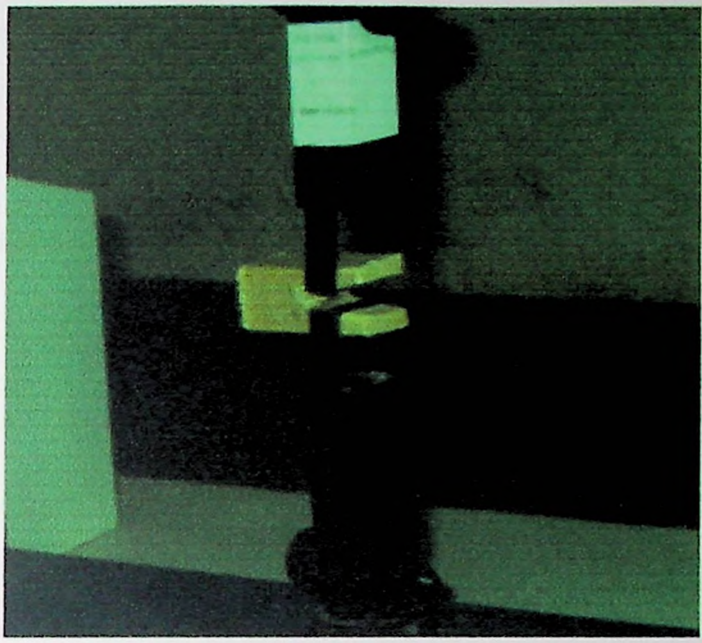

Figure 3.5: Loading set up for cleavage resistance parallel to the grain (BS 373: 1957)

3.5. Comparison of wood properties for clonal eucalypts and parent material

Review of literature was done to establish the wood properties and uses of parent materials i.e.*Eucalyptus grandis, Eucalyptus cammaldulensis and Eucalyptus urophylla.* The properties and uses of the parent material obtained were compared with the study results to predict potential uses of 6-7 year old hybrids.

3.6. Data Analysis

Descriptive statistical procedures were used to obtain means and standards deviations for all test properties. One-way ANOVA was used to assess the variation in test properties with site and position of sample within the tree (NIST/Sematech, 2010). In order to accommodate the influence of natural variations within the trees and any other sources of variation during the experiment, order statics (percentiles) were used to generate a tolerance interval within which

90% of the measured properties of a given clone are likely to fall at 95% confidence level. Tolerance interval was computed according to equation (9)

Tolerence interval = Mean $\pm K_2S$.. (9)

where;

S= Standard Deviation

$$K_2 = \sqrt{\frac{(N-1)(1+{}^{1}/_{N})Z^2_{(1-p)/_2}}{X^2_{\gamma,N-1}}}$$

Where$X^2_{\gamma,N-1}$ is the critical value of chi-square with degrees of freedom,(N-1)that is exceeded with probabilityγ and $Z_{(1-p)/_2}$ is the critical value of the normal distribution which is exceeded with probability$^{(1-p)}/_{2}$. Tolerance interval and mean values of each property were compared with the known values of parent material i.e. *Eucalyptus grandis, Eucalyptus cammaldulensis and Eucalyptus urophylla.*

CHAPTER FOUR

RESULTS

4.1 Overall means and tolerance intervals of properties

The overall means of tested properties of hybrid eucalypts independent of site and position of the specimen with in the tree are presented in Table4.1. Clone GC540 showed the highest mean basic density (664Kg/m^3), maximum compressive strength parallel to the grain (84 N/mm^2) and modulus of rapture (MOR) [122N/mm^2]. GU7 had the highest Calorific Value (17800KJ/Kg) and work to maximum load (58 J/mm^3). GC796 exhibited the highest mean value for modulus of elasticity (MOE) [8950 N/mm^2]. Clone GC550 had the lowest mean values for all properties tested except for calorific value which was lowest (16700 KJ/Kg) in GC796 samples (Table 4.1).

Table 4.1: Overall mean properties of clonal eucalypts

		PROPERTY							
		BD (Kg/m^3)	CV (KJ/Kg)	MCS (N/mm^2)	MSS (N/mm^2)	CLR (N/mm)	Bending properties		
CLONE	STATISTIC						MOE (N/mm^2)	MOR (N/mm^2)	Wmax J/mm^3
GU7	**Mean**	**654**	**17800**	67	**12**	**20**	**7651**	139	**58**
	N	67	30	66	60	65	62	67	58
	SD	38	3541	13	2	4	3279	24	39
GU8	**Mean**	**643**	**17500**	**64**	**11**	**19**	**6946**	**134**	**57**
	N	70	35	63	65	66	64	66	57
	SD	19	2669	11	2	4	2782	21	29
GC540	**Mean**	**664**	**17700**	**84**	**12**	**20**	**8459**	**153**	**53**
	N	70	23	58	64	65	64	70	53
	SD	32	1789	11	2	5	3355	32	21
GC550	**Mean**	**627**	**17500**	**63**	**10**	**18**	**6869**	**122**	**41**
	N	61	29	53	59	61	50	53	34
	SD	44	1366	10	1	4	2175	24	14
GC796	**Mean**	**652**	**16700**	74	**12**	**18**	**8950**	**148**	**51**
	N	70	25	59	62	60	59	61	40
	SD	43	3326	13	2	5	3019	27	18

Key: BD=Basic Density, CV=Calorific Value, MCS=Maximum compression strength parallel to the grain MSS=Maximum shear stress parallel to the grain, MOE= Modulus of Elasticity, MOR= Modulus of Rapture, Wmax= Work to maximum load, N= sample size, SD=standard deviation.

The acceptable ranges within which 90% of measured properties above are likely to fall at 95% confidence level were as shown below.

Table 4.2: Two-sided tolerance interval for the test clone for each test property

PROPERTY	TOLERANCE INTERVAL				
	GU7	GU8	GC540	GC550	GC796
BD (Kg/m^3)	580-728	606-680	602-727	550-713	569-735
CV (KJ/Kg)	10223-25377	11922-23078	13686-21714	14561-20439	9355-24044
MCS (N/mm^2)	42-92	43-85	62-106	43-83	48-100
MSS (N/mm^2)	8-15	7-15	8-16	8-12	8-16
CLR (N/mm)	12-27	11-27	10-30	10-26	8-28
MOE (N/mm^2)	1252-14049	1533-12358	1932-14986	2527-11211	3029-14871
MOR (N/mm^2)	93-186	93-175	91-215	74-170	95-201
W_{max} (J/mm^3)	-19-135	0-114	11-94	12-70	14-88

Key: BD=Basic Density, CV=Calorific Value, MCS=Maximum compression strength parallel to the grain MSS=Maximum shear stress parallel to the grain, MOE= Moment of Elasticity, MOR= Moment of Rapture, Wmax= Work to maximum load,

4.2 Variations in wood properties

The properties varied with growing site as well as a cross and along the stem.

4.2.1 Variation due to growing site

Basic density was significantly (P<0.05) different in sites for clones GU8 ($F_{1,68}$=11.29, P≤0.001);GC540 ($F_{1,68}$=10.42, P≤0.002); GC550 ($F_{1,59}$=5.92, P≤0.02) and GC796($F_{1,68}$=19.93, P≤0.001) and was significantly (P<0.05) higher in Ikulwe except for clone GC540 [Fig. 4.1 (a)]. MSS was significantly (P<0.05) higher for clones GU8 ($F_{1,63}$=6.56, P≤0.02) and GC796 ($F_{1,60}$=39.44, P≤0.000) obtained from Ikulwe while GC540 had significantly ($F_{1,62}$= 9.96, P≤0.002) higher MSS values for samples obtained from Kifu [Fig. 4.1 (b)]. CRL was significantly (P<0.05) higher for clones GU7 ($F_{1,63}$=26.37, P≤0.000); GC540 ($F_{1,63}$=6.15, P≤0.02); GC550 ($F_{1,59}$=13.9, P≤0.02) and GC796 ($F_{1,58}$=56.72, P≤0.00) obtained from Ikulwe while MOE was significantly higher in GC540 ($F_{1, 62}$ =11.14, $P \leq 0.001$), from Kifu [Fig. 4.1 (c) and (d)]. MOR was significantly higher in clones GC540 ($F_{1, 68}$ =5.38, $P \leq 0.02$), and GC796 ($F_{1, 59}$=19.31, $P \leq 0.000$) from Kifu [Fig. 4.1(e)]. Wmax was significantly different for clones GU7 ($F_{1, 56}$=6.09, $P \leq 0.02$), GU8 ($F_{1, 55}$=5.97, $P \leq 0.02$) and GC796 ($F_{1, 38}$=7.38, $P \leq 0.01$), and higher in Kifu [Fig.4.1 (f)]. However, there were no significant ($P>0.05$) differences within clones across sites in relation to calorific value and MCS. The property most influenced by growing site was basic density; it varied significantly ($P<0.05$) in all clones except GU7. In addition, influence of growing site on properties of clones was more pronounced in clone GC540 and GC796 compared to other clones [Fig. 4.1 (a)-(f)].

4.2.2 Variation in properties a long tree height

The position of the sample along the tree height influenced the wood properties tested in some clones. Basic density increased significantly ($P<0.05$) along tree height for clones GU7 ($F_{2, 64}$ = 4.07, $P \leq 0.02$), GU8 ($F_{2, 67}$ = 3.77, $P \leq 0.03$) and GC796 ($F_{2, 67}$ = 4.29, $P \leq 0.02$) contrary to the known systematic variation in a tree i.e. BD was expected to be higher in the butt end decreasing with height [Fig. 4.2 (a)]. MCS increased significantly ($P<0.05$)along tree heightup to 75% of tree height for clones GU7 ($F_{2, 62}$ = 3.98, $P \leq 0.02$) and GU8 ($F_{2, 60}$ = 8.12, $P \leq 0.001$) while for GC550 ($F_{2, 50}$= 4.09, $P \leq 0.02$) and GC796 ($F_{2, 56}$= 3.96, $P \leq 0.03$) a significant increase up to 45% of tree height was followed by a sharp decline [Fig. 4.2 (b)]. MSS increased significantly ($P<0.05$) with tree height for clone GU7 ($F_{2, 57}$ = 7.48, $P \leq 0.001$) [Fig. 4.2 (c)]. CLR decreased significantly ($P<0.05$) with height in clone GC550 ($F_{2, 58}$ = 4.47, $P \leq 0.02$) while MOE increased significantly ($P<0.05$) in GU7 ($F_{2, 57}$ = 8.28, $P \leq 0.001$). MOR increased significantly ($P<0.05$)in clones GU8 ($F_{2, 63}$ = 12.59, $P \leq 0.001$) and GC540 ($F_{2, 67}$ =4.07, $P \leq 0.007$) [Fig. 4.2 (d)-(f)].

4.2.3 Variation in properties across the stem

MCS increased significantly ($P<0.05$) from the pith to bark for clones GC550($F_{2,50}$= 5.96, $P\leq0.005$) and from pith to position 2 and then reduced significantly ($P<0.05$) towards the bark for GC796 ($F_{2,56}$= 4.17, $P\leq0.02$) [Fig. 4.3(a)]. MSS increased significantly ($P<0.05$) from pith to bark for clones GU8 ($F_{2,62}$= 4.75, $P\leq0.01$) and GC 796 ($F_{2,59}$= 3.62, $P\leq0.03$). However, for GC796, the MSS curve was steeper towards the bark [Fig. 4.3 (b)]. MOE increased significantly ($P<0.05$) with GC540 ($F_{2,62}$= 4.69, $P\leq0.01$) from pith to bark while for GU8 ($F_{2,60}$= 4.29, $P\leq0.001$) a significant increase was followed by a sharp decline towards the bark [Fig. 4.3(c)]. Further, there was a significant ($P<0.05$) increase in MOR for clone GC550 ($F_{2,50}$= 11.26, $P\leq0.001$) from pith to bark [Fig. 4.3(c)]. However, there were no significant ($P>0.05$) differences within clones across the stem in relation to basic density, CV and CLR.

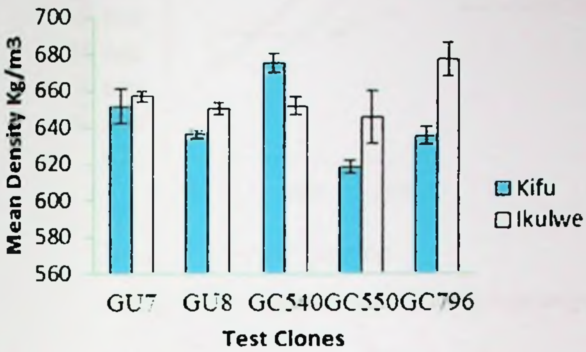

Fig 4.1(a): Influence of growing site on BD

Fig 4.1(b): Influence of growing site on MSS

Fig 4.1(c): Influence of growing site on CLR

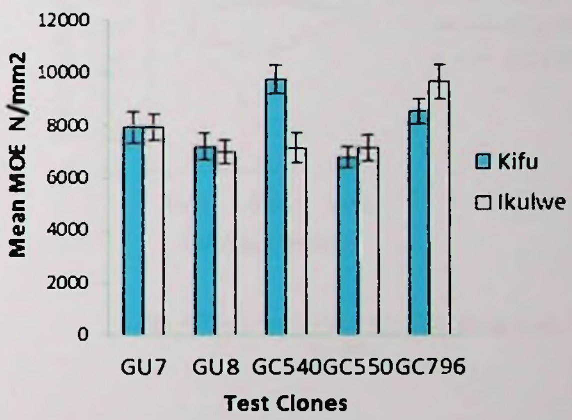

Fig 4.1 (d): Influence of glowing site on MOE

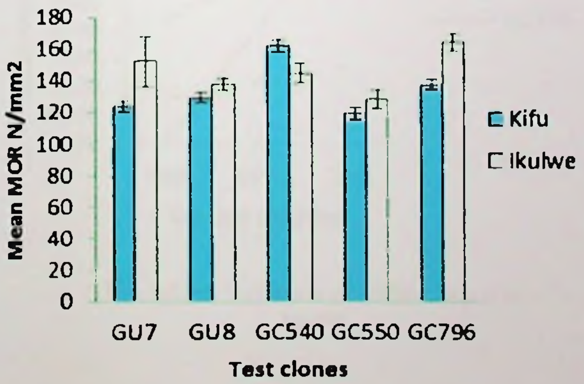

Fig 4.1(e): Influence of growing site on MOR

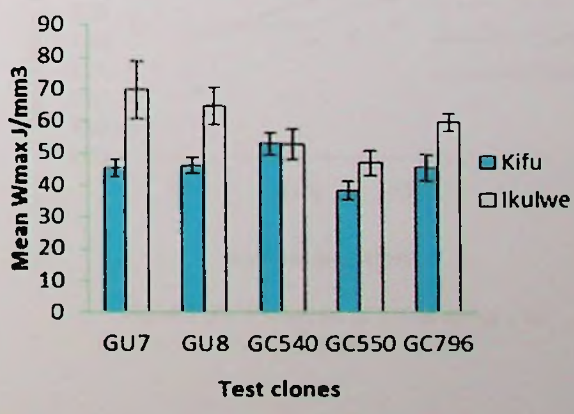

Fig 4.1 (f): Influence of growing site on Wmax

Figure 4.1: Influence of growing site on BD, MSS, CLR, MOE, MOR and Wmax
(Graphs are fitted with standard Error bars; and the sites are in Central and eastern parts of Uganda)

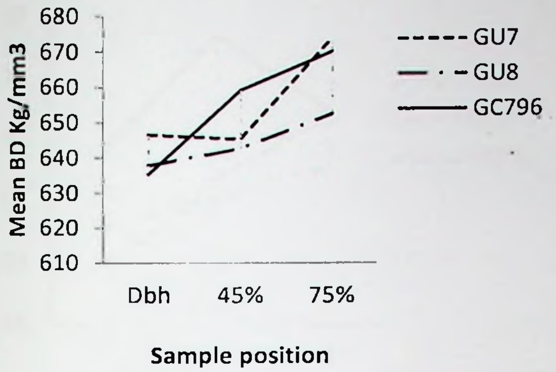

Fig. 4.2 (a): Variation of BD along tree height

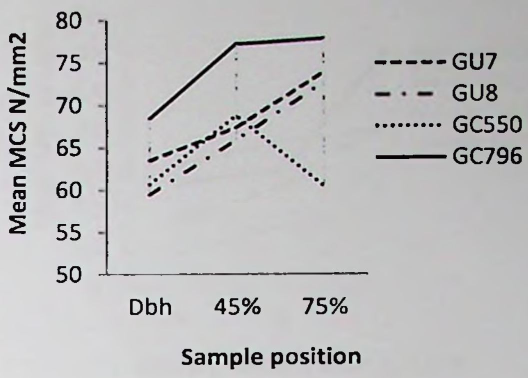

Fig. 4.2 (b): Variation of MCS along tree height

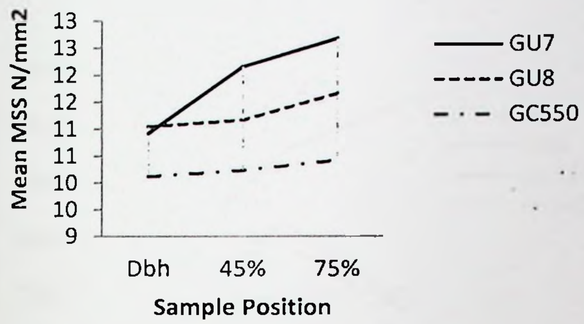

Fig. 4.2 (c): Variation of MSS along tree height

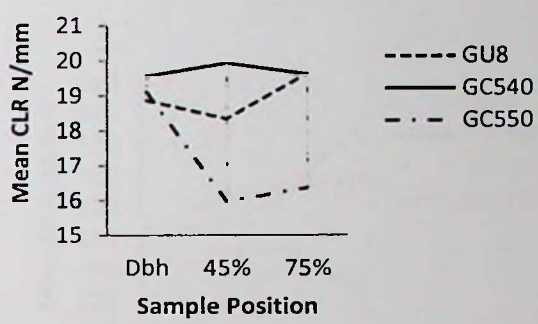

Fig. 4.2 (d): Variation of CLR along tree height

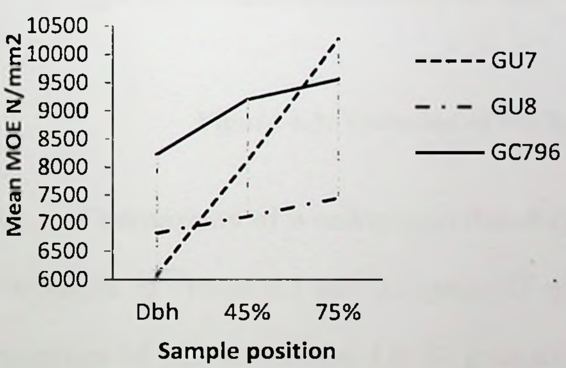

Fig. 4.2 (e): Variation of MOE along tree height

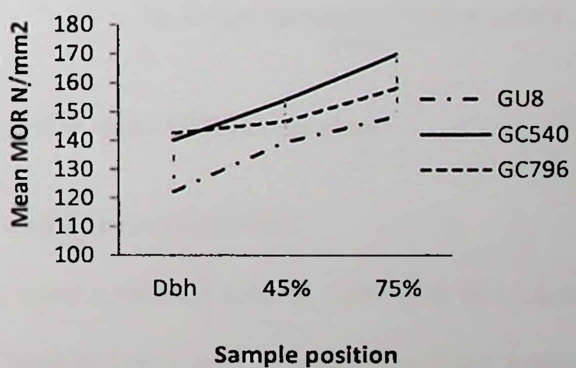

Fig. 4.2 (f): Variation of MOR along tree height

Figure 4.2: Variation of BD, MCS, MSS, CLR, MOE and MOR along tree height

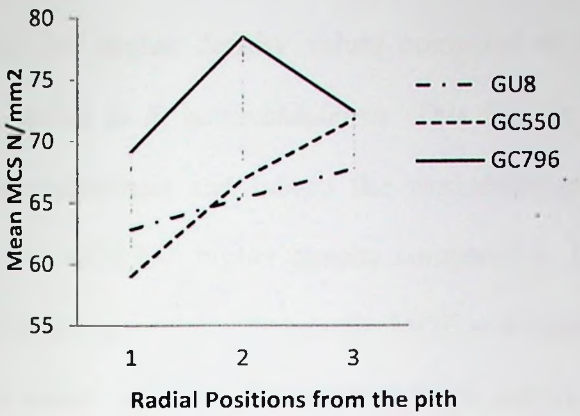

Fig. 4.3 (a): Variation of MCS across the stem

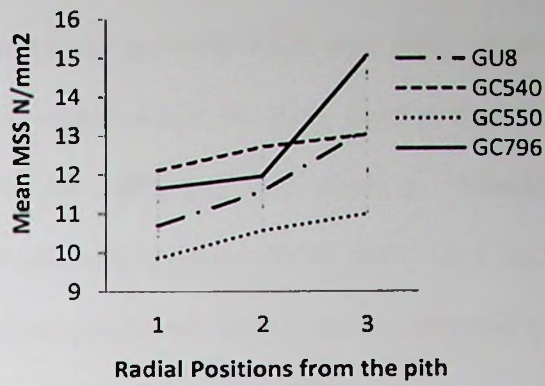

Fig. 4.3 (b): Variation of MSS across the stem

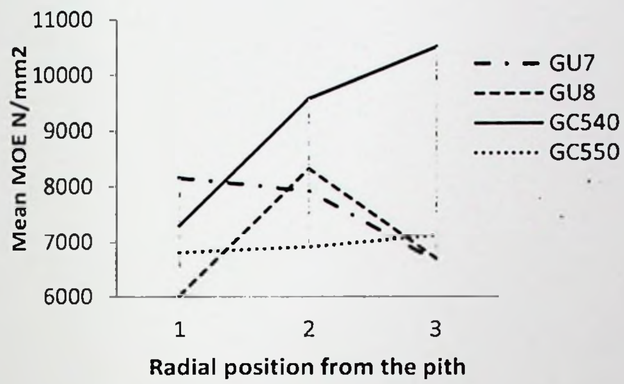

Fig. 4.3 (c): Variation of MOE across the stem

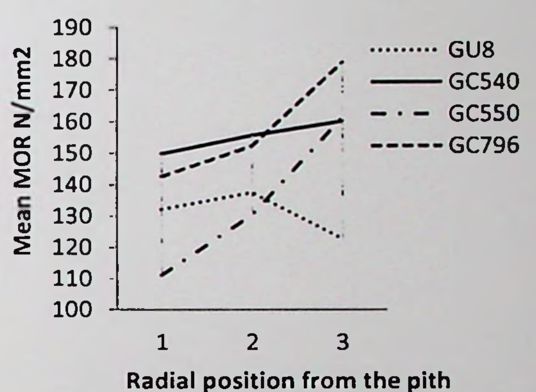

Fig.4.3 (d): Variation of MOR across the stem

Figure 4.3: Variation of MCS, MSS, MOE and MOR across stem

4.3 Comparison of wood properties of clones and parent materials

The results in Tables 4.1 and 4.2 (page 32 and 33) were tabulated side by side with the known properties of parent material i.e. *E. grandis, E. Camaldulensis* and *E. urophyla* from various sources (Tables 4.3 and 4.4). The basic density values for clones were intermediate while MCS, MSS, CLR and MOR approximated the parent material with higher values (Tables 4.3 and 4.4); this is in agreement with Harding and Copley (2000).

GCs had higher density values compared to *E. grandis* and superior CLR and MSS values compared to *E. cammaldulensis.* This implies that GC clones adopt the high density from *E. cammaldulensis* and inherit the workability properties i.e. MSS and CLR from *E. Grandis* parent. GUs had higher density compared to *E. urophylla* and superior MCS, MSS, CLR and MOR comparable to *E. grandis.* MOE and calorific values were lower for all clones compared to the parents while properties MCS, MSS, and CLR were superior to parent values.

Table 4.3: Comparison of wood properties of clones with properties of parent materials at utilisable age (Mean values)

PROPERTIES	MEAN PROPERTIES FROM THIS STUDY					PROPERTIES OF PARENT MATERIALS AT UTILASABLE AGE			
	GU7	GU8	GC540	GC550	GC796	*E.gradis* PROTA	*E.Grandis* Zziwa et al (2006)	*E. Camaldulensis* PROTA	*E. urophylla* PROSEA
BD (Kg/m^3)	654	643	664	627	652	540-775	530	680-980	540-570
CV (KJ/Kg)	17800	17500	17700	17500	16700	18100-19400	-	17700-21000	-
MCS (N/mm2)	67	64	84	63	74	31-68	43	49-72	
MSS (N/mm2)	12	11	12	10	12	7-11	10.42	5-15	
CLR N/mm	20	19	20	18	18	4-6	16.47	16-33	
MOE (N/mm2)	7651	6946	8459	6869	8950	9900-15800	7769	10500-14700	
MOR (N/mm2)	139	134	153	122	148	80-129	68	101-192	
Wmax (J/mm^3)	58	57	53	41	51	-	0.00824	-	-

Key

BD=Basic Density, CV=Calorific Value, MCS=Maximum compression strength parallel to the grain MSS=Maximum shear stress parallel to the grain, MOE= Modulus of Elasticity, MOR= Modulus of Rapture, Wmax= Work to maximum load,

Table 4.4: Comparison of wood properties of clones with properties parent materials at utilisable age (tolerance interval values)

PROPERTY	PROPERTIES FROM THIS STUDY					PROPERTIES PARENT MATERIALS AT UTILISABLE AGE			
	GU7	**GU8**	**GC540**	**GC550**	**GC796**	*E.gradis* PROTA	*E.Grandis* Zziwa et al (2006)	*E. Camaldulensis* PROTA	*E. Urophylla* PROSEA
Basic Density (Kg/m^3)	580-728	606-680	602-727	550-713	569-735	540-775	530	680-980	540-570
Calorific Value (KJ/Kg)	10223-25377	11922-23078	13686-21714	14561-20439	9355-24044	18100-19400	-	17700-21000	-
MCS (N/mm2)	42-92	43-85	62-106	43-83	48-100	31-68	43	49-72	
MSS (N/mm2)	8-15	7-15	8-16	8-12	8-16	7-11	10.42	5-15	
CLR N/mm	12-27	11-27	10-30	10-26	8-28	4-6	16.47	16-33	
MOE (N/mm2)	1252-14049	1533-12358	1932-14986	2527-11211	3029-14871	9900-15800	7769	10500-14700	
MOR (N/mm2)	93-186	93-175	91-215	74-170	95-201	80-129	68	101-192	
Wmax (J/mm^3)	-19-135	0-114	11-94	12-70	14-88	-	0.00824	-	

Key: BD=Basic Density, CV=Calorific Value, MCS=Maximum compression strength parallel to the grain MSS=Maximum shear stress parallel to the grain, MOE= Modulus of Elasticity, MOR= Modulus of Rapture, Wmax= Work to maximum load.

CHAPTER FIVE

DISCUSSIONOF FINDINGS

GC540 and GU7 had higher mean values for basic density, CLR and CV; basic properties for structural timber and fuel wood production. GC540 and GC796 had higher values for MCS, MOR and CRL compared to other clones which indicate a potential for structural use with good workability with joints. The differences in overall means of property values can be as a result of influence of the anatomy of wood from individual hybrids e.g. thickness of the cell wall, size and arrangement of intercellular spaces and vessels (FPL, 2000).

5.1.Variation in properties

BD, MSS, CRL, MOE, MOR and Wmax were shown to be influenced by growing site for the different clones. This is, however, expected when dealing with materials such as wood that reflect the conditions under which they grow (Thelandersson, 2003; Desch and Dinwoodie, 1996). The property most influenced by growing site was basic density; it varied in all clones except GU7. The general variation can be attributed to the differences in altitude, rainfall and soils in the two agro-ecological zones (Wortmann and Eledu, 1999). However, variation in density can probably be explained by the differences in the amount of cell wall and extraneous substances present in clonal wood from the two AEZ. The influence due to site was most expressed in clones GC540 and GC796 in which at least 5 properties (BD, MSS, CLR, MOE, MOR and Wmax) were significantly different. The variations in properties of clones GC540 and GC796 due to site can be explained by the differences in growing conditions in the two AEZ which result in significant differences in the amount of latewood and early wood formed. Thus indicating that clone GC796 and GC540 is site specific to Ikulwe and Kifu respectively.

Basic density and MCS increased significantly along tree height, this behavior is in contradiction with systematic variation of wood properties along tree height which asserts that as a rule the heaviest wood is found at the base of a tree (Desch and Dinwoodie, 1996). BD and MCS varied significantly along tree height especially among GU clones. This kind of variation can be a result of genetic variability and the resulting fast growth rate while the variations in BD and MCS in GU clones can be probably explained by differences in cellular structure e.g. tracheid length and diameter at different levels along the tree height of GU clones compared to GC clones. MCS, MSS, MOE and MOR varied across the stem for the different clones probably due to the differences in width of growth rings and cell structure arrangements for the different clones. However, since basic density and CV did not vary in radial direction it might be that clonal wood at 6-7 years is largely juvenile despite the volume attained.

5.2.Comparison of properties and prediction of potential end use of clonal timber

Clones GC540, GC550 and GC796 have superior MSS and CLR properties and their wood has improved workability advantage compared to *E. camaldulensis* whose wood is susceptible to splits due to the release of growth stresses and has poor nail or nail plate penetration ability (Doran and Wongkaew, 2008). This property is desirable for use of eucalypts wood for furniture and light construction.

Further, all clones tested have medium to low density (Kityo and Plumptre, 1997) and according to Gan, *et al* (2005) fall into the category of light hard wood timbers (density less than 720 Kg/m^3). Therefore, clonal wood would be more flexible and accordingly easier to compress into particle boards with higher specific gravity and more homogeneity (Naumann and Vital, 2008;

Kollmann *et al.*, 1975). It can thus be concluded that clonal wood grown in Uganda has diverse uses such as light wood construction, furniture, pulp and paper.

GU clones derive their superiority from the *E. grandis* parent since *E. urophyla* is known to have low density (Turnbull and Doran, 1997). The high calorific value of GU7 may be explained by high density of the clone and to some extent to the presence of substances such as resin and other extractives in the parent *E.urophyla* (Turnbull and Doran, 1997). The higher MSS, CLR and MOR values of clones compared to parents can be attributed to cellular arrangement of clonal wood or by the fine structure of the cell walls as a result of cloning.

The low CV among clones compared to parent materials could be probably due to the low heartwood to sapwood ratio at this age and probably not enough extractives accumulated. However, clonal timber remains a viable option for fuel wood compared to parent materials since the differences in CV can be compensated by the superior volume increment of clones per unit time.

The low values of MOE compared to parents could be due to variations in density and probably microfibril angle since according to Yang and Evans (2003) the two properties in eucalypts account for variations in MOE with density alone accounting for 81% of the variations. The lower values of MOE can further be explained by the fast-growing nature of the clones that results into large percentage of early wood, large diameter cell with large lumens and thus lower properties. The low property values could also be attributed to substantial presence of juvenile wood in 6-7 years old clones which has inferior properties compared to mature wood (FPL. 1999).

From the results above and the known uses of the parent materials (Doran & Wongkaew, 2008; Nyunai, 2008; Kityo & Plumptre 1997), all clones tested especially GC540, GU7 and GC796 can be satisfactorily used for construction, flooring, joinery, panelling, posts, poles and furniture with an added advantage of better working properties with joints and nailed timber as discussed above. However, since MOE is lower than for the parent materials, clonal eucalypts wood at 6-7 years is not recommended for heavy duty construction especially where members are required in bending such as in beams and joists.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

From the study findings, it is concluded that:-

a) In terms of basic density and calorific value, clone GC540 and GU7 had higher values and could be developed further for timber and fuel wood production. Further GC540 and GU7 showed a potential for good workability with joints owing to their high CRL values.

b) Mean values for MCS, MOR and CRL were high in clones GC540 and GC796 indicating a potential for use as structural timber and poles.

c) All clones have superior cleavage resistance and shear strength properties compared to parent materials, a desirable feature that improves workability of *eucalyptus* wood for structural use especially for the local market.

d) The MOE of all clones tested was lower than that of the known values of parent materials and therefore, clonal eucalypts wood at 6-7 years would not be suitable for heavy duty construction especially where members are required in bending such as in beams and joists. However, timber from clones can be used for light construction on recommendation of registered structural engineers.

e) Clonal wood remains a viable option for fuel wood compared to parent materials since the differences in CV can be compensated by the superior volume increment of clones per unit time.

f) Since at least 5 of the properties tested revealed variations with growing site for Clones GC540 and GC796, it can be concluded that the two clones are site specific.

6.2 Recommendations

Based on the results and conclusions of the study, the following are recommended:

a) The 6-7years old clones grown in Uganda can be used for light construction, furniture and poles. However, there is need to study these properties at a higher rotation e.g. nine years and twelve years since some influences due to juvenile wood were observed.

b) Properties such as microfibril angle, fibre length, kappa number and chemical properties should be studied as soon as possible to assess the suitability of clones for pulp and paper.

c) To build on the gains of the tree biotechnology project in Uganda and commercial forestry, studies of wood properties should be included into the breeding programme to form part of parameters for selection, breeding and routine monitoring.

d) Silvicultural efforts to predict the mean annual increment (MAI), the most appropriate rotation age and thinning regimes be made as these will highly determine the quality of saw logs.

e) Since some properties in some clones were influenced by site, it is prudent that adoption of clones to other regions be guided by studies of wood properties and silvicultural attributes for all trial sites.

REFERENCES

Allaby, M. (2004). A Dictionary of Ecology, Oxford University, London

ASTM E870 – 82 (2006). Standard Test Methods for Analysis of Wood Fuels

ASTM: D 143-94 (2000). Standard Test Methods for Small Clear Specimen of Timber. ASTM International. West Conshohocken, United States.

British Standard No.373 (1957).Method of testing small clear specimens of timber. British Standards Institution. London.

Desch H. E. (1981). Timber: Its structure,properties and utilisation. Macmillan PressLtd., London.

Desch, H. E., and Dinwoodie, J. M. (1996). Timber structure, properties, conversion and use, 7thedition. Food products press, New York.

Dinwoodie, J. M. (1979). Timber its nature and Behaviour. Van Nostrand Reinhold Company, New York.

Dinwoodie, J. M. (2000). Timber - Its nature and behavior. Van Nostrand Reinhold Company, New York.

Doran, J. C. & Wongkaew, W. (2008). *Eucalyptus camaldulensis* Dehnh. [Internet] Record from Protabase. Louppe, D., Oteng-Amoako, A.A. & Brink, M. (Editors).PROTA (Plant Resources of Tropical Africa / Ressourcesvégétales de l'Afriquetropicale), Wageningen, Netherlands.< http://database.prota.org/search.htm>. Accessed 4 November 2009.

Epila-Otara, J. S., and Ndhokero, J. (2009).Selection and site matching of Eucalyptus clones in Uganda. *Journal of East African Natural Resources Management*, Nairobi, Kenya Volume 3 No. 1: 237-248

Epila-Otara, J. (2004): Tree Biotechnology Project: Uganda's experience: In: Ngamau, C., Kanyi, B., Epila-Otara, J., Mwangingo, P., and Wakhusama, S., (Eds): Towards Optimizing the Benefits of Clonal Forestry to Small-scale Farmers in East Africa. *International Service for the acquisition of Agri-Biotechnology Applications* (ISAA). Nairobi, Kenya. No. 33 – 2004

FPL (2000). Wood Hand Book: Wood as an engineering material. Forest service U.S. Department of Agriculture. University Press of the Pacific.

FPL, (1999).Wood Handbook; Wood as an engineering material. General Technical Report 113. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 463 p.

Gan, K. S., Sim, H. C., and Lim, S. C. (2005). Classification of light hardwood timbers for drying purpose, Forest Research Institute Malaysia (FRIM), 52109 Kepong, Selangor Darul Ehsan Kuala Lumpur, Malaysia. Accessed on http://info.frim.gov.my/cfdocs/infocenter/highlight/IRPA_2005/GanKS%20(50-52).pdf 13/11/2009.

Gatsby (2009). Draft 3rd quarter report. *Unpublished*

Hanum, I. F., and Van der Maesen L. J.G., (Editors), (1997). Plant Resources of South East Asia. Auxiliary plants (11).

Harding, K. J., and Copley, T. R. (2000). Wood property variation in Queensland-grown slash x Caribbean pine hybrids. In: Dungey, H. S., Dieters, M. J., and Nikles, D. G., (Editors) "Hybrid Breeding and Genetics of Forest Trees" Proceedings of QFRI/ICRC-SPF symposium, 9-14 April 2000, Nosa, Quensland, Australia.

Isaacs, A. (2004).A Dictionary of Physics, Oxford University, London.

Ishengma, R. C., and Nagoda, L. (1991).Solid wood: Physical and mechanical properties, defects, grading and utilization as fuel. Monograph by Department of Forestry, Agricultural University of Norway.

Ishengoma, R. C. (1986).Basic density and strength properties variations in Cordia Africana (Lam) grown under agroforestry in Arumeru, Tanzania.

Kauman, W. G., Ge´rard, J., Jiqing, H., Huaijun, W., 1995.Processing of eucalypts. Commonwealth Forestry Rev. 74 (2),147–154.

Kityo, P. W., and Plumptre, R.A (1997): The Uganda Timber User's Handbook. *A guide to better timber use.* Common Wealth Secretariat, London.

Kollmann, F., Kuenzi, E., and Stamm, A. (1975). "Principles of Wood Science and Technology II. Wood Based Materials," *Springerling-Verlag, New York.* 703 pp.

Lavers, G. M. (1983). The strength properties of timber. Forest products research bulletin No. 50. London.

Loung, M. P. (2004). Mechanical performance of wood construction materials, 16th world conference on non-destructive testing, Montreal Canada.

Metten, C. J. (1986). Structural Timber design and technology, Timber Research and Development Association, Longman Scientific & technical, Longman Group UK.

Moseley, W. H., Bungey, J. H., and Hulse, R. (1999). Reinforced Concrete Design. Macmillan press Ltd, London.

Mugabi, P., Banana, A. Y., Elikenes, B. (2005). Differences in basic Density and strength properties of *Miliciaexcelsea, Maesopsiseminii, CynometraAlexandri* and *Celtisgomphophyla* from Budongo forest Uganda. *Uganda Journal of Agricultural sciences, 11:2-8.*

Mugabi, P., Rypstra, T., Vermaas, H. F., and Nel D. G.(2009). Relationships between drying defect parameters and some growth characteristics in kiln-dried South African grown *Eucalyptus grandis* poles. *European Journal of Wood and Wood Products*, DOI 10.1007/s00107-009-0375-4 Springer, Berlin / Heidelberg.

Naumann, R. B., and Vital, B. R. (2008). Properties of particle boards from *Eucalyptus urophylla* S. T. Blake and *Schizolobium amazonicum* Herb. R. Árvore, Viçosa-MG, v.32, n.6, p.1143-1150, 2008.

NIST/Sematech, (2010). *NIST/SEMATECH e-Handbook of Statistical Methods*, http://www.itl.nist.gov/div898/handbook/, July 25 2010.

Nyunai, N. (2008). Eucalyptus grandisW.Hill ex Maiden. [Internet] Record from Protabase. Louppe, D., Oteng-Amoako, A.A. & Brink, M. (Editors).PROTA (Plant Resources of Tropical Africa / Ressourcesvégétales de l'Afriquetropicale), Wageningen, Netherlands.< http://database.prota.org/search.htm>. Accessed 4 November 2009.

Oballa, P., Chagala-Odera, E., Wamalwa, L., Oeba, V., Mutitu, E. and Mwangi,L. (2005). The performance of Eucalyptus Hybrid clones and local landraces in Various agro-ecological zones in Kenya. International Service for the acquisition of Agri-Biotechnology Applications (ISAA). Nairobi, Kenya.

Odokonyero, G. (1998). Basic density and some strength properties of *Pinus caribaea, Pinus kesiya and Pinus oocarpa,* Grown in Katugo Uganda. Unpublished MSc. thesis, Sokoine Unversity of Agriculture, Morogoro.

Ranta-Maunus A. (2003). Effects of climate and climate variations: In Thelandersson, S., and Larsen, H. J., (Editors) Timber Engineering. John Wiley & Sons Ltd, Sussex England.

Ruyooka, D.B.A. (1999). Sowing the Eucalyptus seed: a solution to household incomes. Makerere University Printery. Kampala.

Sawlog Production Grant Scheme (2007). Tree Species for Commercial Timber Production and where they grow best in Uganda. Plantations Guidelines Nos. 5& 6 – June 2007.

Sawlog Production Grant Scheme (2008). Uganda's Commercial tree planting. Ministry Water and Environment. Number 22: November 2008-Jan 2009.

Thelandersson, S., (2003). Timber Engineering general introduction: In Thelandersson, S., and Larsen, H. J., (Editors) Timber Engineering. John Wiley & Sons Ltd, Sussex England.

Tinius Olsen, (2003). QMAT Materials Testing and Analysis Software. Bulletin113. United Kingdom.

Tugumisirize, O. (2001). Report on Management Planning Exercise in Conifer plantations. Forest Department, Ministry of Water Lands and Environment, Kampala.

Turnbull, J.W. & Doran, J.C. (1997). *Eucalyptus urophylla* S.T. Blake[Internet] Record from Proseabase.Faridah Hanum, I & van der Maesen, L.J.G. (Editors). PROSEA (Plant Resources of South-East Asia) Foundation, Bogor, Indonesia. http://www.proseanet.org.Accessed from Internet: 04-Nov-2009.

Wortmann, C.S., and Eledu, C.A., (1999). Uganda's Ecological Zones. A Guide for Planners and Policy Makers. CIAT, Kampala, Uganda.56 pp.

Yang, J. L., and Evans, R., (2003). Prediction of MOE of eucalypt wood from microfibril angle and density. *European Journal of Wood and Wood Products,*Volume 61, Number 6, 449-452

Zziwa, A., Kabogoza, J. R. S., Mwakali, J. A., Banana, A. Y. and Kyeyune, R. K. (2006). Physical and mechanical properties of some less utilised tropical timber trees species growing in Uganda. Uganda Journal of Agricultural Sciences, 12 (1): 29-37.