CHARACTERIZATION OF THE PHYSICO-MECHANICAL PROPERTIES OF THE DIFFERENT ZONES OF *Borassus aethiopum* (Mmaa Kube)

BY

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DECLARATION

I hearby declare that this submission is my own work towards the MPhil in Wood Technology and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the university, except the literature cited where due acknowledgement has been made.

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ABSTRACT

The suitability of *Borassus aethiopum* as a potential substitute for the primary timber species in the various timber applications was assessed by characterizing the physical and mechanical properties of the dermal zone, sub-dermal zone, central zone and the bulge area of *Borassus aethiopum*. Logs from five *Borassus aethiopum* trees extracted from Asempanaye were converted into boards. One-half of the boards were used in the green state and the other half air dried. The physical properties and mechanical strength test specimens were prepared and tested in accordance with the British Standard BS 373:1957. The range of mean basic density and density at 12% MC for the dermal, sub-dermal and the central zones were 480.4 - 752.7[582.5 - 957.7]kg/m^3, 229.2 - 652.5 [266.4 -814.9] kg/m^3, and 127.7 - 436.8 [145.9 - 525.7] kg/m^3 respectively. The mean green moisture content for the dermal, sub-dermal and the central zones range were 30% - 82%, 37% - 134%, and 69% - 290% respectively. The ranges of mean moisture content, basic density, and density at 12% MC for the bulge area were 200-298%, 78.43-163.3kg/m^3 and 89.0-187.7kg/m^3 respectively. The range of mean strength values in the green and [dry] conditions for the dermal zone, sub-dermal zone, and the central zone were as follows: Modulus of Elasticity: 2971.0 – 20563.8 N/mm^2 [5253.0 – 25871.8 N/mm^2], 1407.3 – 16661.2 N/mm^2 [18432 – 20323.1 N/mm^2], and 118.7 – 4669.9 N/mm^2 [206.0 – 5857.2 N/mm^2], Modulus of Rupture: 31.1-156.1 N/mm^2 [48.5 – 217.1 N/mm^2], 10.6 - 98.2 N/mm^2 [19.0 – 149.7 N/mm^2], and 1.3 – 22.9 N/mm^2 [2.1 – 31.9 N/mm^2], Compression parallel to the grain: 16.9-91.9 N/mm^2 [27.6 – 99.8 N/mm^2], 2.3-61.5 N/mm^2 [3.2 – 71.8 N/mm^2], and 0.03-17.8 N/mm^2 [0.9 – 18.7 N/mm^2]. Shear parallel to the grain: 2.61-13.74 N/mm^2 [5.47 – 19.75 N/m^2], 0.43-10.40 N/m^2 [1.38 – 14.13 N/mm^2], and 0.09 -5.17 N/mm^2 [0.20 – 6.23 N/mm^2], Hardness: 2.74 - 12.23 kN [5.07 – 17.02 kN], 0.66-10.12 kN [1.42 – 12.95 kN], and 0.04 -1.66 kN [0.1 – 3.13 kN]. The range of mean strength values for the MOE, MOR, Hardness, Compression and Shear Parallel to the grain for the bulge area were 70.27 – 188.46 N/mm^2, 1.1 5- 3.30 N/mm^2, 0.09 - 0.44 kN, 0.47 - 2.34 N/mm^2 and 0.12 - 0.67 N/mm^2 respectively. The overall order of decreasing strength properties and density for the various sections of *Borassus aethiopum* was as follows: dermal zone > sub-dermal zone > central zone > bulge area. The overall order of decreasing Moisture Content of the various sections of the tree was as follows: bulge area > central zone > sub-dermal zone > dermal zone. Analysis of variance (ANOVA) of the physical and mechanical properties of these zones indicated that there were significant difference at $P<0.05$ between the zones. The effect of stem height on Borassus aethiopum "wood" physical properties and mechanical properties for each of the zones were significant at $P<0.05$. There was a good correlation (97.1% ~ 99.9%, 94.9% ~ 99.7, 94.8% ~ 99.9% and 18.3%~89.3% respectively for the dermal zone, sub-dermal zone, central zone and the bulge area) between Density (X) and the various mechanical strength values (Y). Regression models in the form: $Y = mx + c$ were derived with R^2 values of 0.96 – 0.99, 0.95 – 0.99, 0.95 – 0.99 and 0.01 – 0.60 respectively for the dermal zone, sub-dermal zone, central zone and the bulge area. The mechanical properties of the dermal zone compare favourably with Afromosia (*Pericopsis elata*), Dahoma (*Pepdiniastrum africanum*), Kusia, Teak (*Tectona grandis*), and Sapele (*Entandrophragma cylindricum*). While that of the sub-dermal zone compares favourably with Mahogany. Hence, an indication that this monocot giant, *Borassus aethiopum,* is a good substitute for these timber species.

DEDICATION

To the late Mr and Mrs Asafu-Adjaye, may the Almighty God grant them a blissful rest.

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ABBREVIATIONS AND SYMBOL

The following abbreviations and symbol were used in the document.

ASTM	American Society of Testing and Materials
BS	British Standard of testing Small Clear Samples
Comp llg	Compression Parallel to the Grain
Df	Degrees of Freedom
[dry]	Samples tested at 12% Moisture Content
Fig.	Figure
FSP	Fibre Saturation Point
P-value	Probability value
MC	Moisture Content
MOE	Modulus of Elasticity
MOR	Modulus of Rupture
MS	Mean Sum of Squares
ns	No Significant Difference at $P<0.05$
s	Significant Difference at $P<0.05$
Shear llg	Shear Parallel to the Grain
SS	Sum of Squares
$(\pm \delta_{n-1})$	Standard Deviation

CHAPTER ONE

Introduction

1.1 The Impact of Forest and Wood Products on Climate Change

The role of carbon in global climate change and its projected negative impact on ecosystem sustainability and the general health of our planet have never been more elevated in the public's consciousness. Forests play a major role in the Earth's carbon cycle. The biomass contained in our forests and other green vegetation affects the carbon cycle by removing carbon from the atmosphere through the photosynthesis process (Forest Products Laboratory, 2010). According to Lewis *et al* (2009), tropical forests cover 7–10% of the global land area, store 40–50% of carbon in terrestrial vegetation and annually process approximately six times as much carbon via photosynthesis and respiration as humans emit from fossil fuel use. Forests and the use of the products from these forests can have a mitigating effect on the build-up of greenhouse gases in the atmosphere. Trees, which are composed of about 50% carbon, sequester carbon dioxide from the atmosphere and are viewed as an integral component for maintaining worldwide atmospheric carbon dioxide balance in the atmosphere (SWST, 1997). Forest Products Laboratory, (2010) reported that carbon in wood remains stored until the wood deteriorates or is burned. A tree that remains in the forest and dies releases a portion of its carbon back into the atmosphere as the woody material decomposes. On the other hand, if the tree is used to produce a wood or paper product, these products store carbon while in use. For example, solid wood lumber, a common wood product used in building construction sequesters carbon for the life of the building. Carbon contained in wood products currently in-use and as wood debris in landfills is estimated at 2.5 billion tonnes and accumulates at a rate of about 28 million tonnes per year (Skog 2008). Lippke *et al* (2004) also pointed out that wood products also mitigate carbon emissions to the degree that they substitute for steel or concrete, which emit more greenhouse gases in their production.

1.2 The Economic Importance of Wood Resource Exploitation in Ghana

Wood resources continue to play an important role in the world, from packaging materials to buildings and to transportation structures. Wood has been useful to human societies for thousands of years; archeological discoveries have shown that wood was used by ancient civilizations as a construction material, as a substrate for ornate decorative objects, and for providing the final resting place for royalty (Forest Products Laboratory, 2010). The increase in the material needs of the growing human population has put great pressure on the forest resources, and has encouraged many to take another look at the environmental impact of meeting these needs. Some have concluded that the forest should not be harvested. However, both human numbers and consumption continue to increase (SWST, 1997). In Ghana, according to Oteng-Amoako *et al* (2003), the annual rate of forest degradation is estimated to be 1.7% due to continuous and uncontrolled exploitation of the economic timber species, which is a threat to Ghana's forests, contributing to the rapid depletion of the plant genetic resources. Nevertheless, the demand for wood is increasing at an alarming rate such that the Annual Allowable Cut (AAC) of one million m^3 is insufficient. Currently, the annual extraction of logs by the saw mills is estimated to be nearly 3.7 million m^3. This causes problems to the forest in that it is incapable to meet the demands of the wood industry and consequently, forcing saw mills to close down (CSIR-FORIG, 2007). The national and international demand for a handful of primary species has led to their dangerous exploitation. Although there are many other timber species termed lesser-used, these are hardly ever touched because their material properties have not yet been fully determined (Frimpong – Mensah, 2008). However, Abeney (1999) reported that the increasing trend of timber utilization has contributed over the years to the neglect of other non-timber forest products, which play important roles in the domestic economy in forest management. In Ghana, the average consumer of wood believes that hardwoods give the best results when utilized for timber and hence have laid more exploitation emphasis on these woods at the expense of several potentially useful monocotyledonous species that the country is endowed with. Butterfield and Meylan, (1980), however, disagreed with this view and pointed out that although tree-like monocotyledonous species do not produce wood in the usual sense of the word, their stems are physically hard, can grow to about 20-60cm in diameter and hence are potential source of raw materials for use in the manufacture of several wood products. The utilization of other lesser-known species needs to be looked at urgently as an alternative to the primary timber species so as to increase the wood resource base. The development and efficient utilization of *Borassus aethiopum*, which hitherto have not been utilized industrially, could assist in arresting the current wood supply problems and also expand the wood resource base. It is expected that efficient utilization of the lesser-used wood species would reduce the negative ecological imparts such as reduction in biodiversity and desertification (Okai, 1998). The economic importance of palms, especially in the tropics, is well known. In addition to providing food and shelter to many in some tropical regions, palms furnish several valuable commodities such as oil, starch, sugar, wine, wax, and fibre. The coconut (*Coconut nucifera*) and the oil palm (*Elaeis guineensis*) are the best examples of commercially important palms.

Multimillion-dollar industries based on palm products are thriving well in many countries. Yet, compared to other economically important plants, palms have received relatively little research attention. This may in part due to insufficient basic information and to the technical difficulties of working with these monocotyledonous giants (Parthasarathy and Klotz, 1976).

1.3 General Background of *Borassus aethiopum*

Borassus aethiopum, a non-timber forest product and a Palm, belongs to the family Arecaceae or Palmae (Johnson, 1998). *Borassus aethiopum* is an unbranched Palm growing to 20-30m tall and characterized by a crown up to 8m wide (Irvine, 1961). *Borassus aethiopum* with over 25 years old have a swelling of trunk at about 12-15m above ground, which gives it a characteristic structure. There are two varieties of this species: variety *bagamojensis* and variety *senegalensis* (Bayton et al, 2006). The male is more cylindrical and flowers, but does not bear fruits, while the female which bears edible fruits has a stem that is comparatively bigger in the middle and tappers towards both ends (CSIR-FORIG, 2007). A cross section through the stem shows three layers: the dermal, sub-dermal and central zone, (Eaia, 1983). It is mostly found in Tropical and Southern Africa, Savannah and Open forests; specifically in Semi-arid and Sub-humid Zones. In Ghana, it is known by various local names as 'Maakube' (Twi), Wiedzo (Ga) and 'Agor' (Ewe) (Irvin, 1961). It abounds naturally in the transitional and savannah zones of Ghana as well as the West African sub-regions (Ayarkwa, 1997). It also occurs in wetter parts of the coastal areas and grassland, particularly East of the Volta Region (Agbitor, 2005). *Borassus aethiopum* is locally sawn and used as posts and for the construction of bridges. The boards cut from the trunk are used for roofing and for the construction of door frames

(Johnson 1998). These uses are borne out of the availability of the material rather than a detailed knowledge about their technical information on their natural properties.

1.4 The Significance of testing Materials

Generally, wood is considered as dimensionally unstable, subject to decay by fungi, destruction by inserts and marine borers and is easily burned. It is not often realized that the difficulty being faced in its use is due to lack of proper understanding of its properties, rather than to defects in the timber itself (Shrivastava, 1997). Ofori *et al*, (2009) stated that regardless of the source of a wood product, the user may be primarily concerned with variability that may be encountered in the green moisture content and the basic density of wood. These are directly related to the weight of logs and green lumber. Information on green moisture content may be of concern to those who design harvesting and transportation equipments, or must ship or transport green wood; and data on basic density is needed in estimating the variability in the strength of wood product (Haygreen and Bowyer, 1996). Bodig and Jayne (1982) indicated that the strength properties of wood are designed almost exclusively for predicting the performance of wood during service. The mechanical strength properties measured depend on the specific uses to which the timber is to be put. Timber is probably stressed in bending more than in any other mode and there are very many examples of timber being used in bending, (Desch and Dinwoodie, 1996). Examples are when used as floor and ceiling joists and roof trusses. Shear strength parallel to the grain is the most important property that comes into play in structural use of timber in jointing. High Strength in compression parallel to the grain is required of timber used as columns, posts, and as notched timbers. Hardness is an important property when the timber is used for paving blocks, floors decking and bearing blocks (Ofori *et al*, 2009). It is worth noting that, the variation in strength properties found among different sections of the same wood species influences the selection of a section for a particular use. Depending also on a particular use for which wood is intended for, one strength property normally predominates. According to Wilson and White, (1986), the mechanical properties of wood are largely determined by the distribution of the anatomical structures of the wood. A comprehensive knowledge about the anatomical, chemical, mechanical and physical properties will help in the effective utilization of the species and also assist in the establishment of safety values and design functions, especially when it is used for structural purposes.

1.5 Objectives of the Study

1.5.1 Main Objective

The main objective of the study is to characterize the Technological properties of *B. aethiopum.*

1.5.2 Specific Objectives

The Specific Objectives are:

1. To determine the physical Properties of *Borassus aethiopum.*
2. To determine the mechanical properties of *Borassus aethiopum* both in the green and dry state.
3. To assess the within and between trees variation of the properties determined.
4. To determine the basic stresses of *Borassus aethiopum*.

CHAPTER TWO

2.0 Literature Review

2.1 Strength Properties

The term strength properties or mechanical properties as applied to a material such as wood refers to the ability of the wood to carry applied load or forces (Haygreen and Bowyer, 1996). Tsoumis (1991) defined strength properties as the measure of its resistance to exterior forces, which tend to deform its mass. The resistance involves a number of specific mechanical properties and it is these that determine the suitability of different species of timbers for the various purposes for which they are used (Illston *et al,* 1987). Desch and Dinwoodie (1996) also defined the strength of a wood as the ability of the wood to resist applied forces that could lead to its failure. Haygreen and Bowyer (1996) indicated that mechanical properties are usually the most important characteristics of wood products to be used in structural applications. They further explained that the term strength is often used in general sense to refer to all mechanical properties. Nonetheless, there are many different types of strength and elastic properties and as such it is important to be very specific about the type of mechanical property being discussed.

A comprehensive knowledge of the structure of wood, its chemical and physical behavior, and the causes of variability, as they affect its utilization form the basis of present and potential utilization of wood (Panshin and de Zeeuw, 1980). According to Farmer (1972), timber, like all other materials of construction, has the ability to resist applied or external forces. In practice, timber is frequently subjected to a combination of stresses (compressive, bending tensile and shearing), although one usually predominates. Farmer (1972), expressly explained that many other factors have to be considered as well in the selection of species for a particular purpose, but in general, there are few instances where the choice does not depend to some degree upon one or more of its mechanical properties. Hence, a basic knowledge of the strength properties of timber is essential, if it is to be used efficiently. The strength properties largely determine the fitness of wood for structural building purposes and there is hardly a single use of wood that does not depend at least to some degree on one or more of its strength properties (Kollmann and Cote, 1968). Haygreen and Bowyer (1996) pointed out that wood that is relatively strong with respect to a strength property may rank lower in a different property. They also stated that strength properties are designed almost exclusively to obtain data for predicting the performance of wood during service. For it is this data that will aid a forester who is selecting a "superior tree" for genetic breeding, a wood technologist developing a new product, and a design engineer encountering a unique environmental condition.

2.2.0 Mechanical Properties of wood and its significance

These are categorized broadly into elastic properties and strength properties.

2.2.1 Elastic Properties

Wakefield (1957) stated that elastic properties relate the resistance of a material to deformation under an applied stress to the ability of the material to regain its original dimensions when the stress is removed. The elastic properties include the following:

2.2.1.1. Modulus of Elasticity (MOE)

Forest Products Laboratory, (2010) reported that elasticity implies that deformations produced by low stress are completely recoverable after loads are removed. When loaded to higher stress levels, plastic deformation or failure occurs. Modulus of elasticity relates the stress applied along one axis to the strain occurring on the same axis. The three moduli of elasticity for wood are denoted E_L, E_R, E_T, to reflect the longitudinal, radial and tangential directions respectively (Forest Products Laboratory, 2010). Elastic constants vary within and between species and with moisture content and specific gravity. The only constant that has been extensively derived from test data is E_L. Other constants may be available from limited test data but are most frequently developed from material relationships or by regression equations that predict behavior as a function of density (http://www.fpl.fs.fed.us/document/pdf/1994/winam94apdf). The modulus of elasticity (MOE) is a property of importance in determining the deflection of a beam under load. This is usually considered in conjunction with bending strength. The strength of a long timber column or strut is a critical property determined by the stiffness (MOE) of the material (Timings 1991). Shrivastava, (1997) also added that MOE is the measure of stiffness; the higher the MOE, the less is the deflection or the greater the stiffness. He observed that the MOE measures the relation between stress and strain within the limit of proportionality.

2.2.1.2 Modulus of Rigidity

The modulus of rigidity, also called shear modulus, indicates the resistance to deflection of a member caused by shear stresses. As with moduli of elasticity, the moduli of rigidity vary within and between species and with moisture content and specific gravity (Forest Products Laboratory, 2010).

2.2.1.3 Poisson's Ratio

When a member is loaded axially, the deformation perpendicular to the direction of the load is proportional to the deformation parallel to the direction of the load. The ratio of the transverse to axial strain is called Poisson's ratio. Poisson's ratios vary within and between species and are affected by moisture content and specific gravity (Forest Products Laboratory, 2010).

2.2.2 Strength Properties

According to the Forest Products Laboratory, (2010) mechanical properties most commonly measured and represented as "strength properties" for design include modulus of rupture in bending, maximum stress in compression parallel to grain, compressive stress perpendicular to grain, and shear strength parallel to grain. Additional measurements are often made to evaluate work to maximum load in bending, impact bending strength, tensile strength perpendicular to grain, and hardness.

2.2.2.1 Modulus of Rupture (MOR)

Wilcox *et al*, (1991) stated that modulus of rupture (MOR) is an index of the maximum load a bending member can be expected to support before failing, weighted for the effects of span, width and depth. Shrivastava, (1997) also pointed out that modulus of rupture is a measure of the maximum compressive or tensile stress in the fibres at the point of fractures. This is obtained from the static bending property of a material in which the maximum bending strength or equivalent fibre stress at maximum load is measured. The modulus of rupture is important in members subjected to transverse loading as in the loading of roof trusses (Timings, 1991).

2.2.2.2 Compressive Stress

When the applied forces tend to decrease the length of a body, it is under compression, and the stress is called the compressive stress. Compressive stress may be parallel to or perpendicular to the grain (Shrivastava, 1997). Compressive strength parallel to the grain or maximum crushing strength is the property that measures the ability of timber to withstand loads when applied on the end grain (Timings 1991).Wakefield (1957) elucidated that when wood is stressed in compression parallel to the grain, failure initially begins as the micro fibrils begin to fold within the cell wall. As stress in compression parallel to the grain increases, the wood cells themselves fold into S shapes, forming visible wrinkles on the surface. Large deformations occur from the internal crushing of the complex cellular structure (http://www.fpl.fs.fed.us/document/pdf/1994/winam94apdf). High strength in longitudinal compression is required of timber used as columns, props and chair legs. Compressive strength perpendicular to the grain which is the resistance to crushing is and important property in a few selected end uses such as railway sleepers, rollers, wedges, bearing blocks and bolted timbers. Those timbers which are high in density have high compression strength across the grain (Desch and Dinwoodie, 1996). According to Forest Products Laboratory, (2010) compressive stress perpendicular to the grain is reported as stress at proportional limit and added that there is no clearly defined ultimate stress for this property. Compression perpendicular to the grain strength is often not carried out but is computed from the side hardness of the timber since there is a very high correlation between the two properties (Lavers, 1983).

2.2.2.3 Toughness

Dinwoodie (1989) defined toughness as the energy required to propagate cracks. Tsoumis (1991) referred to toughness as the energy in dynamic bending and explained that it is the resistance against sudden loading contrast to static bending. He added that the energy absorbed by wood is higher with sudden rather than static loads. Also with sudden loading, the deflection of a beam is about double in comparison to static loading.

Toughness, or resistance to impact, is an essential requirement of timber for hammer handles, shafts and many sports goods (Desch and Dinwoodie, 1996). Shrivastava (1997) had noted that the term toughness is commonly applied to more than one property of wood. Thus, wood which is difficult to split is said to be tough or again a tough wood is one that will not rupture until it had deformed considerably, or is one that still hangs together after it had been ruptured and may be bent backwards and forward without breaking apart. Nonetheless, he expressed that technically the toughness is the ability to resist shocks and blows and is synonymous with impact strength.

2.2.2.4 Work to Maximum Load

Haygreen and Bowyer, (1996) defined Work to Maximum Load as the measure of the energy absorbed by a specimen as it is slowly bent. Again, Work to Maximum Load in bending is defined by Forest Products Laboratory, (2010) as the ability to absorb shock with some permanent deformation and more or less injury to a specimen. Work to maximum load is a measure of the combined strength and toughness of wood under bending stresses.

2.2.2.5 Shearing Stresses or shearing

According to Shrivastava (1997), shear strength measures the ability of wood to resist forces that tend to cause one part of the material to slide or slip on another part adjacent to it. Shearing stresses may be parallel to, or perpendicular to the grain, but it can be shown that a shearing stress sets up an equal stress at right angel to it, and since wood is much stronger in shear across the grain than it is along the grain, it is extremely difficult to obtain the true shear strength perpendicular to the grain, as failure always occurs by shear parallel to the grain. There exist also, a shearing force that tends to move the fibers of a beam past each other in a longitudinal direction. This shear, called horizontal shear, results from the slipping over one another of the fibers as several boards are placed longitudinal on each other, tend to bend. These forces are considered in designing structural forms of wood that may be subjected to bending while in service (Wangaard, 1950). Tsuomis (1991) added that the strength of wood in axial shear has the greatest practical importance; under the influence of shearing loads, wood usually fails in this manner.

2.2.2.6 Tensile

Tensile strength is the ability of a material to resist the force that pulls the material and tries to elongate or stretch it. Tensile strength perpendicular to the grain is important in design of the connections between wood members in a building. In contrast, tensile strength parallel to the grain is important for the bottom member in a wood trusses and in the design of connection between structural members (Haygreen and Bowyer, 1996). However, because of the excessive variability associated with ultimate stress in tension perpendicular to the grain, design situations that induce this stress should be avoided (Bodig and Jayne, 1982).

2.2.2.7 Hardness

Hardness represents the resistance of wood to indentation and marring. Hardness is comparatively measured by force required to embed an 11.3 ball one-half its diameter into the wood. Hardness determines the material that can be used for flooring; paving blocks and bearing block (Hoadley, 1980).

2.3.0 Factors Affecting Strength Properties

Density is perhaps the most important single factor influencing the strength and stiffness of timbers, but there are many other variables, some anatomical in origin such as knots, slope of grain and microfibrillar angel, and some environmental such as moisture content and temperature, all of which play a significant role in determining the strength and stiffness of wood (Desch and Dinwoodie, 1996).

2.3.1 Density and Specific Gravity

Haygreen and Bowyer (1996) indicated that density and specific gravity are perhaps the most important factor influencing the mechanical properties of timber and possibly, it is for this reason that density was the first wood property to be scientifically investigated. Tsoumis (1991) pointed out that density is the best and simplest index of the strength of a clear wood, with increasing density, strength also increases. This is because density is a measure of the amount of cell wall materials contained in a given volume of wood. Therefore, higher density denotes larger amount of cell wall available to resist external forces. It serves as a measure for the mechanical properties such as bending and represents the simplest and the best indicator of wood quality (Kubler, 1980). Increasing density results in corresponding increases in all strength properties, except for axial tension (Dinwoodie, 1989). For elasticity and shock resistance properties, density is less correlated. High density is associated with thick fibre walls and a higher proportion of fibres. These are the very qualities which contribute to strength and in the absence of any other data about the properties of a particular species, wood density is used as a guide to its utilization (Shrivastava, 1997). Desch and Dinwoodie, (1996) also elucidated that some strength properties show a very marked correlation with density; naming compression strength parallel to the grain, bending strength and hardness falling into this category of properties. They added that the density of a piece of wood is determined not only by the amount of wood substance present, but also by the presence of both extractives and moisture. The presence of moisture in wood not only increases the mass of the timber, but also increases the volume. Density is determined using the relation:

$$Density = \frac{Mass\ of\ wood}{Volume\ of\ wood}$$

Donaldson *et al* (1995) reported that density usually decreases with height in the stem. Specific gravity is an excellent index of the amount of wood substance contained in a piece of wood; it is a good index of mechanical properties as long as the wood is clear, straight grained, and free from defects. However, specific gravity values also reflect the presence of gums, resins, and extractives, which contribute little to mechanical properties. In fact, mechanical properties within a species tend to be linearly, rather than curvilinearly, related to specific gravity (Forest Product Laboratory, 2010). Haygreen and Bowyer, (1996) added that specific gravity is the ratio of the density of wood to the density of water; is always calculated using oven-dry weight or mass. Specific gravity is computed using the relation:

$$Specific\ Gravity = \frac{Density\ of\ oven\ dried\ wood}{Density\ of\ water}$$

2.3.2 Slope of Grain

Deviations from straight grain in a typical board are termed slope of grain or cross grain. The terms relate fibre direction to the edges of the piece. Any form of cross grain can have detrimental effect on mechanical properties (Hoadley, 1980). According to (Haygreen and Bowyer, 1996) the slope of grain in lumber is expressed as the length in inches through which a one inch deviation in the grain occurs. The mechanical properties of wood are quite sensitive to fibre an ring orientation. For example, tensile parallel to the grain or compression strength parallel to the grain values are generally 10 to 20 times greater than that of perpendicular to the grain (Panshin and de Zeeuw, 1980) Dinwoodie (1981) indicated that anisotropy in strength is due in part to the cellular nature of the timber and in part to the structure and orientation of the microfibrils in the cell wall layers.

2.3.3 Moisture Content (MC)

Moisture affects the strength properties when it changes below the fiber saturation point. When moisture is reduced, strength increases and vice versa. This increase is due to changes in the cell walls, which become more compact (Tsoumis, 1991). However, Desch and Dinwoodie (1996) indicated that the change in strength with changing moisture content is non-linear and that the percentage increase in strength for a given reduction in moisture content is greater at low compared with high levels of moisture content. Generally, as water is removed from the cell wall, the long chain molecules move closer together and thus become more tightly bound and increase in strength begins as the moisture level drops slightly below the fiber saturation point usually around 30% moisture content. According to Findlay (1978), at 12% MC air-dried wood may carry twice the load green timber is able to bear. All strength properties values are not affected in the same way by changes in MC. Toughness for instance may decrease with a decrease in MC, therefore it is necessary to control and measure the moisture content of test samples during the laboratory investigations on strength properties. Desch and Dinwoodie (1996) reported that moisture content may also vary with height in a tree.

2.3.4 Knots

Tsoumis (1991) pointed out that knots also influence strength properties of a given piece of wood to varying degrees, depending on their size, position and manner of loading. He further explained that the adverse influence of knots is mainly due to local grain deviations and checks caused by their presence. Checks are formed due to differential shrinkage and swelling of knots, because their density is higher, they usually contain compression or tension wood, and their fiber orientation is different in comparison to those of the adjacent wood. According to Desch and Dinwoodie (1996), one method of estimating the effect of knots is to express that shape of the knot in terms of the knot area ratio, this relates the sum of the sectional area of all the knots at a particular cross section to the cross sectional area of the entire piece of timber.

2.3.5 Temperature

The effect of temperature on the mechanical properties of wood is grouped into two namely reversible and irreversible effects, according to Forest Product Laboratory, (2010).

Reversible Effects

In general, the mechanical properties of wood decrease when heated and increase when cooled. At constant moisture content and below approximately 150 °C (302 °F), mechanical properties are approximately linearly related to temperature. The change in properties that occurs when wood is quickly heated or cooled and then tested at that condition is termed an immediate effect. At temperatures below 100 °C (212 °F), the immediate effect is essentially reversible; that is, the property will return to the value at the original temperature if the temperature change is rapid.

Irreversible Effects

In addition to the reversible effect of temperature on wood, there is an irreversible effect at elevated temperature. This permanent effect is one of degradation of wood substance, which results in loss of weight and strength. The loss depends on factors that include moisture content, heating medium, temperature, exposure period, and to some extent, species and size of piece involved. Brandon (2005) stated that strength of wood is inversely proportional to the temperature; if the temperature of wood at 12% MC is increased from 20 °C to 40 °C the modulus of rupture will decrease by around 15%. Short term heat soaking will not permanently affect strength but long periods at high temperatures will reduce the ultimate modulus of rupture and modulus of elasticity values. Tsoumis (1991) added that generally the strength of wood decreases with increasing temperature. This reduction is influenced by such factors as moisture content of wood, level of temperature and duration of heating and also it may stem from defects such as checks. A good rule of thumb is that an increased in temperature of 1°C produces1% reduction in the ultimate value (Desch and Dinwoodie, 1996). They further explained that this effect of temperature is dependent on moisture content; the effect being considerably greater the higher the moisture content.

2.3.6 Time

Haygreen and Bowyer, (1996) stated that the strength of wood does not decrease over time unless the product is subjected to the deleterious effect of micro-organisms, high temperature, drastic moisture fluctuation, or strong chemicals. They further indicated that changes do not occur after centuries, but these are usually the result of environmental factors and not aging per se. However, Tsoumis (1991) explained that some loss of strength will occur in wood if aging is accompanied by continuous loading of the members.

2.3.7 Rate and Duration of Loading

The mechanical performance of wood is time-dependent, thus the material can be described as having viscoelastic behavior. Dinwoodie (1989) described viscoelastic solids as those materials which are neither truly elastic nor truly plastic, but a combination of both. When a load is applied to a viscoelastic material such as wood, there is an initial instantaneous elastic deformation, then a period of increasing deformation with duration of loading. If the load is removed before failure sets in, part of the deformation disappears instantly. This is referred to as initial elastic deformation and it is known as elastic recovery. Further recovery according to Dinwoodie (1989) will be obtained after a period of time, but there exist a certain amount of deformation which is irretrievable. This is termed creep, and is a function of time and stress. It is generally the non-elastic deformation of a material and will occur if the elastic limit is exceeded for an appreciable length of time. The rate of loading has a significant influence on the ultimate strength of timber. The more rapid, way of loading members, the higher the apparent strength. Thus, the necessity to carry out tests on wood under standardized conditions, where the rate of loading is specified for the different tests methods (Lavers, 1983). Substantial reduction factors are applied to stress values obtained from the laboratory tests in which the load duration is a few minutes to convert them to working stresses suitable for long-term loading. The stresses for shorter periods of loading in service are usually higher than those for longer periods. Addae-Mensah (1990) investigated and observed that, the load which a structural member sustains increases as the duration of loading increases and with time. Accordingly, the ultimate or fatigue strength of timber falls to approximately 50-70% of the short-term laboratory test value. Addea-Mensah (1990) noted that, some form of correlation exist between the proportional limit (P) and the fatigue strength of timber structures. This, he noted, have been investigated for a number of European softwoods and suggested that, tropical hardwoods should also be studied. According to Gerhard's (1988), there is a constant load effect on the strength of lumber in bending regardless of the static strength level. Lower grades of lumber loaded at the same fraction of static strength tend to have shorter load durations. Allowable strength properties of lumber therefore need to consider real loads for product safety.

2.3.8 Decay and Insect Damage

According to Kollman and Cotê (1968), wood is susceptible to decay and insect damage in moist, warm conditions. Decay within a structure cannot be tolerated because strength is rapidly reduced in even the early stages of decay. It has been estimated that a 5% weight loss from decay can result in strength losses as high as 50%. If the warm, moist conditions required for decay cannot be controlled, then the use of naturally resistant wood species or chemical treatments is required to impede decay. Insects, such as termites and certain types of beetles can be just as damaging to mechanical performance. Insect infestation can be controlled via mechanical barriers or chemical treatments or by using naturally durable species.

2.4 Methods of Determining Strength Properties

Dinwoodie (1989), reported that two methods are employed in the determination of strength properties of wood. These are Service test and Laboratory experiments. The former have the advantage of being carried out under the same condition to which timber is exposed in use. According to ASTM D143-94 (2008), the need to classify wood species by evaluating the physical and mechanical properties of small clear specimens has always existed. Because of the great variety of species, variability of the material, continually changing conditions of supply, factors affecting test results, and ease of comparing variables, the need will undoubtedly continue to exist. In addition, Desch and Dinwoodie (1996) asserted that this method still remains valid for characterizing new timbers and for the strict academic comparison of wood from different trees or different species. Tsoumis (1991) explained that small clear specimens present the possibility of wider sampling and the systematic study of the effects of various factors like moisture content, density, growth - ring structure, physical and chemical treatment on mechanical properties, while such effect are difficult to transfer to full size members due to variation of wood structure and the presence of defects. In addition, he explained that when small clear specimens are used, reduction factor must be applied to obtain safe working stresses. Test on timber of structural sizes are more representative of service conditions, but they have the disadvantage of being costly and time consuming since large wood samples are required and they take a longer time to rapture. British Standards B.S 373 (1957) stated that timber should be tested both in the green state and in the seasoned condition. British Standard (B.S) 373 (1957), further indicated that the testing of small clear specimens of timber serve mainly to provide data for the comparison of the strength properties of different species, but in addition, the test results may be used to determine the relationship between strength and such properties as density and moisture content, and also to assist in the establishment of design functions for structural use.

2.4 Variation and Causes of Variation in Wood Properties

The natural origin of wood both physical and mechanical properties of wood frequently exhibit unusually wide degree of variability. It is therefore essential to understand the variation that occur in wood, because they affect wood processing and utilization. Thus a comprehensive knowledge of the structure of wood, its chemical and physical behavior and the causes of its variability as they affect its utilization form the basis of present and potential utilization of wood (Panshin and de Zeeuw, 1980). They further explained that wood is an inherently variable material owing to its origin as a product of metabolism and its properties are subject to wide variations culminating from the physiology of tree or its genetic constitution and environmental influences affecting its growth condition. Dinwoodie (1989), also pointed out that differences in structure and hence performance occur not only between different species growing in different environment but also between different parts of a single tree. The variations in properties of wood occur principally between species, within a single species in a geographical area, in a single tree, in the stem in the radial direction, in tangential and in the longitudinal directions (Bodig and Jayne, 1982). Haygreen and Bowyer (1996) stressed that strength varies widely within and among species. Within any species there is a considerable variation in clear wood strength properties, which corresponds to the variation in density and to the density – relationship for that property. Panshin and de Zeeuw (1980) again revealed that the variability of wood characteristics within individual trees is fundamentally influenced by changes in the cambium as it ages, genetic controls that govern form and growth of the tree and environmental influences such as seasonal or geographical conditions or nutrient supply. These may give rise to modifications of the basic patterns for variance of wood. They mentioned for example that variation in the amount of cell wall substance in wood are the results of changes in cell morphology (length, diameter and wall thickness) and changes in the proportionate volumes of different cell types with position in the tree, although additional modifications arise from the presence of extractives and also from the influence of growth rate . Nevertheless, it is difficult to ascribe this variability of wood characteristics to a single factor or even to a combination of factors affecting tree growth. This is because of the interactive influence of these factors. Dinwoodie (1989) has noted that variability in wood is one of its characteristic deficiencies as a structural material. Structural differences do occur not only between different species of timber but also between different parts in a single tree (Carmicheal, 1984; Mettem, 1986; and Desch and Dinwoodie, 1996). Within a tree trunk, there are systematic patterns of variation in cell length, cell wall thickness, and angle of grain (Dinwoodie, 1981). Panshin and De Zeeuw (1980) also reported that, horizontal variation exist in wood structure from the pith to the bark and a vertical variation from the base to the crown. At any height level, and from the pith to the bark, there is a general variation in structural characteristics. The parenchyma cells in any zone after some time lose their living protoplasm and the vessels and tracheids cease their conductive function, wood then function as a supporting tissue as these changes take place. In the development stages, from juvenile to maturity, changes are observed under normal conditions of growth of the tree. Wood from different parts of a tree is noted to show differences in density (Jane, 1970).

2.4.1 Anatomy and Extractives of wood in relation to Strength Variation

In woods, certain common features such as the pattern of their structure, the cellular micro-structure and porosity, their lack of homogeneity and chemical constitutes differ in diverse ways (Hillis, 1962). The physical and mechanical properties of wood have been noted to be determined by the anatomical structure of the wood. According to Desch and Dinwoodie (1996), a minimum length of cell is necessary to ensure sufficient overlap for transfer of stresses from one cell to another. The strength properties of wood have been noted to depend on structures beyond the range of the normal microscope. The cells of wood are glued together with hemicelluloses and pectin and are composed of lignified cellulose tubes. These lignocellulosic have properties which affect the strength of wood. Middleton (1989) also reported that the strength properties of wood could be predicted from its visible structures. For example, timbers which are ring porous, with good development of latewood fibers tend to be tough with considerable shock resistance. Variations in the properties of wood from different sites have been reported to reduce the effective strength to 75% of the value obtained from laboratory test results (Richardson, 1976). Extractives have little or no direct effect on the mechanical properties of wood. However, extractives are responsible for increasing specific gravity and lowering the equilibrium moisture content. Consequently, extractives can modify many mechanical properties indirectly. For example, relationships between specific gravity and strength for several species are influenced by the presence of extractives (Bodig and Jayne, 1982).

2.5 Wood Moisture Content

Wood moisture content is one of the many variables that affect the performance and utilization of wood. The amount of water present in wood does not only influence its strength, stiffness and mode of failure, but also, it affects its dimensions, its susceptibility to fungal attack, its workability as well as its ability to accept adhesives and finishes. There is a considerable amount of moisture in the timber of living trees and newly felled logs. The actual amount will vary significantly among trees of different species Desch and Dinwoodie (1996). They pointed out that the water content in some logs is only about 40% of the oven-dry mass of the wood. While in others it may exceed 20% of the mass. Also in most species there is usually a marked difference in the moisture content which may vary with height in the tree. Desch and Dinwoodie (1996) stated that water present in wood is in two forms, namely that water present within the cell cavities described as free water and that found in the cell wall also known as bound water. The removal of free water during seasoning has no effect on both the mechanical performance of the wood and its dimensions. Bound water is chemically bonded to constituents of the cell wall by hydrogen bonding. In most timbers the wall can hold about 20 to30% of their dry mass. As bound water is removed, it affects the physical and mechanical properties of wood; the wood begins to shrink, most strength properties exhibit improved electrical resistance, resistance to decay, better gluing characteristics and nail-holding power, and a continued reduction in density.

2.6 Moisture Content Determination

There are five distinct methods of determining the moisture content of wood: oven-dry method, distillation method, titration method, hygrometric method, and electric method.

Oven-dry method is the most accurate of all the methods, but it is slow and requires that samples be cut from the tests material. The sample should be thick in the direction of the grain and not from the end of the board to avoid the effect of rapid drying along the grain and they should be clear and free from defects. Each sample is immediately weighed and is then oven-dried and weighed. The moisture content is then calculated from the formula:

$$U = \frac{M_u - M_o}{M_o} \times 100\%$$

Where U = moisture content, Mo = Oven dry mass of specimen,

Mu = mass of specimen at moisture content, u percentage.

Distillation method is recommended when a sample of wood contains a significant amount of volatile constituent or preservatives. In this method, a water immiscible solvent like toluene is used to distill the samples in a form of chips or sawdust. This method is not suitable for an exact determination of the water content due partly to its destructive influence on the wood tissues and to its inaccuracies in reading (Kollmann and Cotê 1968). They further explain that the titration method is an iodometric titration in which elementary iodine reacts with Sulphur dioxide (SO_2) and water to form hydrogen iodide and sulphuric acid. The equation of the reaction is as follows:

$$I_2 + 2SO_2 + 4H_2O \longrightarrow H_2 + 2HI + 2H_2SO_4$$

Stoichiometry is used to compute the amount of water present, knowing the amount of iodine consumed. This method requires much time and is rather expensive. The hygrometric method is faster than the oven-dry method and the titration method. A 6mm diameter hole is freshly drilled into a piece of wood and it is assumed that the relative humidity of the hole corresponds with the moisture content of the wood. The electrical method is the fastest. It facilitates rapid moisture content determination. It make use of electrical properties of wood which depend considerable on moisture content, namely its resistance, dielectric constant and radio-frequency power loss (Kollmann and Cotê 1968).

Shrivastava (1997) reported that the electrical method gives quick readings and for this reason they are used in routine quality control during kiln-seasoning. However, this method is subject to certain limitations namely: the moisture in wood is not, as a rule, distributed evenly throughout the cross section, so that if resistance is measured at the surface, it will differ from the resistance in the core. Again, the electrical resistance of wood varies with temperature and with species, so that calibrations are necessary if this method is used.

2.7 Stress Grading

Grading of timber is necessary to identify the quality of lumber from it. Structural grades have been established in relation to strength properties and use classification so that allowable stresses for design could be assigned (Parker and Ambrose, 1988). The strength properties of the various species of timber were noted as not clearly defined as those of other construction materials such as steel. Test on specimens of the same species and sizes in the same condition may therefore exhibit a considerable spread in strength values. Grading for strength of the principal engineering and construction timbers has been carried out to a high extent in some major timber consuming countries of the world.

It has been suggested by Ocloo (1985) and Addae-Mensah (1989) that species with similar strength properties should be grouped. Stress grading must therefore be carried out in Ghana to enable the selection and grouping of species with similar strength properties. Currently, the visual grading method has the disadvantage of being an arduous task that leads to under-design and hence failure or over-design. To ensure economic and efficient use of Ghana's lesser utilized species, there is a need for grading criteria based on strength properties.

2.8 Utilization of *Borassus aethiopum*

All the parts of the tree are used extensively by the locals; the wood, which is reported to be termite-proof, is usually used for tool handles, canoes, bridges and shelter, Johnson, (1998). The leaves are used for roofs, baskets, mats and rugs. The petiole used for fencing. The roots serve for the treatment of stomach parasites, bronchitis, sore thorax and asthma as well as for mouth wash. The fruit are eaten as food supplement either cooked or raw. Juice tapped from the inflorescence is fermented into toddy which can be converted into alcohol, vinegar or sugar (Irvine, 1961; Johnson, 1998).

2.9 Description of the Anatomical Structure of Borassus Palm

Eaia (1983) revealed that the gross physical features of the palm timber trunk in cross section are markedly different from those of traditional timber. It has no growth rings. In the cross section, the trunk is made up of three distinct zones; dermal zone, sub-dermal zone, central zone. According to the same author, the dermal zone is the periphery part of the stem consisting of dark brown fibre tissues which resembles the bark. The sub-dermal zone is the transitory zone between the dermal and the central one, and it is chiefly composed of bundles of hoary vascular strands interspersed with soft and ground tissues. The central zone consists of ground tissues. In addition, he reported that the dark or hard portion (dermal and sub-dermal zones) occupies about 47.72% of the trunk cross section, and the soft part (part of the sub-dermal and central zone) occupies about 52.27%. However, the ratio of the soft to the hard portions varies along the height of the trunk.

Observation of the cross section (butt disc) of Borassus trunk showed that in the dermal zone, the fibrovascular bundles are relatively higher in number and congested. The fibrovascular bundles in the sub-dermal zone are less congested compared to the dermal zone. There are very few vascular bundles in the central zone. The ground tissue in the central zone is soft and spongy. The soft tissue consists of thin walled cells. The walls of the cells are progressively thicker and darker from the center to the periphery of the trunk. The sclerenchyma fibres associated with vascular strands or steles have relatively thin walls and large lumina at the center zone. At the periphery, the walls are very thick and the sclerenchyma cell walls and in the number of steles accounted for the significant variation in density and hardness www.borassus-projecj.net/reports/BORASSUS%20First20%Report%20INCO-CT-2005-510745.pdf (Dated: 7/11/2008; Time: 2:05pm).

2.10 The General Structure of Monocotyledonous Stems

According to Weiner and Liese (1988), the structure of the monocotyledonous stems differs from that of dicotyledonous stems and conifers in two principal ways: The vascular tissues are usually organized into separate bundles and these as seen in cross-section are scattered throughout the stem instead of a cylindrical arrangement. As a result of the scattered distribution of the vascular bundles, no distinction can be drawn between the pith and the cortex. All the cells of the provascular strands mature into xylem and phloem. A cambium is therefore absent. Lack of a lateral meristem results in the tissues of a monocotyledonous stem being primary in origin. The absence of secondary growth causes their stems, even of palms and bamboos, to be columnar rather than tapering. According to Raven and Johnson (1999), the vascular bundles of primary phloem and primary xylem are not arranged in a cylinder but are instead scattered throughout the parenchyma cells of the ground tissues. The ground tissue is not separated into cortex and pith and it makes up the remaining volume of the stem and that palm trees have parenchyma that continue to divide after they are produced and as a result they grow considerably taller than most monocots. Unlike most monocot stems, palm stems can grow in girth by an increase in the number of parenchyma cells and the vascular bundles. This primary growth is due to a region of actively dividing meristematic cells called the "primary thickening meristem" that surrounds the meristem at the tip of a stem. In woody monocots, this meristematic region extends down the periphery of the stem where it is called the "secondary thickening meristem". New vascular bundles and parenchyma tissue are added as the stem grows in diameter (Raven and Johnson, 1999).

2.10.1 Vascular Bundles

According to Liese (1985), the vascular bundles of bamboo culms consist of the xylem with one or two smaller proto-xylem elements, two larger meta-xylem vessels and the phloem with thin walled unlignified sieve tubes connected to companion cells. Similarly, Ebanyenle (2002) reported that rattans consist of a centrally located xylem and an external phloem, both of which are surrounded by a fibre and a parenchyma sheath. In the case of coconut wood, Butterfield and Meylan (1980) have reported that vascular bundles in the transverse face appear as dark spots embedded in a parenchymatous ground tissue. Each bundle comprises one or larger meta-xylem vessels surrounded by axial parenchyma cells, an area of phloem and capped with fibres. Liese (1985) reported that vascular bundles of Rattans have xylem with one or two smaller proto-xylem elements and two large meta-xylem vessels with the phloem being thin-walled, with unlignified sieve tubes connected to companion cells, the vascular bundles of bamboo, according to Ebanyenle (2002), is made up of meta-xylem vessels, proto-xylem vessels and associated parenchyma sheath with the meta-xylem consist of either one or two vessels. The arrangement of xylem and phloem in the vascular bundle, according to Hsieh and Wu (1991), is of the collateral vascular bundle type with equal parts of xylem and phloem for the bamboo culm. The xylem is at the inner side and the phloem is at the opposite side. According to Liese (1985), the vascular bundle is scattered in the culm wall. This scattered arrangement can also be seen in all monocotyledonous stems.

2.10.2 Fibres

According to Liese (1994), fibres of Rattan palms constitute the sclerenchymatous tissue and occur in the internodes as caps of vascular bundles. They constitute 40-50% to the total culm tissue and account for 60- 70% by weight. The length shows considerable variation both between and within species. Fibres constitute over half the volume of each vascular bundle and give palm stems their axial strength. The percentage of the stem cross-sectional area that fibres occupy depends both on the position in the stem also on the species. (Butterfield and Meylan, 1980). According to Butterfield and Meylan (1980), fibres generally have thin walls and large lumina near the stem centre and thick walls and small lumina near the stem periphery. Fibres of bamboo culm have a poly-lamellate wall structure and this especially at the periphery leads to an extremely high tensile strength. (Liese, 1985). A similar report by Butterfield and Meylan (1980) highlighted on the fact that palm is made up of a multi-layered fibre wall built up of a series of repeating SI and S2 type layers. Fibres are particularly important in the determination of density, since their small cross sections allow a greater number of them to be massed in a small place. According to Panshin and de Zeeuw (1980), if the fibres are thick walled then the density tends to be high. On the other hand, if they are thin walled, the density will be low.

2.10.3 Parenchyma

Parenchyma cells have large vacuoles, thin walls and an average of 14 sides at maturity. They are the most abundant cells of primary tissues and may also occur to a much extent in secondary tissues. (Raven and Johnson, 1999). Parenchyma cells of bamboo culms are mostly vertically elongated with short, cube-like ones interspersed in between (Liese, 1985). Elongated axial parenchyma cells are also a feature of the vascular bundles of many palms. These cells are usually closely associated with the vessel elements. Axial parenchyma cells which are thin-walled with large simple pits and transverse end walls and are closely associated with vessels are known as "Paratracheal parenchyma cells". Those cells that are further removed from vessels are thick walled with smaller pits and are known as " Apotracheal parenchyma" (Butterfield and Meylan, 1980).

2.11 The Structure of Palmwood

Palm stem wood consists of a number of scattered vascular bundles (each having vessels for water conduction, phloem for elaborated food conduction, and fibres for mechanical support) set in a matrix of more or less spherical parenchyma cells. The vascular bundles are much more abundant toward the outside of the stem. A typical stem at one metre height would have about ten bundles/cm^2 in the central portion and about 50 bundles/cm^2 near the outside. As the palm has no branches there are no branch remains (knots) in the wood. Consequently no piece is weakened by the presence of natural defects (FAO, 1985). Palm stems comprise a large central core of primary vascular bundles embedded in a parenchymatous ground tissue surrounded by a cortex. In some palms, the density and texture of the central core of the wood varies greatly between different parts of the stem. The basic density decreases with increasing height in the stem and increases from the stem centre to the outside at anyone height (Butterfield and Meylan, 1980). The vascular bundles in the peripheral zone of many palms are commonly capped by massive radially extended fibrous sheath. Because vascular bundles are also crowded near the periphery than nearer the stem centre, the overall effect produces a stem with the greatest strength around the outside. Fibres constitute over half the volume of each vascular bundle and give palm stems their axial strength. The percentage of the stem cross-sectional area that fibres occupy depends both on the position in the stem and also on the species. Generally, fibres have thin walls and large lumens near the stem centre and thick walls and small lumen near the stem periphery. High up the stem, the difference becomes less marked. The fibre walls are commonly multi-layered (Butterfield and Meylan, 1980). Each layer is believed to consist of two lamellae comparable in thickness and microfibril orientation to the SI and S2 wall layers of conifer tracheids or hardwood fibres. A multi-layered palm fibre wall is therefore built up of a series of repeating SI and S2 type layers. A common feature of both the vascular and non- vascular bundles of many palms is the occurrence of silica containing cells called 'Stegmata'. Stegmata usually develops in longitudinal files adjacent to fibres. They are similar to axial parenchyma cells but generally smaller. Fibres in contact with stegmata frequently have scalloped walls with the individual stegmata occupying each depression (Butterfield and Meylan, 1980).

2.12 General Anatomy of Coconut Wood

The coconut trunk is made up of three layers when sectioned. These are: Dermal zone, the most peripheral part of the stem consisting of dark brown fibrous tissues which resemble the bark. Sub-dermal section, a transition between the dermal and the central zones. It is mainly made up of horny vascular bundles set closely together in soft tissues.

Central zone or region is made up of ground tissues. (Oduor and Githiomi, 2009). Because coconut palms have no vascular cambium (lateral growing tissue) they do not increase in diameter with age. It is uncommon to find a stem over about 30 cm in diameter. Minor variations in diameter from one stem to another, or between different locations, are a reflection of the growing conditions for the individual stem during the early stages of its life (FAO, 1985). Although, Parthasarathy and Klotz (1976) made it clear that palms in general lack cambium and hence incapable of secondary growth, the thick-walled sclerenchyma fibres of the fibrovascular bundle serves as palm's major mechanical support thereby strengthening the wood of coconut (FAO, 1985). The fibres usually have a well developed secondary wall with a characteristically multi- layered appearance with the fibres in close association with silica containing cells known as 'Stegmata.', which according to Parthasarathy and Klotz (1976), are very much smaller than adjacent parenchyma cells, abundant and adjacent to the vascular and fibrous bundles of the stem. The typical range of basic density in (*Cocos nucifera*) for example is 100-900 Kg/m^3 which is considerably greater than that found in some softwood and hardwood. This is as a result of the differences in the size and distribution of the vascular bundles and variations in the thickness of the parenchyma and fibre walls (Butterfield and Meylan, 1980). They added that the vascular bundles in coconut wood are grouped much closer together in the peripheral zone than nearer the stem centre. Each vascular bundle consists of xylem, phloem, axial parenchyma and fibres. Non-vascular bundles composed of fibres only are also present in some palms especially at higher levels near the stem centre.

2.13 Some Mechanical and Physical Properties of Palms

According to Oduor and Githiomi, (2009) Coconut wood has the following properties:

Table 2.1 Physical and Mechanical Properties of Coconut

Density (g/cm^3) air dry	0.248 – 0.852
Bending MOR (N/mm^2)	16.34 – 109.21
MOE KN (N/mm^2)	1.982 – 12.705
Shear strength parallel to the grain (N/mm^2)	2.1 - 17.37
Hardness kN	0.66 - 14.905

Okai, (2008) on Skill development and training on the use of logging Residues and discarded Oil Palm trunk as raw material for the down stream wood processing sector revealed the following strength properties for Oil Palm.

Table 2.2 Mechanical properties of Oil Palm wood at 12% MC

MOR (N/mm^2)	MOE (N/mm^2)	Compression Parallel to the grain (N/mm^2)
25	2924	13
(9)	(887)	(1.5)

The values in brackets are their Standard deviations.

Ayarkwa, (1997) pointed out the following Physical and Mechanical properties of *Borassus aethiopum* as contrasted with *Milicia excelsa* in Table 2.3.

Table 2.3 Physical and Mechanical properties of *B. aethiopum* and *Milicia excelsa*.

Species	MC %	Density Kg/m^3	MOR N/mm^2	MOE N/mm^2	Compression ll to grain N/mm^2	Shear ll to grain N/mm^2
Borassus aethiopum	12	670	104	11300	58	7.8
Milicia excels	12	652	80	10041	52	13

CHAPTER THREE

3.0 Materials and Methods

3.1 Study and Experimental Area

Five *Borassus aethiopum* trees were extracted from Asempanaye in the Ashanti Region in a 28 years old natural stands. Wood samples preparation for the physical and mechanical studies were carried out at the Faculty of Renewable Natural Resources' (FRNR) Wood Science Workshop and Laboratory. All the mechanical properties of the studied species were carried out at the Forestry Research Institute of Ghana's (FORIG) Wood Engineering Department.

3.2 Measurements of Sampled Trees

The trees were labelled as 1, 2, 3, 4, and 5 and fell. Some measurements taken at the felling site include the merchantable bole lengths. These figures were recorded as in Table 3.1. Each fell tree was in turn cut into 6 logs of 1.5m. The bulge area for each tree was also cut to 1.5m. The logs were immediately removed from the forest and conveyed to the Wood Science and Technology Workshop for further processing.

Table 3.1: Measurements of Sampled Trees.

Tree No	Merchantable Bole Length (m)
1	13.3
2	12.9
3	13.2
4	13.1
5	13.2

3.3. Sampling Procedure for Specimen

The samples were processed with the facilities at the Wood Science and Technology workshop of KNUST. The bolts sampled were taken from the butt through to the bulge area of each tree and labelled as $T_1$1, $T_1$2, $T_1$3, $T_1$4, $T_1$5, $T_1$6, and T_b1 for tree 1. The same process was used for trees 2, 3, 4, and 5 respectively. The heights from the stump height to the various sections of the bole at 1.5m within which sampled bolts were taken were also recorded. An interval of 0.2m was left between each section (Fig. 3.1).

For tree 1, $T_1$1 = 1.5m represents the height from the stump height to the end of the first bolt (the 1.5m mark) within which samples were taken.

$T_1$2 = 3.2m represents the height from the first 1.5m height to the end of the second bolt (the 1.5m mark) within which samples were taken.

$T_1$3 = 4.9m represents the height from the second 1.5m height to the end of the third bolt (the 1.5m mark) within which the bolted samples were taken.

$T_1$4 = 6.6m represents the height from the third 1.5m height to the end of the forth bolt (the 1.5m mark) within which samples were taken.

$T_1$5 = 8.3 represents the height from the forth 1.5m height to the end of the fifth bolt (the 1.5m mark) within which samples were taken.

$T_1$6 = 10.0m represents the height from the fifth 1.5m height to the end of the sixth bolt (the 1.5m mark) within which samples were taken.

T_b1= 14.3m represents bolt from the bulge area.

Similarly, the same measurements were used for trees 2, 3, 4, and 5. However, their bulge area heights differed considerably for trees 2, 3, 4, and 5 respectively as in the following: 13.8m, 14.1m, 14.3m, and 13.9m.

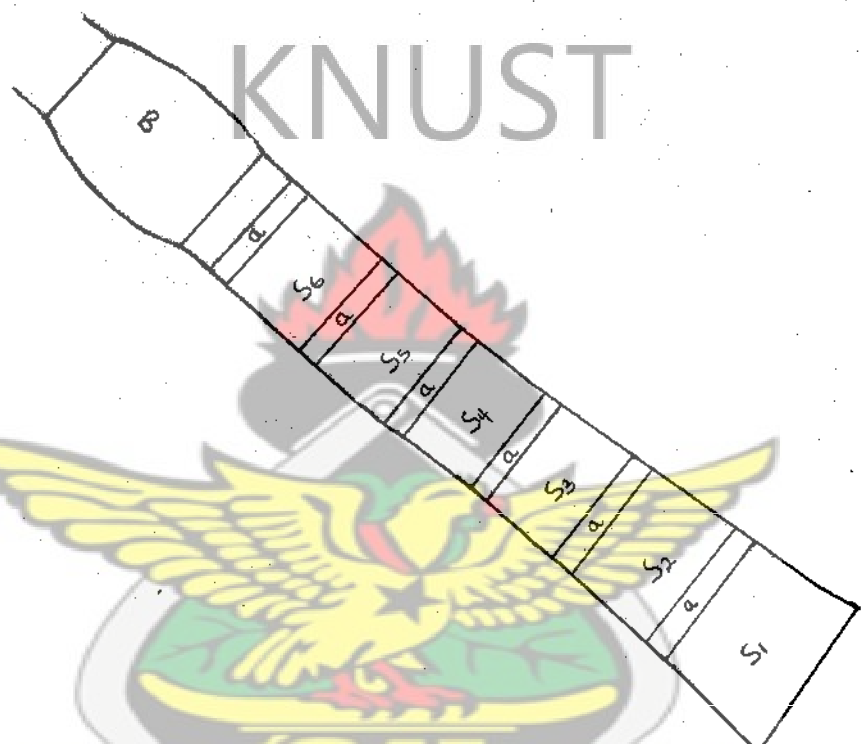

Figure 3.1 Schematic diagram of the merchantable bole including the bulge area of *Borassus aethiopum* and its divisions.

a – represents the 0.2m interval left in between adjacent bolts. S_1, S_2, S_3, S_4, S_5, and S_6 represent the 1.5m height divisions for the trees which are respectively equals to 1.5m, 3.2m, 4.9m, 6.6m, 8.3m and 10.0m. B represents the bulge area for the trees.

3.4 Processing of Sampled Bolts

A cross section through the stem of the bolts showed three distinct layers: the dermal zone which is the most periphery portion just below the cortex. The sub-dermal zone is the transitory zone between the dermal and the central zones, and the central zone. The distinct delineation of the cross section revealed varied colours and hardiness. The dermal zone revealed a relatively dark brown colour suffused with closely packed black spots. The sub-dermal zone, which looked like the dermal zone, had relatively dark brown colour interspersed with black spots but the spots density is very low compared to the dermal zone. The sub-dermal zone is almost as hard as the dermal zone when pressed with the hand. The central zone revealed a relatively white to light yellow colour on its cross section having a spongy texture with scattered black spots. It is very soft when pressed with the hand. There is colour variation along and across the stem of the tree as the compactness of the black spots reduces for both the dermal, sub-dermal and the central zones. Each portion of the three zones was converted into boards with a power chain saw. Strips of dimensions 25 x 25 x 1500 mm and 55 x 55 x 1500mm were prepared from the bolts representing each section of the trees sampled. The green test specimen, samples with the wood moisture content above the fibre saturation point, for the mechanical tests were cut into sizes and orientations required by the British Standards BS 373:1957 (BSI, 1957). The strips were immediately placed in black polythene bags and were kept in deep freezers pending the test to avoid moisture loss. Strips for the dry test were however, dipped in a Dursban solution to prevent insect damage during drying. The strips were then stacked for air-drying under shed. After these strips were fully dried, test specimens for the dry test samples for the mechanical testing were prepared to the standard sizes and orientations required by the British Standard BS 373:1957. Strips were prepared from the dermal, sub-dermal, and the central zones.

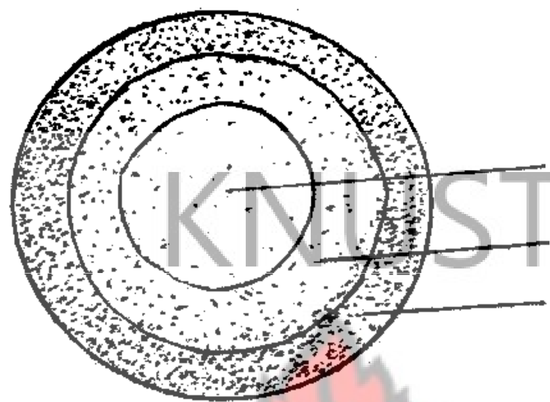

Figure 3.2: Schematic diagram of the cross section of *Borassus aethiopum.*

3.5 Mechanical Tests

Four mechanical properties were carried out using the universal testing machine Instron 4482. These were static bending test, compression and shear parallel to the grain test, and the hardness test. According to Bodig and Jayne (1982) these tests are used intensively save the hardness test in assessing the mechanical behaviour of wood by the methods of small clear specimens.

3.5.1 Static Bending Test

Random specimens of dimensions 20 x 20 x 300 mm were cut from the strips representing each section of the trees for the dermal, sub-dermal and central zones. The pieces were supported over a span of 280 mm in trunions carried on roller bearings to provide friction free lateral movement of the bearing points to accommodate horizontal shortenings of the specimen due to deflection. A crosshead load was applied to the centre of each specimen at a rate of 0.11 mm/s until the specimen fails. The orientation of each specimen was parallel to the direction of loading (BS 373, 1957). Load deformation diagrams, were plotted automatically which was displayed on a computer monitor for the entire test specimen until the specimen failed. The maximum load that caused fracture in each piece was also recorded. Strength properties determined from the test were the modulus of elasticity (MOE) and modulus of rupture (MOR). The Instron machine employed the three-point bending for the MOE and the MOR and these were respectively calculated from the following equations:

$MOE = (\Delta P_L . L^3)/48.\ \Delta Y.I$..................... (1)

Where MOE = Modulus of elasticity (N/mm^2)

L = Span between supports (mm)

Δy = Maximum deflection at mid-span (mm) which corresponds to the load ΔP_L.

ΔP_L = any load at or below the proportional limit (N).

I = Moment of inertia of the section (mm^4).

$MOR = kPL/\ (bd^2)$....................... (2)

where P = maximum load(N) that caused failure of specimen,

b and d are width (20mm) and breadth (20mm) of specimen respectively,

L is the span (280mm) and k is constant = 1½

The test was conducted for nine hundred and twenty five (925) samples for both the green (450) and the dry (475) samples. Five replicates were used for each section of the various divisions of each tree which included the dermal, sub-dermal, the central zones and the bulge area for the five trees. However, the green test specimen for all the mechanical tests were not prepared for the bulge area as the wood was very spongy, very soft, and also not compact enough to enable test procedures.

3.5.2 Compression Parallel to the Grain Test

Four hundred and fifty (450) samples of the green specimens and four hundred and seventy five (475) specimens of the dry test specimens of dimensions 20 x 20 x 60mm representing each section of the trees sampled were tested. A crosshead load was applied at a rate of 0.01 mm/s through a ball contact plunger. The compressive strength parallel to the grain of each piece was calculated by dividing the maximum load (Pmax) recorded during test by the cross- sectional area (A) of the specimen.

3.5.3 Shear Parallel to the Grain

The shear parallel to the grain test was performed on a cube of side 50mm using a pivoted-arm shear test apparatus such that when the cube was loaded at about.0.01mm/s shear occurred along the grain. 450 and 475 test samples representing the green and the dry tests respectively were sampled and tested. Each specimen was loaded in turns at a rate of 0.01 mm/s. The ultimate shear strength was hence deduced from the relation P/bh, where P is the maximum load causing the shear and the bh are the breadth and depth respectively representing the area in shear.

3.5.4 Hardness

The hardness test was made on specimen of dimensions 50 x 50 x 150 mm. 195 test samples were used for the test of which 90 specimens were used in the green state and 105 specimens used in the dry condition. The hardness was assessed by the wood's resistance to impregnation of a special hardened steel tool rounded to a diameter of 11.3 mm which is embedded to half of its diameter. The rate of penetration of the hardness tool for each specimen was 0.11mm/s. The applied load was immediately removed when the correct depth had been detected by a sensor fitted in the Instron machine. The test was carried out on each of the radial and tangential surfaces of each specimen and the average of the two recorded.

3.6 Physical Tests

The physical tests carried out were the basic density, moisture content and density at 12% MC.

3.6.1 Determination of Basic Density and Density at 12% MC

The basic density of the wood species was determined on the oven-dried weight per green volume basis. The method made use of Archimedes' principle – a body which is wholly or partially immersed in a fluid suffers a loss in weight equal to the weight of fluid which it displaces. The green wood specimens were soaked in water at room temperature over-night prior to the test to ensure that it was swollen to its green volume and to eliminate error that might occur if wood absorbed water during the weighing operation. The weight of the container (beaker) and water it contained were determined. The wood specimens were submerged in the water, and the weight of container plus water plus specimen was determined (the increase in weight is equal to the weight of liquid displaced by the specimen in grams (g) and is numerically equal to the volume of water displaced in centimetres cube (cm^3). The wood blocks were then oven-dried at 101ºC - 105ºC to constant mass and the oven-dry mass determined. The basic specific gravity or basic density of the wood specimen was calculated from the relation:

$$\text{Basic density} = \frac{\text{Oven dry mass of specimen kg}}{\text{Mass of water displaced by swollen specimen } (m^3)}$$

Ten replicates of dimensions 2 x 2 x 2 cm^3 were used for each section and each zone of the sampled bolts and the basic density obtained (in kg/m^3). For the density at 12% MC, the basic specific gravity was converted to specific gravity at 12% MC using the formula for finding the specific gravity of wood below the fibre saturation point (Forest Product Laboratory, 2010): $G_a = G_b/[1-0.265G_b\ (1-a/M_{fs})]$, where G_a= Specific gravity at any MC below the fibre saturation point (12% MC), G_b = basic specific gravity, M_{fs} = Moisture Content at fibre saturation point =30%. The density at 12% MC was then interpolated from the specific gravity at 12% MC, G_a, using the formula: Density = G_a (1 + M/100) 1000 [kg/m]. Where G_a = specific gravity at 12% MC, M =12 %.

3.6.2 Moisture Content (MC) Determination

Two 2.5 cm strips were extracted from all the sections and zones of the trees and planed to 2cm thickness. Each strip was then sawn to produce 2cm by 2cm square sections. The 2cm x 2cm square sections were then cross cut to 2cm cubes. 30 samples were used for each section: 10 replicates for each zone. The green mass (w) of the specimen cubes was determined and then oven – dried at 101ºC -105ºC until a constant mass (D) was attained. The moisture content (MC) was then calculated according to the formula:

MC = ((W – D)/D) x 100%. Also, the moisture content for each mechanical test carried out was determined by cutting sections near the point of fracture except for the compression parallel to the grain test where the entire test piece was used as the sample. The procedure used in the determination of the moisture content followed the same as that described above. The loss in weight expressed as a percentage of the final oven-dry weight was taken as the moisture content of each test piece.

3.7 Data Analysis

After the data has been obtained from the sample tests, Single Factor One-way Analysis of Variance (ANOVA) of Microsoft Office Excel 2007 was employed to determine whether the differences between the measured physical and mechanical properties for each 1.5m division along the bole of the dermal zone, sub-dermal zone, central zone and the bulge area for each tree and for all the trees were significant. Tukey's Multiple Comparison Test was used to test the statistical significance of each pair of means of the various mechanical and physical properties along the bole heights for the zones. The linear regression model was used to analyze the relationship among the wood's various properties.

3.8 Hypothesis

Null hypothesis (H_0): There is no significant difference between the dermal zone, sub-dermal zone, the central zone and the bulge area of the individual trees for the physical and mechanical properties studied. Alternate Hypothesis (H_1): There is significant difference between the dermal zone, sub-dermal zone, the central zone and the bulge area of the individual trees for the physical and mechanical properties studied.

3.9 Limitation of study

The “wood” of *Borassus aethiopum* tends to be quite difficult to work with both machine and hand tools and easily blunt knives and saws. The hard fibres contrasted with the soft body of the “wood”, turned to cause splinters or pull out during cutting. The “wood” of the bulge area was very spongy and very soft at the green state making it more difficult to obtain the appropriate dimensions for the standard procedures.

CHAPTER FOUR

4.0 RESULTS

4.1 Strength Adjustment

Mechanical properties of wood are significantly affected by the moisture content of the specimen at the time of testing hence properties that are measured at different dry test moisture levels are adjusted to a standard moisture content base of 12%. The results of the ultimate strength (σbw) in static bending (MOR and MOE), Compression parallel to the grain, Shear parallel to the grain and Hardness tests at their respective moisture content w were adjusted to strength at 12% moisture content using the formula $\alpha b_{12} = \sigma bw\ [1+ \alpha\ (w-12)]$, (Ishengoma and Nagoda, 1999). Where w is the moisture content, αb_{12} is strength at 12% moisture content and α is the correction factor for moisture content, whose value is obtained from national standards, however, if it is not available, a factor of 0.03, 0.04, and 0.05 are respectively used for the hardness and compression tests, bending test, and shear test for rough estimates.

4.2 Formulae for Calculating the Strength Values

The formulae used in calculating the strength values from the test data were those given in the British Standards BS 373:1957 (BSI,1957) which was followed in the test program of this study. The bending strength (MOR) and the stiffness (Modulus of elasticity, MOE) were computed using the three-point loading equations.

4.3 Physical Properties

4.3.1 Moisture Content (MC) Variation

The mean green moisture contents for the dermal, sub-dermal and the central zones for each of the five tree species along the bole is presented in Figure 4.1. A typical summary of the basic statistics of the green moisture contents for each of the five *Borassus aethiopum* tree species for the dermal, sub-dermal and the central zones is shown in Appendix 1A.

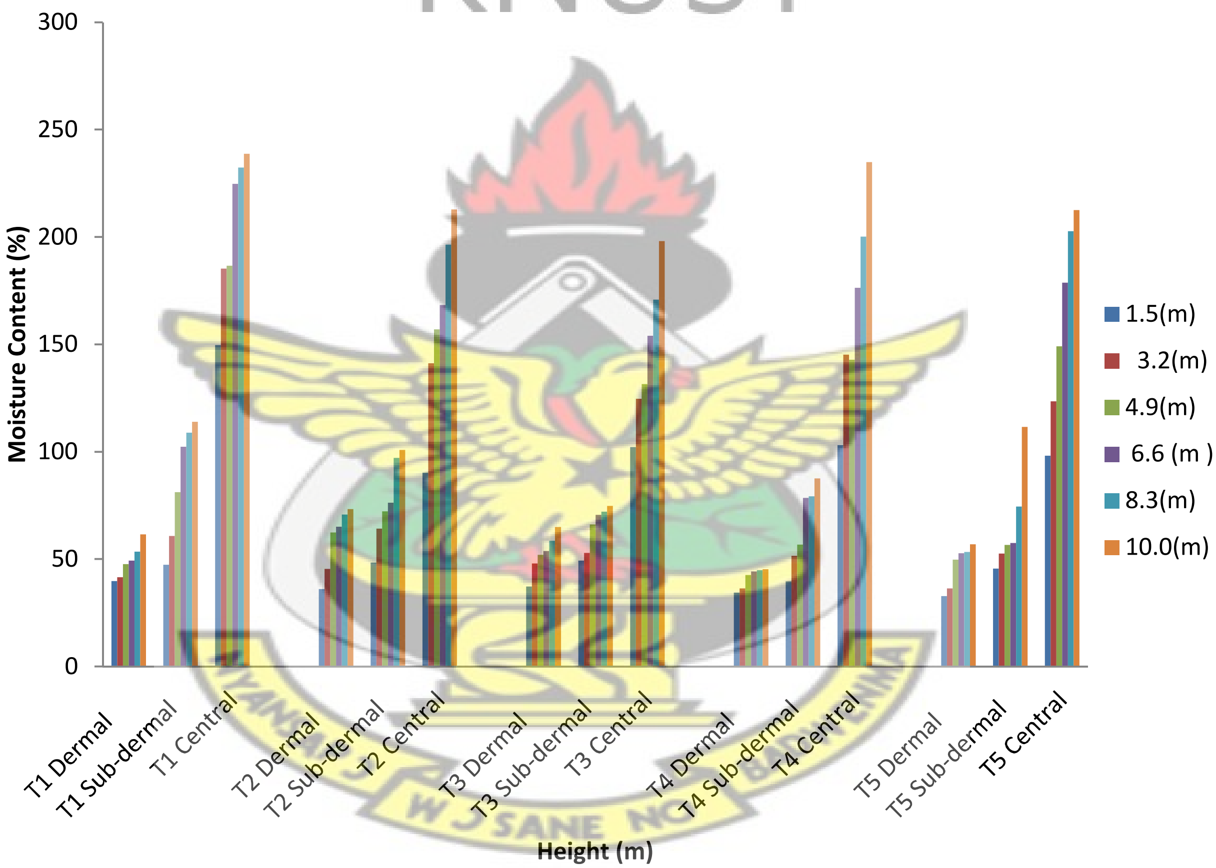

Figure 4.1: The mean green Moisture Content of the dermal zone, sub-dermal zone and the central zone for each of the five *Borassus aethiopum* trees along the stem.

From Figure 4.1, the mean MC at the 10m height was the highest for all the three zones (dermal zone, sub-dermal zone and the central zone) in all the 5 trees. Nonetheless, the mean MC at the base, the 1.5m height, for all the zones recorded the smallest value. Thus, the mean MC for all the 5 trees of the dermal, sub-dermal and the central zones increased axially from the 1.5m height at the base of the trees through to the 10m height at the top of the trees. Similarly, the mean green MC of all the 5 trees increased radially from the dermal zone through to the central zone at each interval. The green moisture content for all 900 specimens ranged from 30% to 290%. The overall average was 96% with standard deviation 61%. The within tree average green moisture content for the dermal, sub-dermal and the central zones range were 30% to 82%, 37% to 134%, and 69% to 290% respectively. The overall average for the dermal, sub-dermal and central zones with their standard deviations in brackets were 50% (12%), 72% (23%), and 168% (50%) respectively (Appendix 1A). The within tree average moisture content range was 88%-113% (Appendix 1B). The results of the analysis of variance (Appendices 1B and 1C) of the green MC of the 5 trees indicated that the differences among the mean MC for all the 5 trees, the three different zones along each stem, all the 5 dermal zones, all the 5 sub-dermal zones and all the 5 central zones were highly significant ($P<0.05$). The Tukey's multiple comparison test (Appendices 1D to 1I) within each zone for each 1.5m interval along the bole confirmed this significant difference and revealed that the differences between the mean green MC for each zone in all the 5 individual trees and the differences between the mean green MC for all the trees were also significant ($P<0.05$).

4.3.2 Basic Density Variation

The mean basic density and density at 12% MC for the dermal, sub-dermal and the central zones for each of the five tree species along the bole are presented in Figures 4.2 and 4.3. A typical summary of the basic statistics for each of the five *Borassus aethiopum* tree species for the dermal, sub-dermal and the central zones are shown in Appendices 2A and 3A.

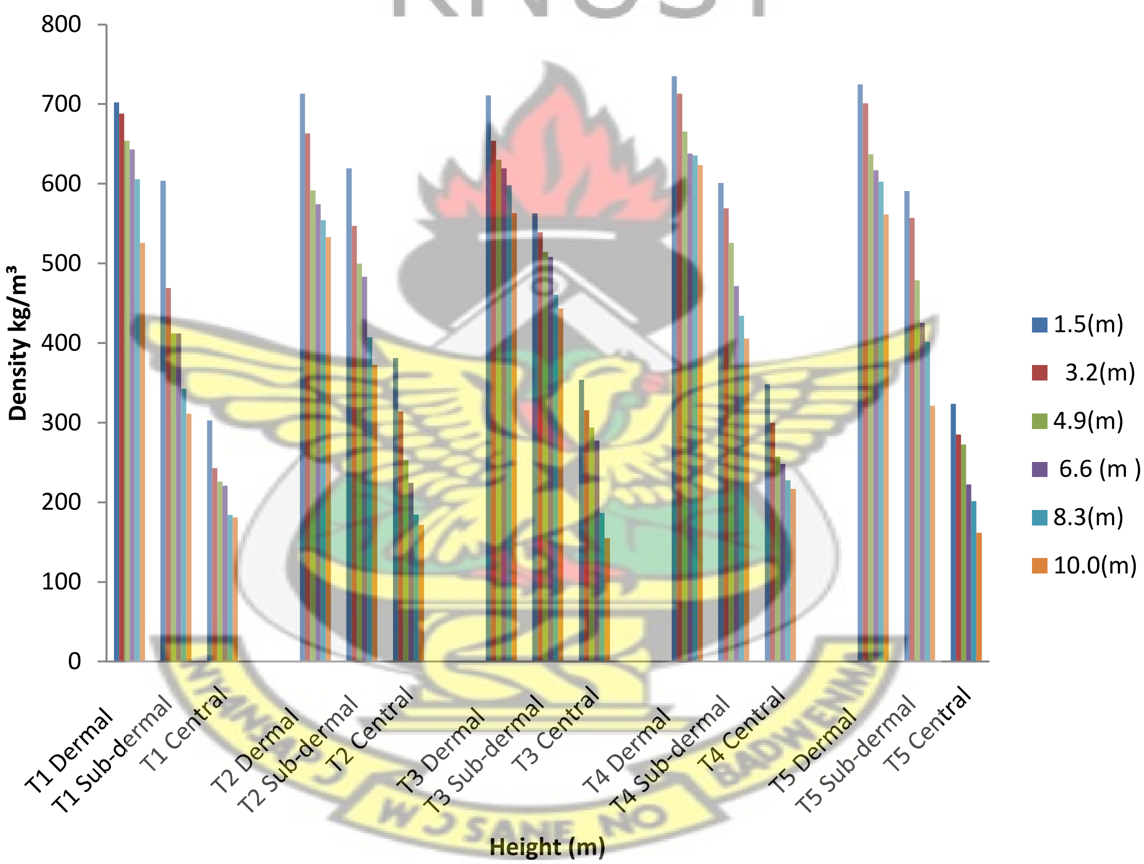

Figure 4.2: The mean Basic Density of the dermal zone, sub-dermal zone and the central zone for each of the five *Borassus aethiopum* trees along the stem.

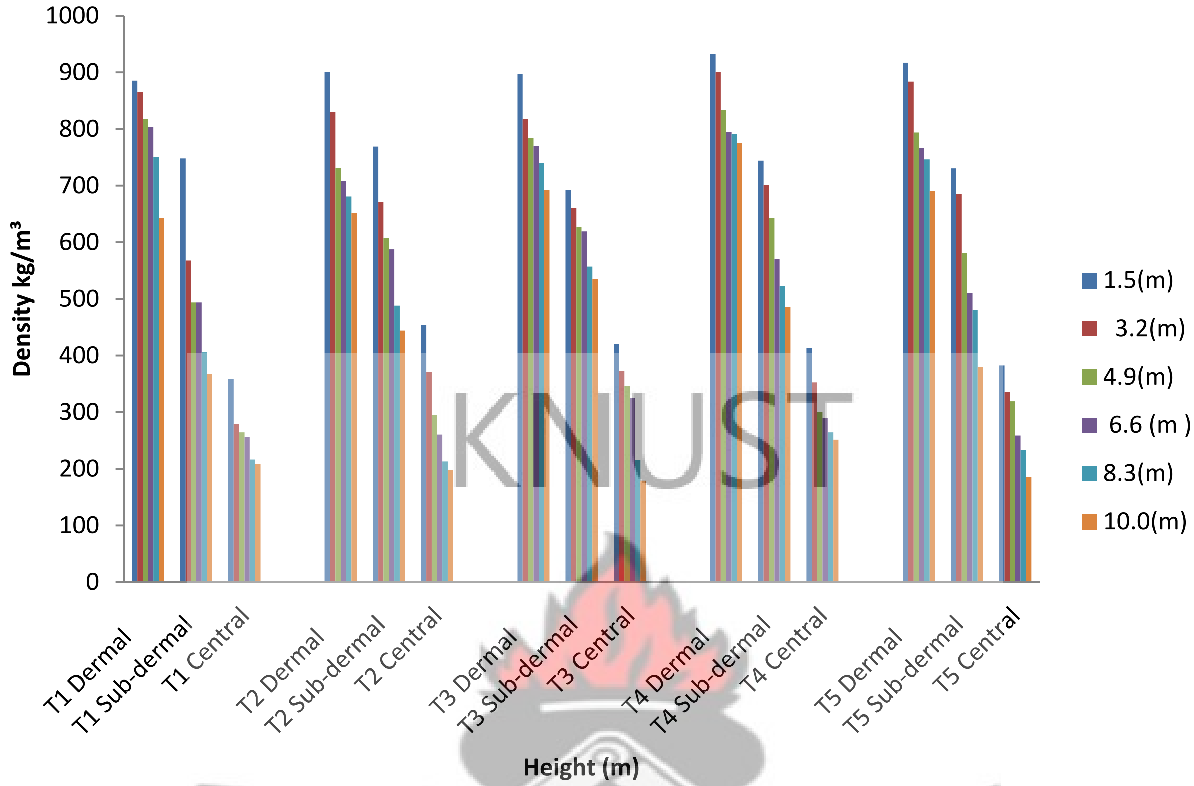

Figure 4.3: The mean Density at 12% MC of the dermal zone, sub-dermal zone and the central zone for each of the five *Borassus aethiopum* trees along the stem.

Figures 4.2 and 4.3 of the axial variation in the mean basic density and density at 12% MC for the dermal, sub-dermal and the central zones for each of the 5 trees revealed that the mean basic density and [density at 12% MC] were greatest at the 1.5m height for all the three zones in all the 5 trees. However, the mean basic density and [density at 12% MC] at the 10m height for all the three zones recorded the smallest value. Thus, indicating an axial decrease in mean basic density and density at 12% MC of the dermal, sub-dermal and the central zones for all the 5 trees from the base of the trees through to the 10m height at the top of the trees. A similar decrease in the mean basic density and density at 12% MC is observed radially in all the 5 trees at each 1.5m interval from the dermal zone through to the central zone. The basic density and [density at 12% MC] for all 900 specimens ranged from

127.7 kg/m^3 to 752.7 kg/m^3 and [145.9 to 957.7 kg/m^3]. The overall averages were 454.5 kg/m^3 [and 555.4 kg/m^3] with standard deviations respectively 174.1 kg/m^3 and [225.8 kg/m^3]. The within tree average basic density and density at 12% MC for the dermal, sub-dermal and the central zones range were 480.4 kg/m^3 to 752.7kg/m^3 [582.5 kg/m^3 to 957.7 kg/m^3], 229.2 kg/m^3 to 652.5 kg/m^3 [266.4 kg/m^3 to 814.9 kg/m^3], and 127.7 kg/m^3 to 436.8 kg/m^3 [145.9 kg/m^3 to 525.7 kg/m^3] respectively. The overall average for the dermal, sub-dermal and central zones with their standard deviations in brackets were 636.0 kg/m^3 (59.8 kg/m^3) and [793.3 kg/m^3 (82.8 kg/m^3)], 475.4 kg/m^3 (90.3 kg/m^3) [579.1 kg/m^3 (118.2)], and 257.2 kg/m^3 (66.1 kg/m^3) [293.9 kg/m^3 (80.7 kg/m^3)] respectively. The within tree average basic density and density at 12% MC range were 429.3 kg/m^3 to 478.7 kg/m^3 and [523 kg/m^3 to 587.1 kg/m^3] (Appendices 2B and 3B). The results of the analysis of variance (Appendices 2B to 2C and [3B to 3C]) of the basic density and [density at 12% MC] of the 5 trees indicated that the differences between the mean basic density and [density at 12% MC] for all the three different zones along each stem for the individual trees, all the 5 dermal zones, all the 5 sub-dermal zones, all the 5 central zones and density at 12% MC for all the 5 trees were highly significant ($P<0.05$). The Tukey's multiple comparison test (Appendices 2D to 2I and [3D to 3I]) carried out on the five trees within each zone for each 1.5m interval along the bole also revealed that the differences between the mean basic density and density at 12% MC for the three different zones along each stem for the individual trees, all the 5 dermal zones, all the 5 sub-dermal zones, and all the 5 central zones were also highly significant ($P<0.05$). However, the differences between the mean basic densities and density at 12% MC for all the trees were not significantly different.

4.4 Mechanical Properties

4.4.1 Modulus of Elasticity Variation

The mean green MOE and dry MOE for the dermal, sub-dermal and the central zones for each of the five tree species along the bole are presented in Figures 4.4 and 4.5 respectively. A typical summary of the basic statistics for each of the five *Borassus aethiopum* tree species for the dermal, sub-dermal and the central zones are shown in Appendices 4A and 5A respectively for the green and MOE at 12 % MC.

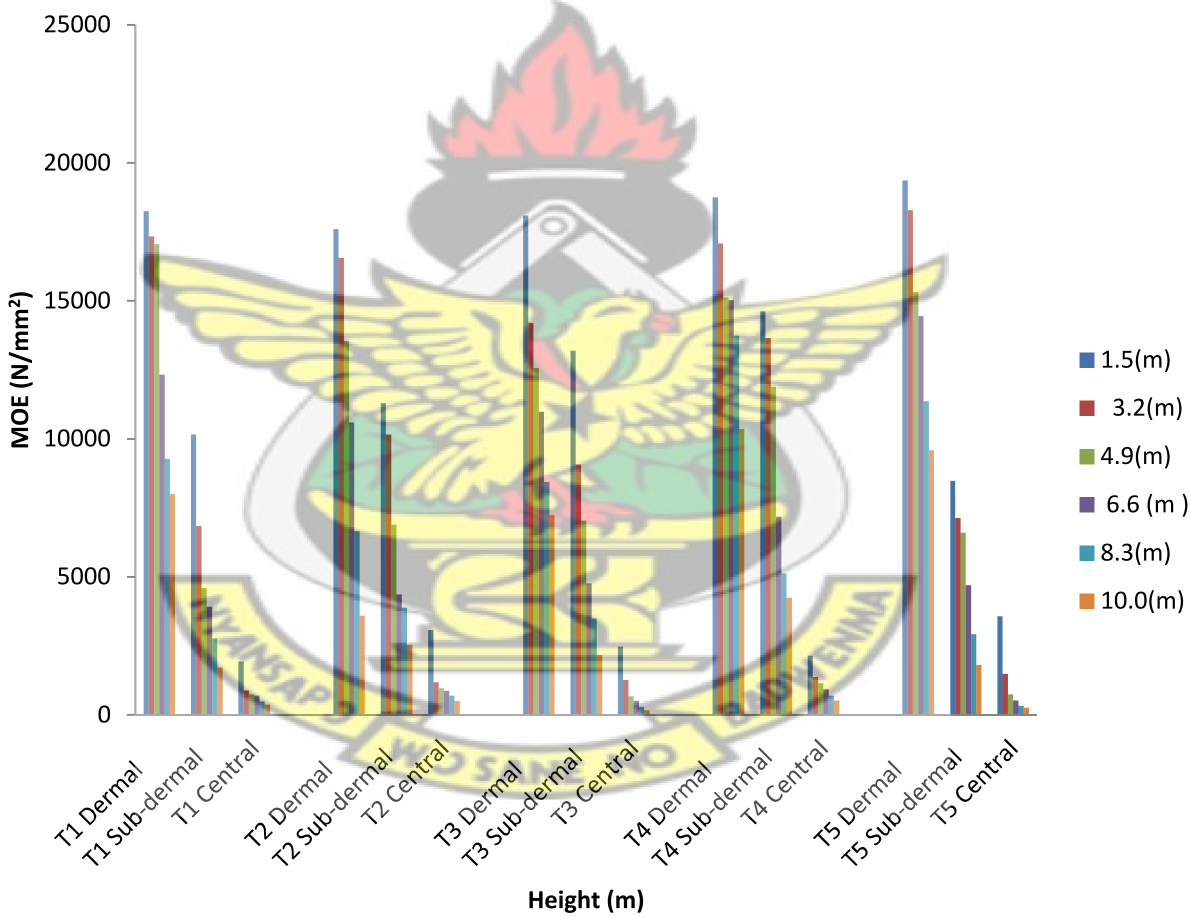

Figure 4.4: The mean green MOE of the dermal zone, sub-dermal zone and the central zone for each of the five *Borassus aethiopum* trees along the stem.

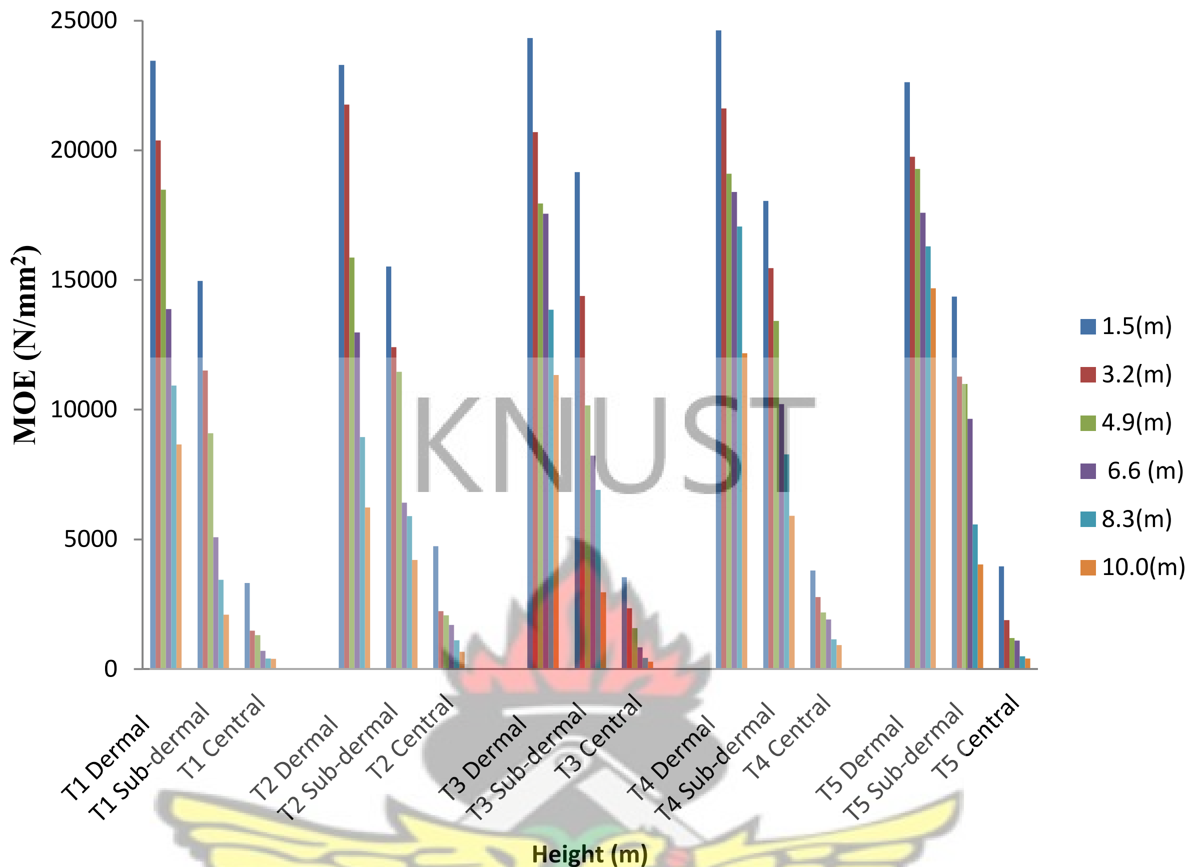

Figure 4.5: The mean MOE at 12% MC of the dermal zone, sub-dermal zone and the central zone for each of the five *Borassus aethiopum* trees along the stem.

The mean green MOE [and MOE at 12 % MC] at the 1.5m height was greatest (Figure 4.4 and 4.5) for all the three zones in all the five trees. Figures 4.4 and 4.5 further revealed that the mean green MOE [and MOE at 12 % MC] at the top, the 10m height, for all the 3 zones recorded the smallest value. The mean green MOE [and MOE at 12 % MC] of the dermal, sub-dermal and the central zones for all the 5 trees decreased axially from the 1.5m height at the base of the trees through to the 10m height at the top of the trees. A Similar decrease in the mean green MOE [and MOE at 12 % MC] is noticed radially in all the 5 trees at each interval from the dermal zone through to the central zone. All the 450 specimens each of the mean green [and MOE at 12 % MC] ranged from 118.7 – 20563.8 N/mm^2 and [206.5 – 25871.8 N/mm^2] respectively. The overall averages were 6994.5 N/mm^2 [and 9510.0 N/mm^2]. The within tree average green [and dry] MOE for the dermal, sub-dermal and the central zones range were 2971.0 – 20563.8 N/mm^2 [5253.0 – 25871.8 N/mm^2], 1407.3 – 16661.2 N/mm^2 [1843.2 – 20323.1 N/mm^2], and 118.7 – 4669.9 N/mm^2 [206.0 – 5857.2 N/mm^2] respectively. The overall average for the dermal, sub-dermal and central zones with their standard deviations in brackets were 13358.6 (4513.4) N/mm^2 [17127.3 (5203.2) N/mm^2], 6573.4 (3864.9) N/mm^2 [9704.1 (4860.4) N/mm^2], and 1051.5 (860.8) N/mm^2 [1698.6 (1231.3) N/mm^2] respectively. The within tree average MOE range were 6387.9 - 8531.8 N/mm^2 [8310.7-10946.4] N/mm^2 (Appendix 4B and 5B). Apart from the Analysis of Variance (ANOVA) of the green MOE for all the 5 trees, all the Central zones and the ANOVA of the dry MOE for all the 5 trees (Appendix 4C), the results of the Analysis of Variance (Appendices 4B to 4C [5B to 5C]) of the mean green [and dry] MOE of the 5 trees indicated that the differences between the mean green [and dry] MOE for each tree, all the three different zones along each stem for the individual trees, all the 5 dermal zones, all the 5 sub-dermal zones and all the 5 central zones were highly significant ($P<0.05$). The post test, Tukey's Multiple Comparison test (Appendices 4D to 4I [5D to 5I]), within each zone for each 1.5m interval along the bole revealed that the differences between the mean green, [and dry] MOE for each zone along the bole height in all the 5 individual trees, all the 5 dermal and sub-dermal zones were also highly significant at $P<0.05$. Nonetheless, the differences between the mean green [and dry] MOE for all the 5 *Borassus aethiopum* trees and all the central zones of the 5 trees were not significant at $P<0.05$ (Appendices 4I and 5I).

4.4.2 Modulus of Rupture (MOR) Variation

The mean green MOR and MOR at 12% MC for the dermal, sub-dermal and the central zones for each of the five tree species across and along the bole are presented in Figures 4.6 and 4.7 respectively. A typical summary of the basic statistics for each of the five *Borassus aethiopum* tree species for the dermal, sub-dermal and the central zones are shown in Appendices 6A and 7A respectively for the green and MOR at 12% MC.

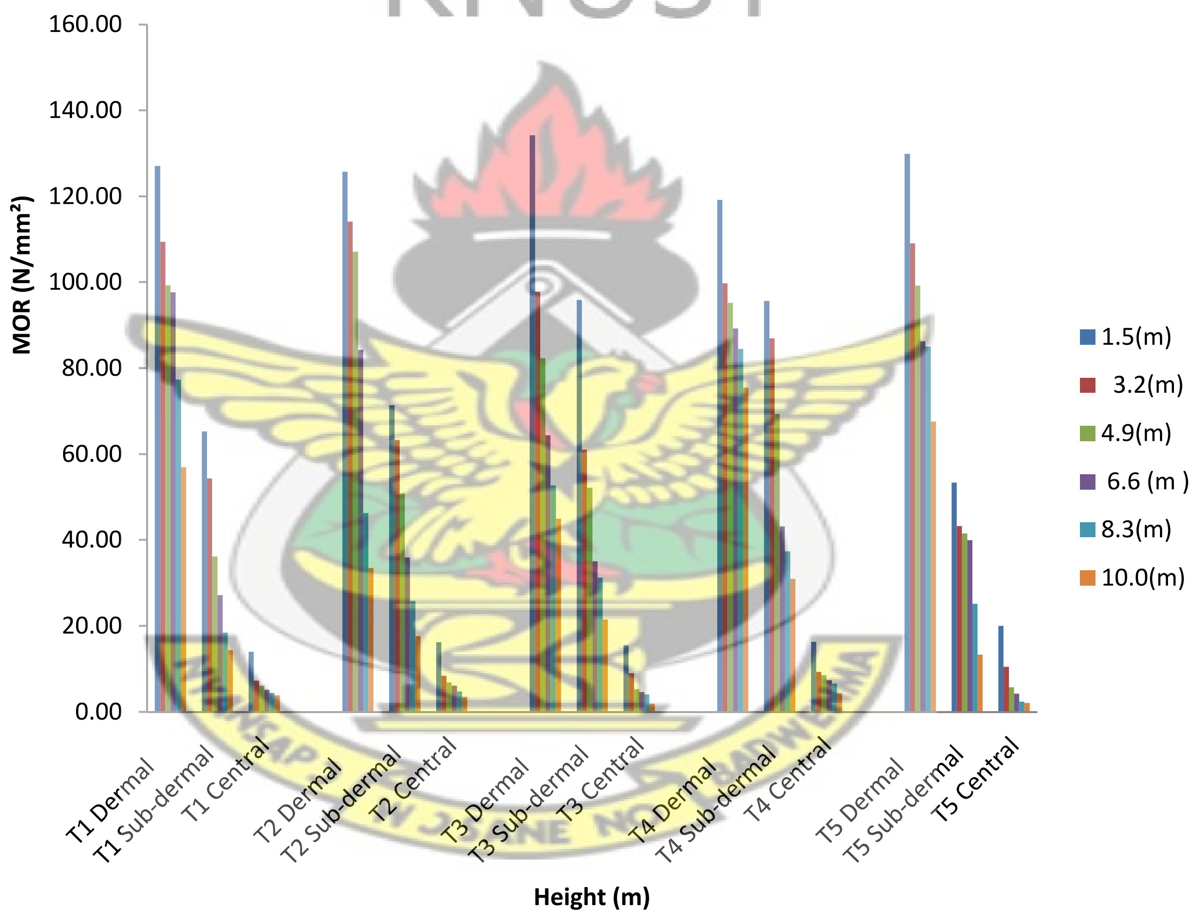

Figure 4.6: The mean green MOR of the dermal zone, sub-dermal zone and the central zone for each of the five *Borassus aethiopum* trees along the stem.

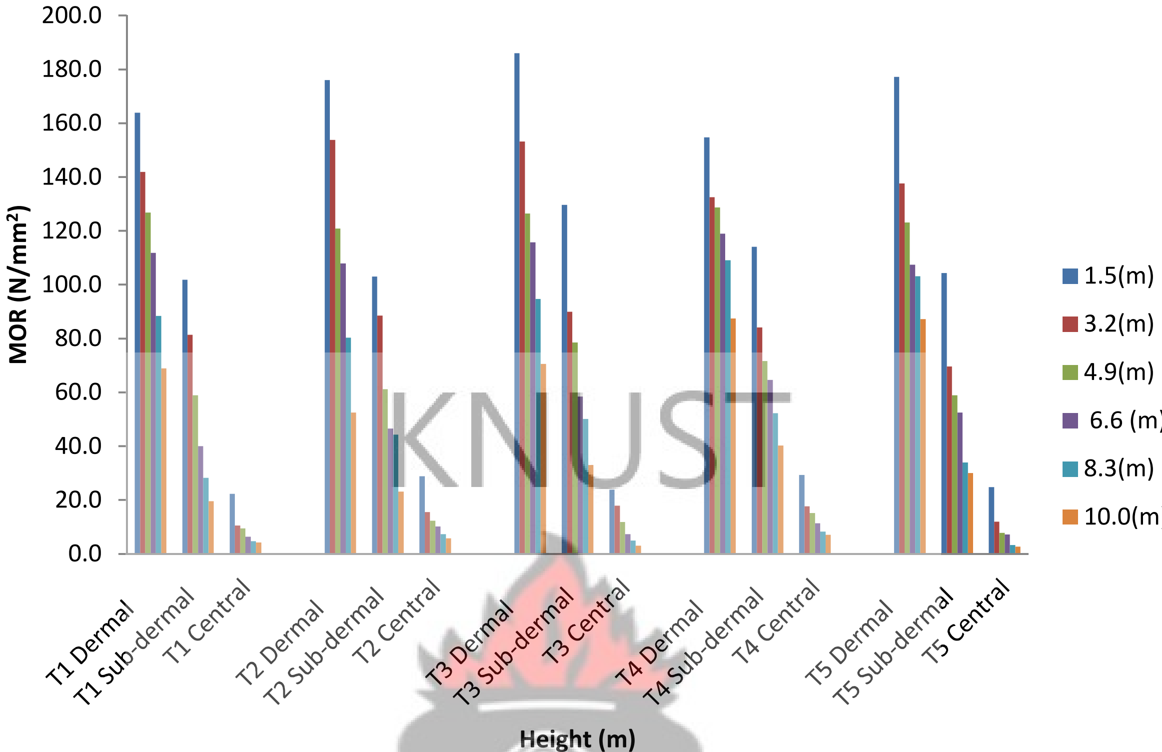

Figure 4.7: The mean MOR at 12% MC of the dermal zone, sub-dermal zone and the central zone for each of the five *Borassus aethiopum* trees along the stem.

From Figures 4.6 and 4.7, the mean green MOR [and MOR at 12% MC] at the 1.5m height was greatest for all the three zones in all the five trees. The axial variation in the mean green MOR [and MOR at 12% MC] of Figures 4.6 and 4.7 for the dermal, sub-dermal and the central zones for each of the 5 trees further revealed that the mean green MOR [and MOR at 12% MC] at the top, the 10m height, for all the 3 zones recorded the smallest value. The mean green MOR [and MOR at 12% MC] of the dermal, sub-dermal and the central zones for all the 5 trees decreased axially from the 1.5m height at the base of the trees through to the 10m height at the top of the trees. Radial decrease in the mean green [and 12% MC] MOR in all the 5 trees at each interval from the dermal zone through to the central zone was also observed. All the 450 specimens each of the mean green [and 12% MC] MOR ranged from 1.3-156.1 N/mm^2 and [2.1 – 217.1 N/mm^2] respectively. The overall averages were 47.5 N/mm^2 [and 65.2 N/mm^2]. The within tree average green [and 12% MC] MOR for the dermal, sub-dermal and the central zones range were 31.1-156.1 N/mm^2 [48.5 – 217.1 N/mm^2], 10.6 - 98.2 N/mm^2 [19.0 – 149.7 N/mm^2], and 1.3 – 22.9 N/mm^2 [2.1 – 31.9 N/mm^2] respectively. The overall average for the dermal, sub-dermal and central zones with their standard deviations in brackets were 89.8 (28.0) N/mm^2 [120.2 (34.3) N/mm^2], 45.2 (22.9) N/mm^2 [63.8 (29.1) N/mm^2], and 7.5 (4.7) N/mm^2 [11.8 (7.6) N/mm^2] respectively. The within tree average MOR range were 45.2 – 54.4 N/mm^2 [and 60.6-69.7] N/mm^2 (Appendix 6B and 7B). The results of the Analysis of Variance (Appendices 6B and 6C [7B and 7C]) of the mean green [and 12% MC] MOR of the 5 trees indicated that the differences between the mean green [and dry] MOR for each tree, all the three different zones along each stem for the individual trees, all the 5 green sub-dermal zones, and all the 5 central zones at 12% MC were highly significant ($P<0.05$). However, the ANOVA of Appendices 6C and 7C of the MOR at 12% MC also revealed respectively that the differences between all the 5 trees dermal and central zones of the green MOR, and the differences between all the 5 trees dermal and sub-dermal zones of the MOR at 12% MC were not significantly different ($P<0.05$). Similarly, there were no significant difference in all the 5 trees for both the mean green MOR and the mean MOR at 12% MC at ($P<0.05$). The post test, Tukey's Multiple Comparison test (Appendices 6D to 6I [7D to 7I]), within each zone for each 1.5m interval along the bole revealed that the differences between the mean green [and dry] MOR for each zone in all the 5 individual trees were also highly significant ($P<0.05$). The post test also revealed that the differences between the mean green MOR for all the 5 individual *Borassus aethiopum* trees species, and all the central zones of the 5 trees species were not significant at P<0.05 (Appendices 6Z). Appendix 7Z of the mean MOR at 12% MC also indicated that the differences between the mean green MOR for all the 5 *Borassus aethiopum* trees species, all the dermal, sub-dermal, and central zones of the 5 trees species were not significant at P<0.05 (Appendices 7Z).

4.4.3 Compression Parallel to the Grain Variation (Comp llg)

The range of mean strength values for the green [and dry] Compression Parallel to the Grain of the dermal, sub-dermal and the central zones for each of the five tree species across and along the bole are presented in Figures 4.8 and 4.9 respectively. A typical summary of the basic statistics for each of the five *Borassus aethiopum* tree species for the dermal, sub-dermal and the central zones are shown in Appendices 8A and 9A respectively for the green and [dry] Compression Parallel to the Grain.

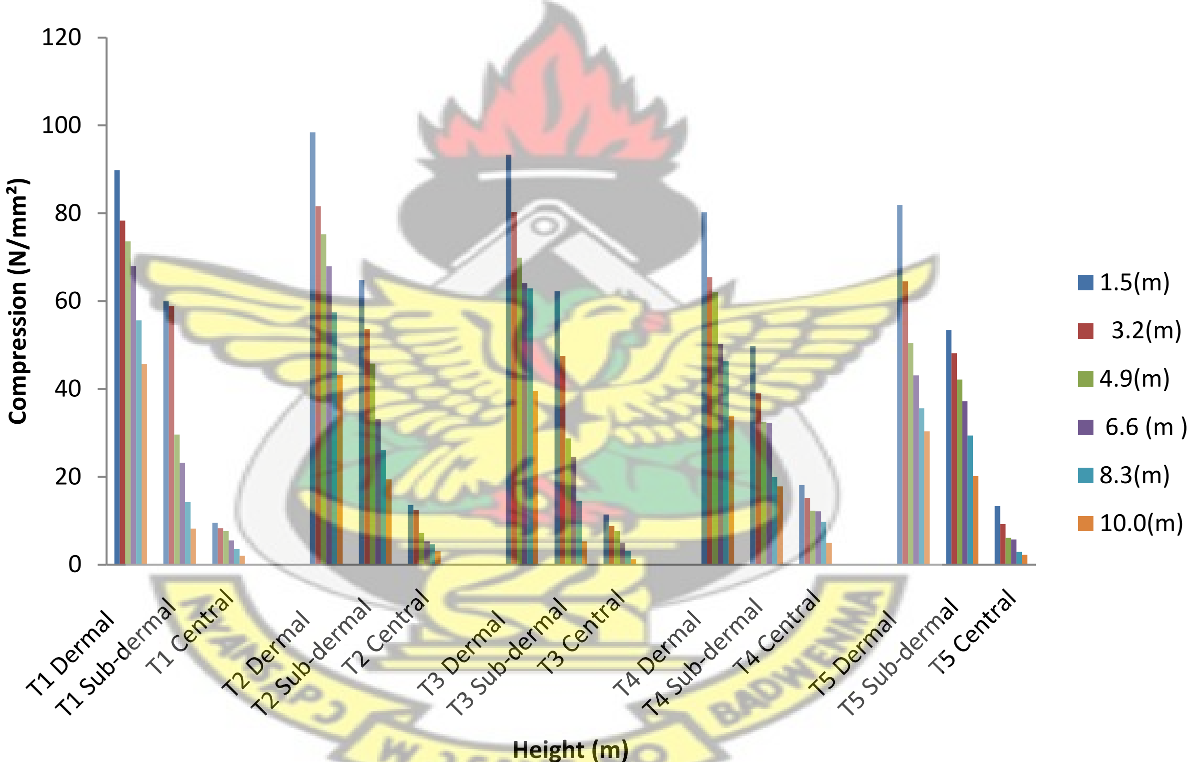

Figure 4.8: The mean green Compression parallel to the grain of the dermal zone, sub-dermal zone and the central zone for each of the five *Borassus aethiopum* trees along the stem.

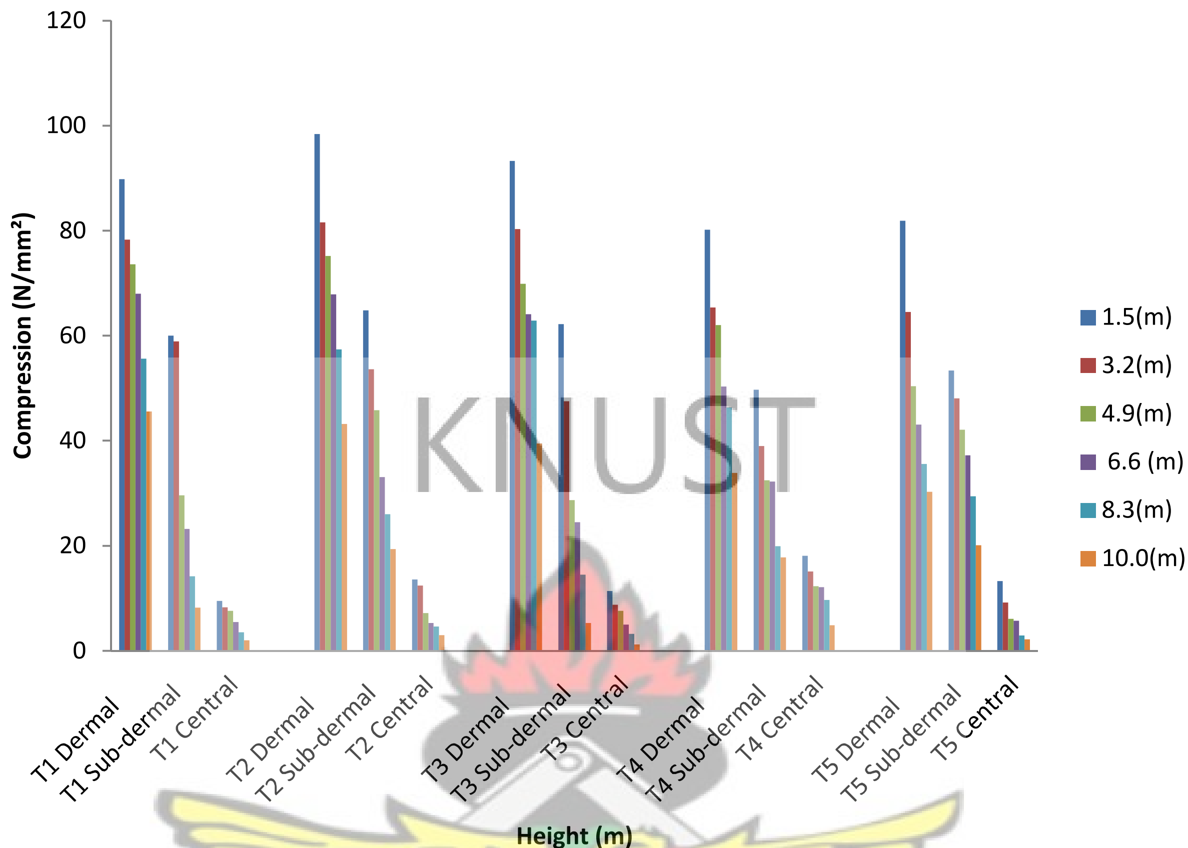

Figure 4.9: The mean Compression parallel to the grain at 12% MC of the dermal zone, sub-dermal zone and the central zone for each of the five *Borassus aethiopum* trees along the stem.

From Figures 4.8 and 4.9, the 1.5m height for all the three zones recorded the highest mean green [and dry] Compression Parallel to the Grain strength. The axial variation in the mean green [and dry] Compression Parallel to the Grain strength of Figures 4.8 and 4.9 for the dermal, sub-dermal and the central zones for each of the 5 trees further revealed that the mean green [and dry] Compression Parallel to the Grain at the top, the 10m height, for all the 3 zones registered the smallest value. The mean green [and dry] Compression Parallel to the Grain values of the dermal, sub-dermal and the central zones for all the 5 trees decreased axially from the 1.5m height at the base of the trees through to the 10m height at the top of the trees. A Similar decrease in the mean green [and dry] Compression Parallel to the Grain is revealed radially in all the 5 trees at each interval from the dermal zone through to the central zone. All the 450 specimens each of the mean green [and dry] Compression Parallel to the Grain ranged from 0.03-91.9 N/mm^2 and [0.9 – 99.8 N/mm^2] respectively. The overall averages were 26.0 N/mm^2 [and 35.1 N/mm^2]. The within tree average green [and dry] Compression Parallel to the Grain for the dermal, sub-dermal and the central zones range were 16.9-91.9 N/mm^2 [27.6 – 99.8 N/mm^2], 2.3-61.5 N/mm^2 [3.2 – 71.8 N/mm^2], and 0.03-17.8 N/mm^2 [0.9 – 18.7 N/mm^2] respectively. The overall average for the dermal, sub-dermal and central zones with their standard deviations in brackets were 48.4 (16.2) N/mm^2 [62.9 (18.4) N/mm^2], 24.7 (14.4) N/mm^2 [34.7 (16.8) N/mm^2], and 4.9 (3.6) N/mm^2 [7.7 (4.4) N/mm^2] respectively. The within tree average Compression Parallel to the Grain range were 23.8-29.7 N/mm^2 [and 31.2–39.6 N/mm^2] (Appendix 7B and 8B). Apart from the ANOVA of all the 5 trees and all the 5 trees sub-dermal for both the green [and dry] Compression Parallel to the Grain test, the results of the Analysis of Variance (Appendices 8B to 8C [9B to 9C]) of the green [and dry] Compression Parallel to the Grain of the 5 trees pointed out that the differences between the mean green [and dry] Compression Parallel to the Grain for each tree, all the three different zones along each stem for the individual trees, all the 5 dermal zones, and all the 5 central zones were highly significant ($P<0.05$). The Tukey's Multiple Comparison test (Appendices 8D to 8H [9D to 9H]), within each zone for each 1.5m interval along the bole revealed that the differences between the mean green [and dry] Compression Parallel to the Grain for each zone in all the 5 individual trees were also highly significant ($P<0.05$). However, the post test also confirmed that the differences between the mean green [and dry] Compression Parallel to the Grain for all the 5 *Borassus* *aethiopum* trees species, and all the Sub-dermal zones of the 5 trees species were not significant at P<0.05 (Appendices 8I [and 9I]).

4.4.4 Shear Parallel to the Grain Variation (shear llg)

The range of mean strength values for the green [and dry] Shear Parallel to the Grain of the dermal, sub-dermal and the central zones for each of the five tree species across and along the bole are presented in Figures 4.10 and 4.11 respectively. A typical summary of the basic statistics for each of the five *Borassus aethiopum* tree species for the dermal, sub-dermal and the central zones are shown in Appendices 10A and 11A respectively for the green and [dry] Shear Parallel to the Grain.

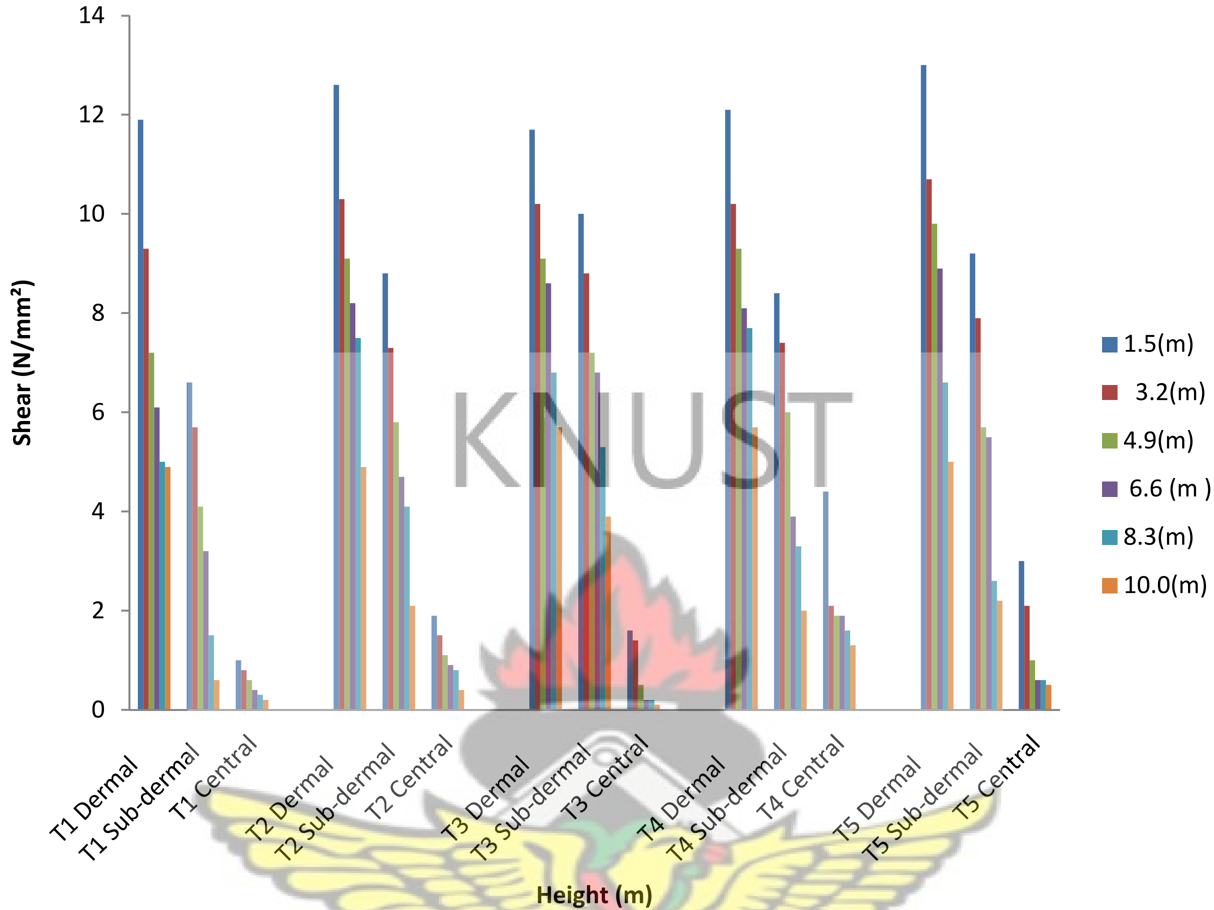

Figure 4.10: The mean green Shear parallel to the grain of the dermal zone, sub-dermal zone and the central zone for each of the five *Borassus aethiopum* trees along the stem.

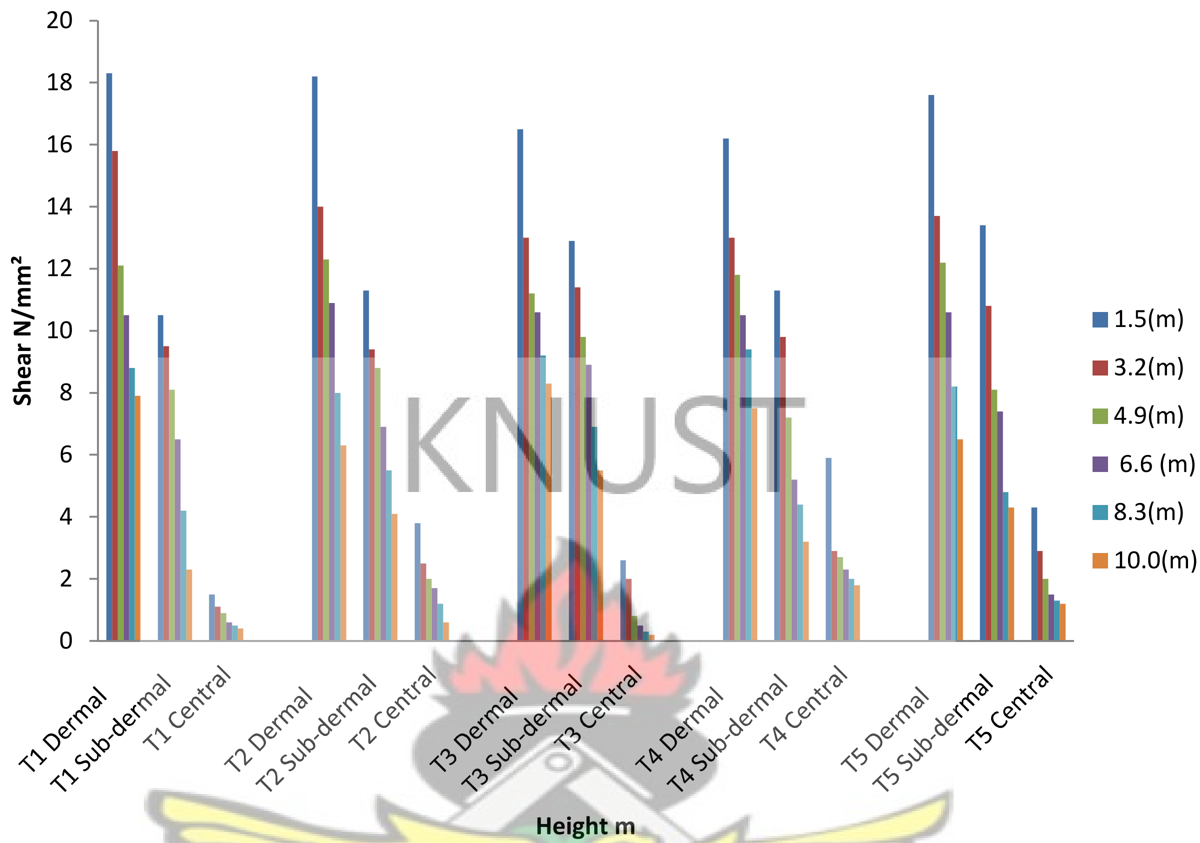

Figure 4.11: The mean Shear parallel to the grain at 12% MC of the dermal zone, sub-dermal zone and the central zone for each of the five *Borassus aethiopum* trees along the stem.

The axial variation in the mean green [and dry] Shear Parallel to the Grain strength of Figures 4.10 and 4.11 for the dermal, sub-dermal and the central zones for each of the 5 trees revealed that the top, the 10m height, for all the 3 zones registered the smallest value. However, the 1.5m height for all the three zones recorded the highest mean green [and dry] Shear Parallel to the Grain strength. The mean green [and dry] Shear Parallel to the Grain values of the dermal, sub-dermal and the central zones for all the 5 trees decreased axially from the 1.5m height at the base of the trees through to the 10m height at the top of the trees. A similar decrease in the mean green [and dry] Shear to the Grain is revealed radially in all the 5 trees at each interval from the dermal zone through to the central zone. All the 450 specimens each of the mean green [and dry] Shear Parallel to the Grain ranged from 0.09 - 13.74 N/mm^2 and [0.20 – 19.75 N/mm^2] respectively. The overall averages were 5.02 N/mm^2 [and 7.06 N/mm^2]. The within tree average green [and dry] Shear Parallel to the Grain for the dermal, sub-dermal and the central zones range were 2.61-13.74 N/mm^2 [5.47 – 19.75 N/m^2], 0.43-10.40 N/mm^2 [1.38 – 14.13 N/mm^2], and 0.09 -5.17 N/mm^2 [0.20 – 6.23 N/mm^2] respectively. The overall average for the dermal, sub-dermal and central zones with their standard deviations in brackets were 8.53 (2.56) N/mm^2 [11.64 (3.46) N/mm^2], 5.36 (2.59) N/mm^2 [7.74 (3.05) N/mm^2], and 1.15 (0.96) N/mm^2 [1.80 (1.29) N/mm^2] respectively. The within tree average Shear Parallel to the Grain range were 3.9 -5.4 N/mm^2 [and 6.6–7.3 N/mm^2] (Appendix 10B and 11B). With the exception of the ANOVA of all the 5 trees dry Shear strength, and the green and [dry] dermal shear strength of all the 5 trees (Appendices 11B, and 10C [11C]) respectively, the results of the Analysis of Variance (Appendices 10B to 10C [11B to 11C]) of the green [and dry] Shear Parallel to the Grain of the 5 trees pointed out that the differences between the mean green [and dry] Shear Parallel to the Grain for each tree, all the three different zones along each stem for the individual trees, all the 5 sub-dermal zones, and all the 5 central zones were highly significant (P<0.05). The Tukey's Multiple Comparison test (Appendices 10D to 10H [11D to 11H]) within each zone for each 1.5m interval along the bole revealed that the differences between the mean green [and dry] Shear Parallel to the Grain for each zone in all the 5 individual trees, all the 5 sub-dermal and central zones were also highly significant (P<0.05). Again, the post test also confirmed that the differences between the mean green [and dry] Shear Parallel to the Grain of all the 5 *Borassus aethiopum* trees dermal, and all the 5 trees shear strength at 12% moisture content were not significant at P<0.05 (Appendices 10I [and 11I]).

4.4.5 Hardness Test Variation

The range of mean strength values for the green [and dry] Hardness test of the dermal, sub-dermal and the central zones for each of the five tree species along the bole are presented in figures 4.12 and 4.13 respectively. A typical summary of the basic statistics for each of the five *Borassus aethiopum* tree species for the dermal, sub-dermal and the central zones are shown in Appendices 12A and 13A respectively for the green and [dry] Hardness test.

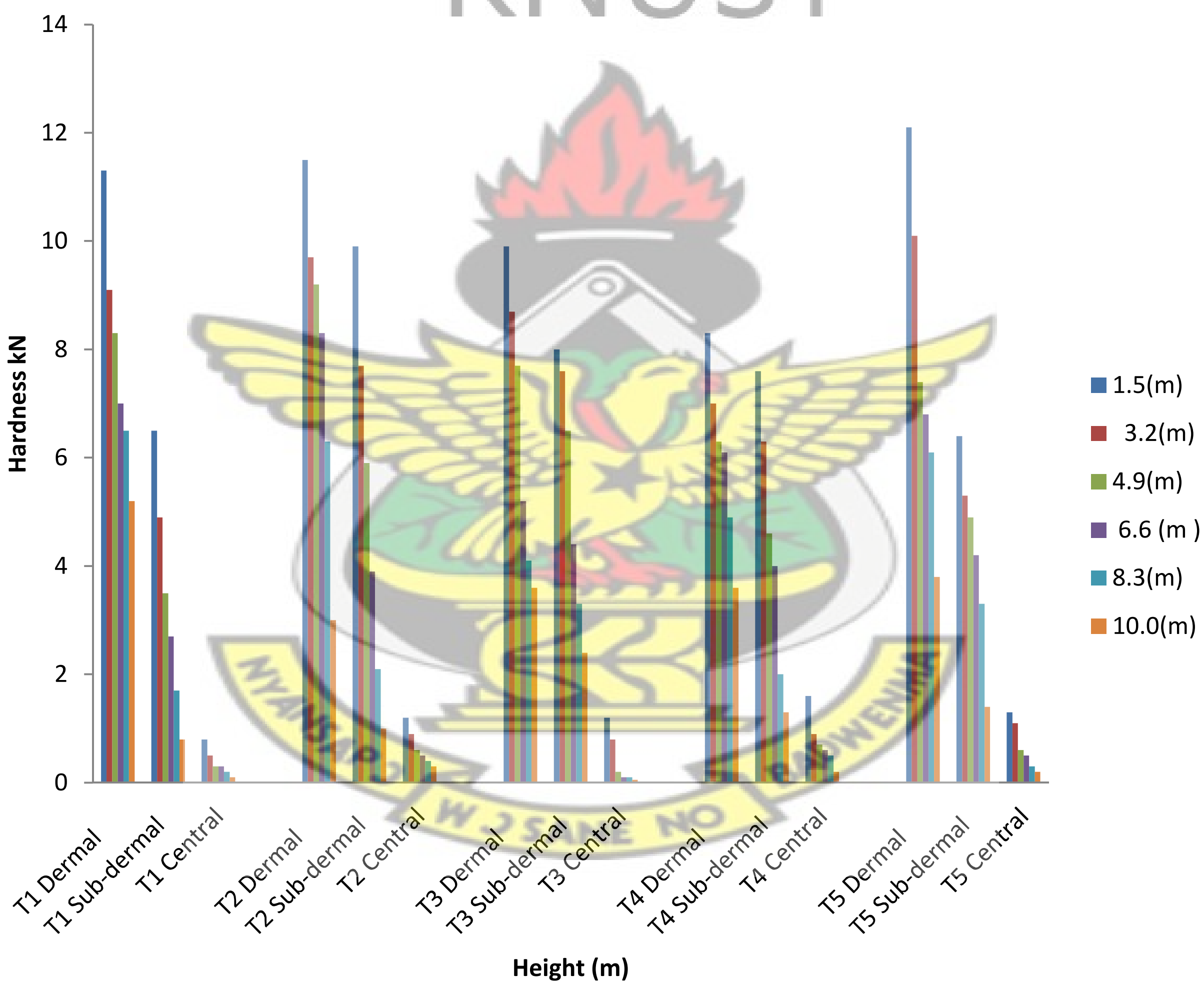

Figure 4.12: The mean green Hardness of the dermal zone, sub-dermal zone and the central zone for each of the five *Borassus aethiopum* trees along the stem.

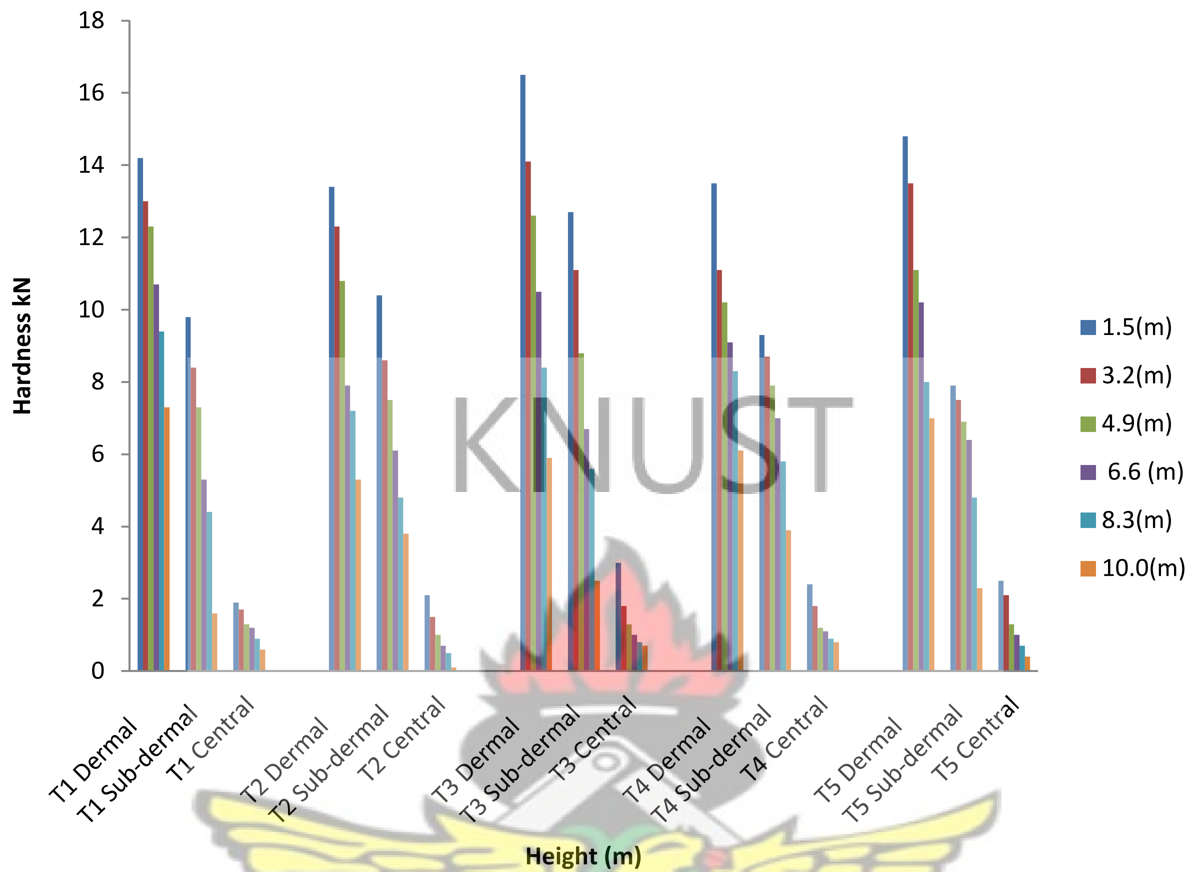

Figure 4.13: The mean Hardness at 12% MC of the dermal zone, sub-dermal zone and the central zone for each of the five *Borassus aethiopum* trees along the stem.

From Figures 4.12 and 4.13, the axial variation in the mean green [and dry] Hardness strength values of the dermal, sub-dermal and the central zones for each of the 5 trees revealed that the top section, the 10m height, for all the 3 zones recorded the smallest value. However, the 1.5m height for all the three zones recorded the highest mean green [and dry] Hardness strength. The mean green [and dry] Hardness values of the dermal, sub-dermal and the central zones for all the 5 trees decreased axially from the 1.5m height at the base of the trees through to the 10m height at the top of the trees. Similar decrease in the mean green [and dry] Hardness is revealed radially in all the 5 trees at each interval from the dermal zone through to the central zone. All the 450 specimens each of the mean green [and dry]

Hardness ranged from 0.04 – 12.23 kN and [0.1 – 17.02 kN] respectively. The overall averages were 4.09 kN [and 6.18 kN]. The within tree average green [and dry] Hardness for the dermal, sub-dermal and the central zones range were 2.74 -12.23 kN [5.07 – 17.02 kN], 0.66-10.12 kN [1.42 – 12.95 kN], and 0.04 -1.66 kN [0.1 – 3.13 kN] respectively. The overall average for the dermal, sub-dermal and central zones with their standard deviations in brackets were 7.23 (2.47) kN [10.49 (2.93) kN], 4.46 (2.39) kN [6.79 (2.61) kN], and 0.57 (0.40) kN [1.27 (0.67) kN] respectively. The within tree average Hardness range were 3.7 - 4.6 kN [and 5.7 – 6.9 kN] (Appendix 12B and 13B). With the exception of the ANOVA of all the 5 trees' green [and dry] Hardness, all the 5 trees' sub-dermal green [and dry] and that of the dry Hardness strength value for all the 5 trees dermal and central zones the results of the Analysis of Variance (Appendices 12B and 12C [13B and 13C]) of the green [and dry] Hardness of the 5 trees pointed out that the differences between the mean green [and dry] Hardness for each tree, all the three different zones along each stem for the individual trees, all the 5 sub-dermal zones for the green Hardness strength and all the green Hardness strength for the 5 central zones were highly significant ($P<0.05$). The Tukey's Multiple Comparison test (Appendices 12D to 12H [13D to 13H]) within each zone for each 1.5m interval along the bole revealed that the differences between the mean green [and dry] Shear Parallel to the Grain for each zone in all the 5 individual trees, all the 5 sub-dermal and central zones were also highly significant ($P<0.05$). However, the post test also confirmed that the differences between the mean green [and dry] Shear Parallel to the Grain of all the 5 *Borassus aethiopum* trees species dermal, and all the 5 trees shear strength at 12% moisture content were not significant at $P<0.05$ (Appendices 12I [and 13I]).

4.5 Mechanical Properties of the Bulged area

A typical summary of the basic statistics of the mechanical properties of each of the trees for the bulged area is shown in Appendix 15A. The range of mean strength values for the MOE, MOR, Hardness, Compression and Shear Parallel to the grain were respectively 70.27 – 188.46 N/mm^2, 1.15-3.30 N/mm^2, 0.09-0.44 kN, 0.47-2.34 N/mm^2 and 0.12-0.67 N/mm^2. The overall averages for the mechanical properties: MOE, MOR, Hardness, Compression and Shear parallel to the grain of all the trees with their standard deviations in brackets were 109.68 (30.89) N/mm^2, 2.24 (0.66) N/mm^2, 0.25 (0.12) kN, 1.10 (0.59) N/mm^2 and 0.36 (0.16) N/mm^2 respectively (Appendix 15A). The Analysis of Variance (ANOVA) of the mechanical properties (Appendix 15B) of all the 5 trees bulged areas revealed that the differences between each mean mechanical property (MOE, MOR, Hardness, Compression and Shear Parallel to the grain) for all the 5 trees were highly significant ($P<0.05$). The post test, Tukey's Multiple Comparison test, also confirmed this highly significant difference between the trees for each of the mechanical properties (Appendices 15C).

4.6 Physical Properties of the Bulged area

The basic statistics of the physical properties of each of the 5 trees for the bulged area is shown in Appendix 14A. The ranges of mean Moisture Content, Basic Density, and Density at 12% MC for all the trees were 200-298%, 78.43-163.3kg/m^3 and 89.0-187.7kg/m^3 respectively. The overall averages for the physical properties: Moisture Content, Basic density and Density at 12% MC of all the trees with their standard deviations in brackets were 242.7 (25.5) %, 134.7 (16.7) kg/m^3 and 154.3 (19.5) kg/m^3. The Analysis of Variance (ANOVA) of the physical properties (Appendices 14B) of all the 5 trees Bulge areas revealed that the differences between each mean Physical property (Moisture Content, Basic

Density and Density at 12 % MC) for all the 5 trees were not significant ($P<0.05$). The Tukey's Multiple Comparison test further confirmed this insignificance between the trees for each of the physical properties (Appendices 14C).

4.7 Ratio of Dry to Green 'Clear' Mechanical Strength Values

Below the fibre saturation point, changes in the moisture content affected the mechanical properties of *Borassus aethiopum.* All the strength properties, generally, increased as the wood dried. However, most of the mechanical properties are not affected by changes in moisture content above the fibre saturation point. Appendix 16 shows the ratio of the mechanical properties at 12% moisture content to that when green for the species studied, the comparative range ratios for USA hardwoods (ASTM 1978) and that of Ghanaian hardwoods (Ofori *et al* 2009). Ratios for the Ghanaian Palm species, *Borassus aethiopum,* were generally highest in Hardness, followed by Shear parallel to the grain, MOR, Compression parallel to the grain and MOE in that order for the dermal zones. The sub-dermal zones ratios were highest in Hardness, followed by MOE, Shear parallel to the grain, MOR; and least in Compression parallel to the grain. The ratios for the Central zones were generally highest in Hardness, followed by MOE, coupled with Compression and Shear parallel to the grain and least in MOR. Mean ratios of dry to green MOR and MOE for the dermal, sub-dermal and the central zones were respectively [1.35 and 1.29], [1.44 and 1.51], and [1.57 and 1.61]. The ratios of the Ghanaian Palms were generally lower in the dermal zone followed by the sub-dermal zone. However, the central zone had the highest dry to green strength ratios. The ratios for the Ghanaian Palms' dermal zone were generally lower than the hardwoods of Ghanaian and USA origin. It is apparent that the mechanical strength increases associated with drying small clear specimens from the green condition to 12 percent moisture content were generally greatest in the central zones (1.29-3.344); followed by sub-dermal zone (1.18-1.88); and least in the dermal zone (1.16-1.66).

4.8 Correlation between Density and Mechanical Properties

The correlations between the densities and mechanical properties of the three distinct layers or zones of the five trees are presented in Appendices 17A to 17F for the green and dry conditions respectively. The correlations revealed that there was a good correlation between density and the mechanical strength values for the dermal, sub-dermal and the central zones. The densities and mechanical properties for the green condition and dry condition in square brackets were highly correlated at 98.4% ~ 99.8% [97.1% ~ 99.9%], 98.6% ~ 99.7% [94.9% ~99.7], and 92.4% ~ 99.8% [94.8% ~ 99.9] respectively for the dermal, sub-dermal and the central zones. However, the correlation of density with the mechanical properties of the Bulge area indicated very weak correlation for the Compression Parallel to the grain, weak and negative correlation for the MOE and the MOR (Appendix 17 G). The correlation was good and positive for the Shear Parallel to the grain and Hardness strength. The density and mechanical properties of the Bulged area was correlated at 18.3%~89.3%.

4.9 Functional Relationship between Density and Mechanical Properties (MOR, MOE, Hardness, Compression and Shear parallel to the grain)

The relationship between density and the various mechanical strength values of the dermal, sub-dermal and the central zones in the green and the dry conditions are presented graphically as scattered diagrams in Fig 4.14 and 4.15.

4.9.1 Relationship between Density and Mechanical Properties for the Dermal zone.

Scattered plots from the pooled means of each 1.5m interval for the density and the various strength properties of all the dermal zones are shown in the relationship between the density and the mechanical properties in the green and dry conditions in Figures 4.14 and 4.15. From the graphs, density showed a direct relationship with the strength properties both in the green and dry conditions. As the density increases, the strength properties also increase with their coefficient of determinations (R^2) respectively 0.957 [0.982], 0.969 [0.986], 0.984 [0.980], 0.984 [0.978], and 0.979 [0.960] for the MOE, MOR, Compression parallel to the grain, Shear parallel to the grain, and Hardness. The squared brackets values are the coefficients of determination in the dry condition. Regression equations (Table 4.1) in the form Y= mx + c were derived for the density-mechanical properties relationship of the dermal zone in the green and dry conditions with R^2 values ranging between 0.96 – 0.99. For the 'green' wood, basic density was based on green volume and oven dry weight. However, for the dry wood, density was based on volume at 12% moisture content and oven dry weight.

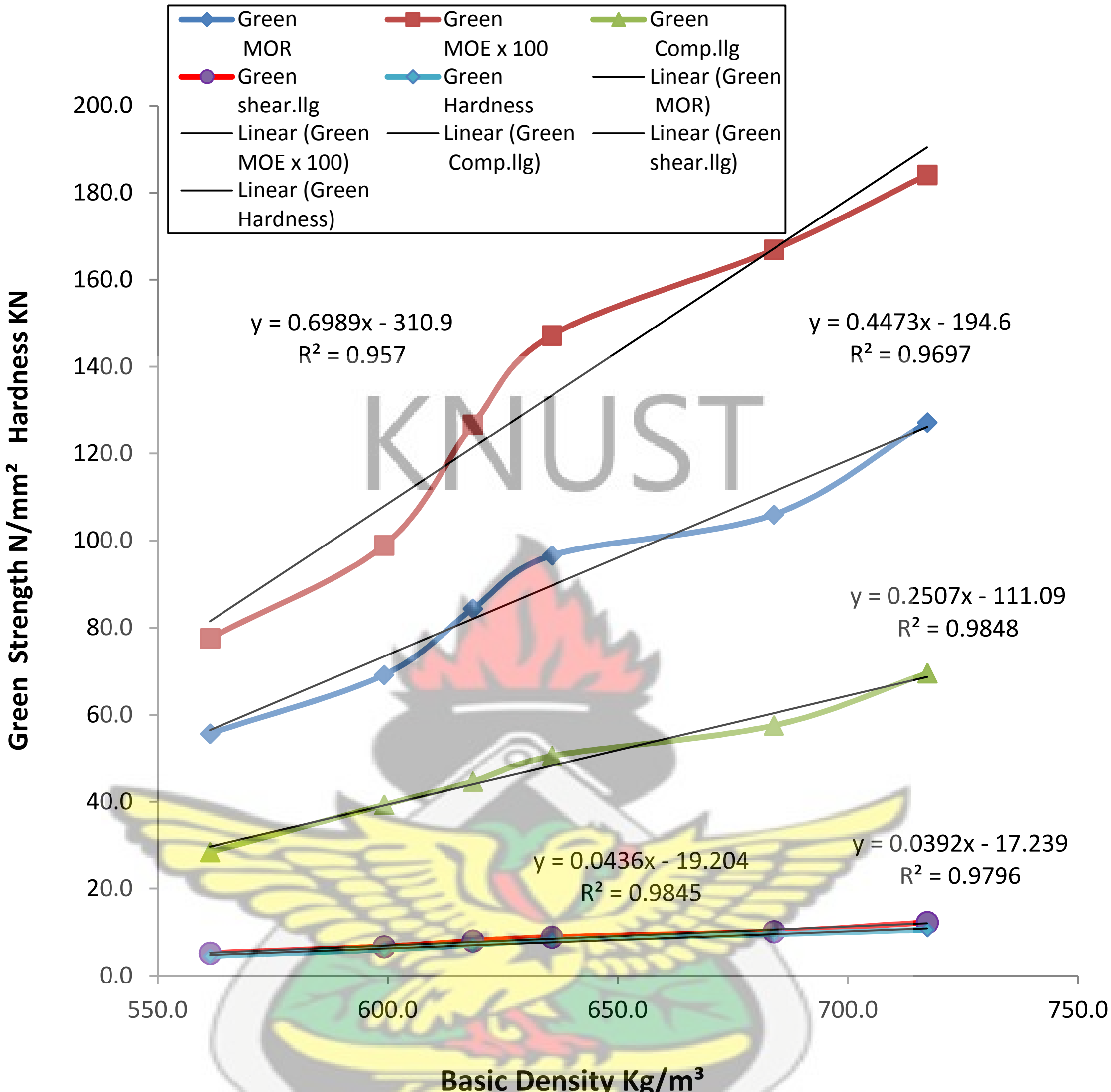

Figure 4.14: Relationship between Basic density and green strength - Dermal zone

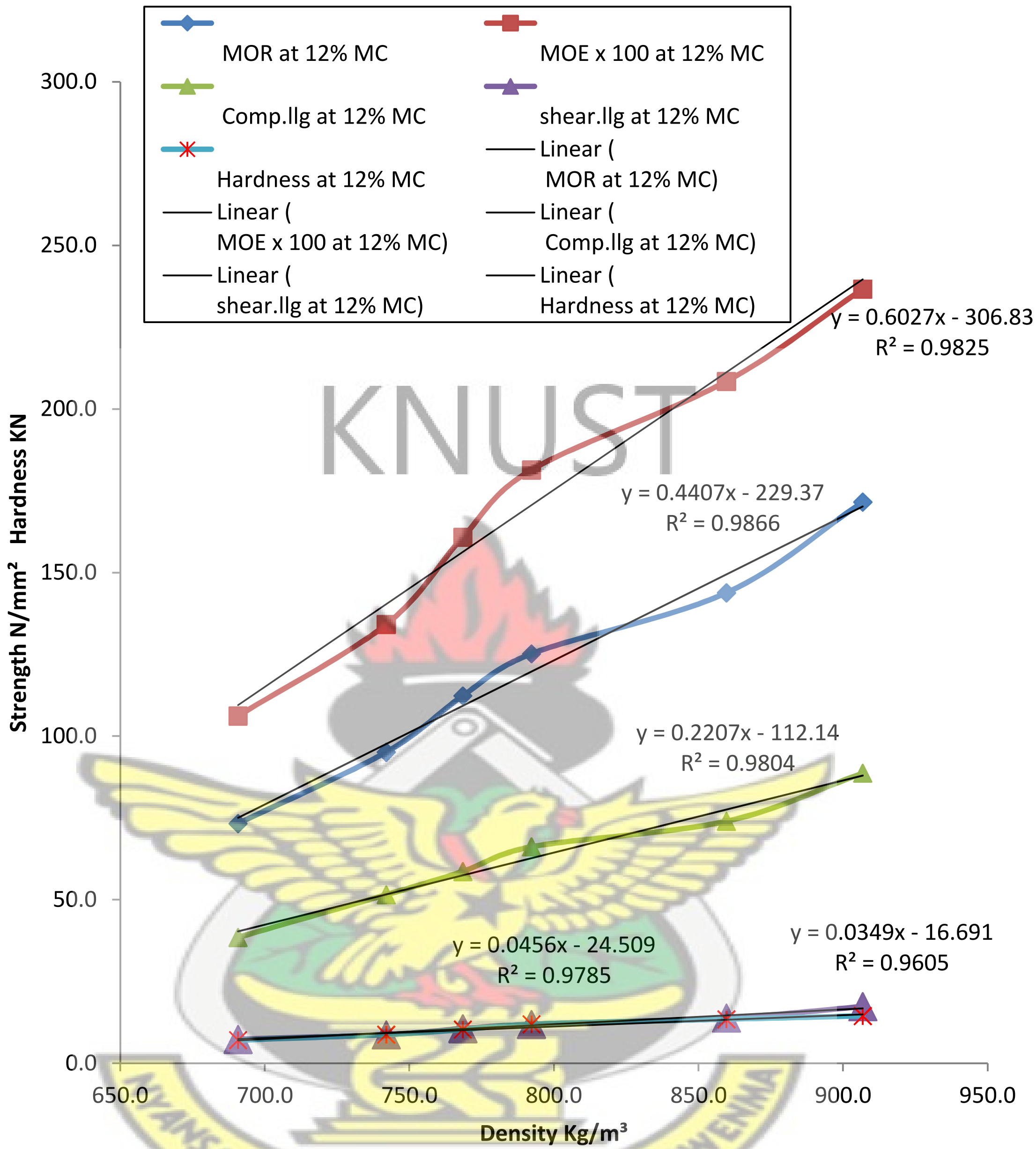

Figure 4.15: Relationship between density at 12% MC and strength at 12% mc – Dermal zone

Table 4.1: Functions relating mechanical properties to density (basic and 12% MC) of clear straight grain for the Dermal zones.

Mechanical Property	'Green' wood		Wood at 12% MC	
	Density (x) Strength (Y) Relationship	R^2	Density (x) Strength (Y) Relationship	R^2
MOE (N/mm^2) x 100	Y = 0.698x - 310.9	$R^2 = 0.957$	Y = 0.602x - 306.8	$R^2 = 0.982$
MOR (N/mm^2)	Y = 0.447x - 194.6	$R^2 = 0.969$	Y= 0.440x - 229.3	$R^2 = 0.986$
Comp llg (N/mm^2)	Y = 0.250x - 111.0	$R^2 = 0.984$	Y= 0.220x - 112.1	$R^2 = 0.980$
Shear llg (N/mm^2)	Y = 0.043x - 19.20	$R^2 = 0.984$	Y = 0.045x - 24.50	$R^2 = 0.978$
Hardness KN	Y = 0.039x - 17.23	$R^2 = 0.979$	Y = 0.034x - 16.69	$R^2 = 0.960$

4.9.2 Relationship between Density and Mechanical Properties for the Sub-dermal zone.

The pooled mean of each 1.5m interval for the density and the various strength properties in the green and the dry conditions of all the sub-dermal zones are shown in Figures 4.16 and 4.17. From the graphs, density showed a direct relationship with the strength properties in the green and dry conditions. As the density increases, the strength properties also increase with their coefficient of determinations (R^2) respectively 0.980 [0.987], 0.986 [0.986], 0.979 [0.992], 0.993 [0.993], and 0.976 [0.951] for the MOE, MOR, Compression parallel to the grain, Shear parallel to the grain, and Hardness. The squared brackets values are the coefficients of determination in the dry condition. Regression models (Table 4.2) in the form Y= mx + c were derived for the density- mechanical properties relationship of the sub-dermal zone in the green and dry conditions with R^2 values ranging between 0.95 – 0.99. For the 'green' wood, basic density was based on green volume and oven dry weight. However, for the dry wood, density was based on volume at 12% moisture content and oven dry weight.

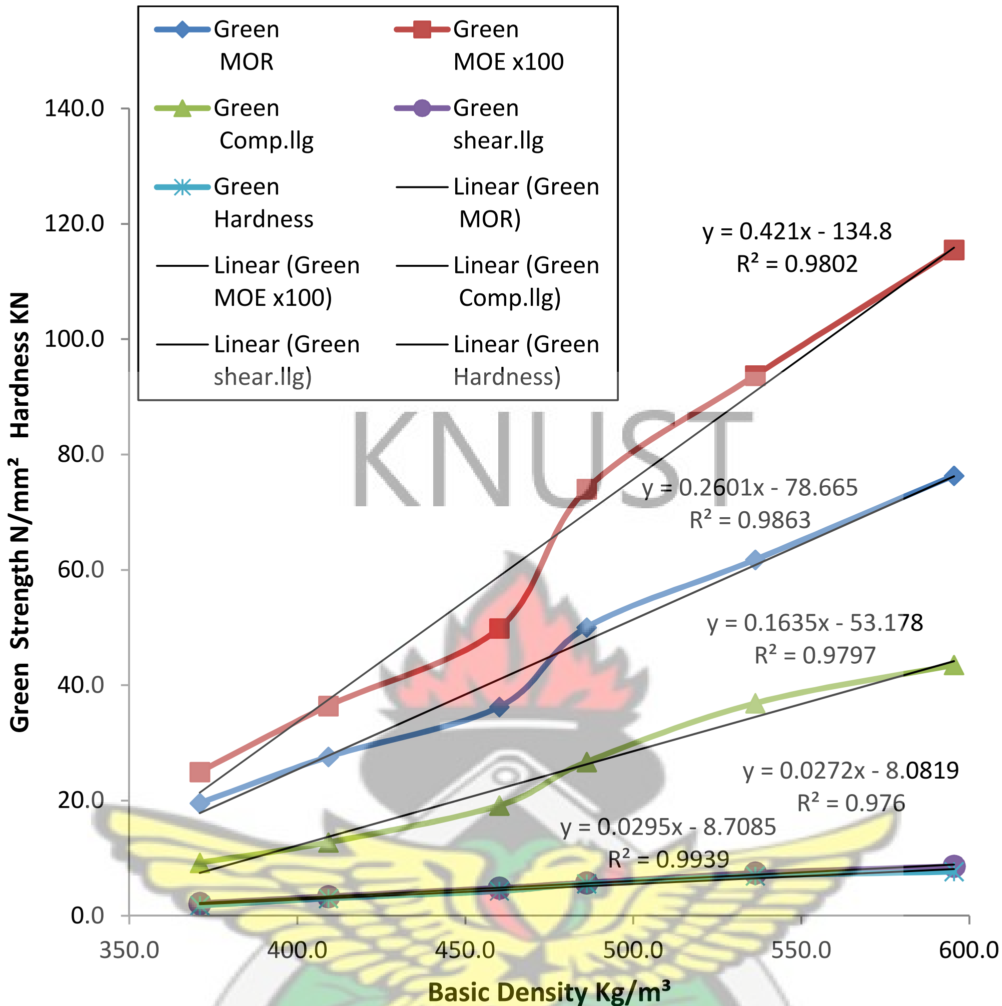

Figure 4.16: Relationship between basic density and green strength – Sub-dermal zone

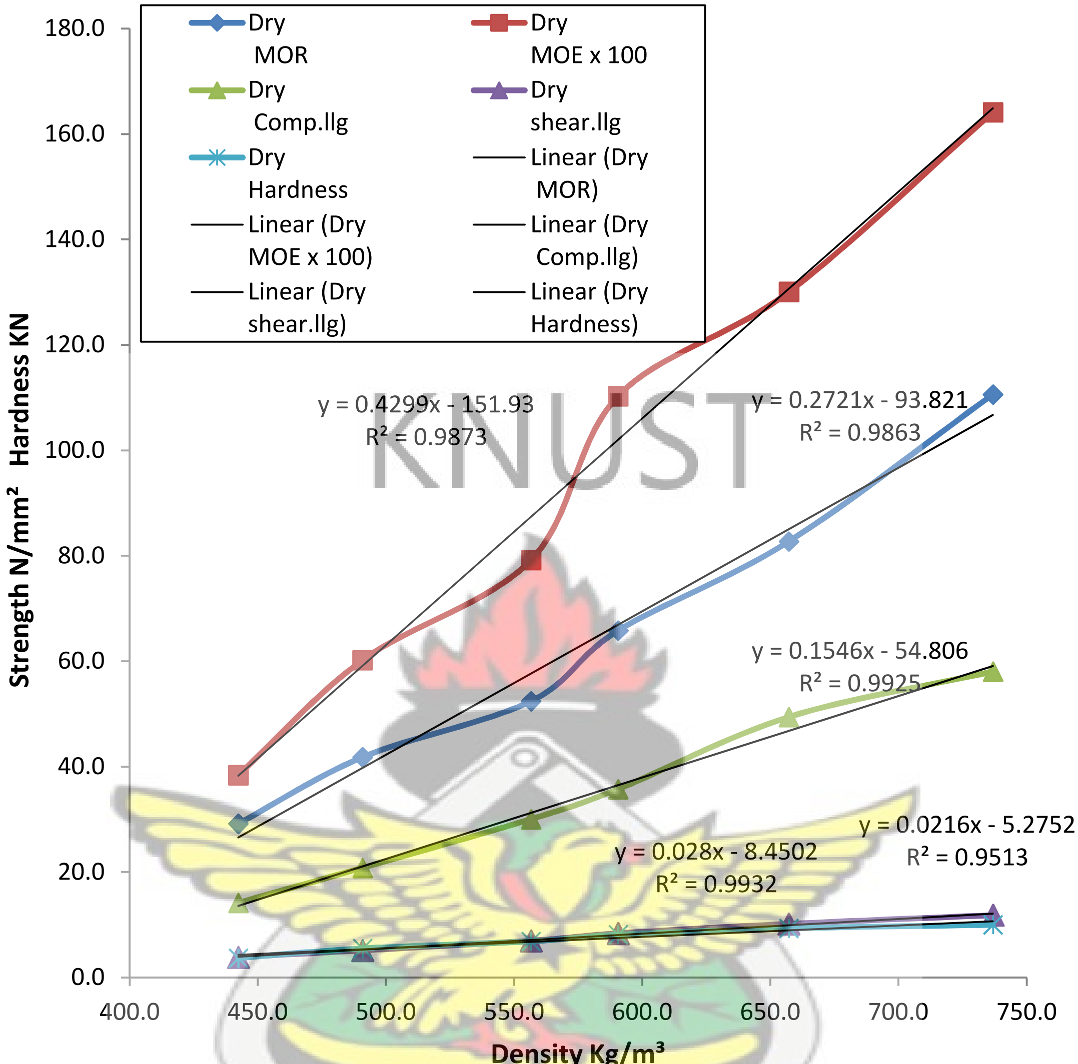

Figure 4.17: Relationship between density at 12% MC and strength at 12% MC–Sub-dermal zone

Table 4.2: Functions relating mechanical properties to density (basic and 12% MC) of clear straight grain for the sub-dermal zones.

Mechanical Property	Green' wood		Wood at 12% MC	
	Density (x) Strength (Y) Relationship	R^2	Density (x) Strength (Y) Relationship	R^2
MOE (N/mm²) x 100	Y= 0.421x -134.8	$R^2 = 0.984$	Y = 0.429x - 151.9	$R^2 = 0.987$
MOR (N/mm²)	Y = 0.260x - 78.66	$R^2 = 0.986$	Y = 0.272x - 93.82	$R^2 = 0.986$
Comp llg (N/mm²)	Y= 0.163x - 53.17	$R^2 = 0.979$	Y = 0.154x - 54.80	$R^2 = 0.992$
Shear llg (N/mm²)	Y= 0.029x - 8.708	$R^2 = 0.993$	Y = 0.028x - 8.450	$R^2 = 0.993$
Hardness kN	Y= 0.027x - 8.081	$R^2 = 0.976$	Y = 0.021x - 5.275	$R^2 = 0.951$

4.9.3 Relationship between Density and Mechanical Properties for the Central zone.

Figures 4.18 and 4.19 present the scattered plots of the pooled mean of each 1.5m interval for the density - strength properties relationship in the green and the dry conditions of all the central zones. This indicated that density had a direct relationship with the strength properties in the green and dry conditions. As density increases, strength properties also increase with their coefficient of determinations (R^2) respectively 0.853 [0.943], 0.883 [0.932], 0.985 [0.989], 0.918 [0.930], and 0.954 [0.972] for the MOE, MOR, Compression parallel to the grain, Shear parallel to the grain, and Hardness. The squared brackets values are the coefficients of determination in the dry condition. Regression equations (Table 4.3) in the form Y= mx + c were derived from the linear regression for the density - mechanical properties relationship of the central zone in the green and dry conditions with R^2 values ranging between 0.95 – 0.99. For the 'green' wood, basic density was based on green volume and oven dry weight. However, for the dry wood, density was based on volume at 12% moisture content and oven dry weight.

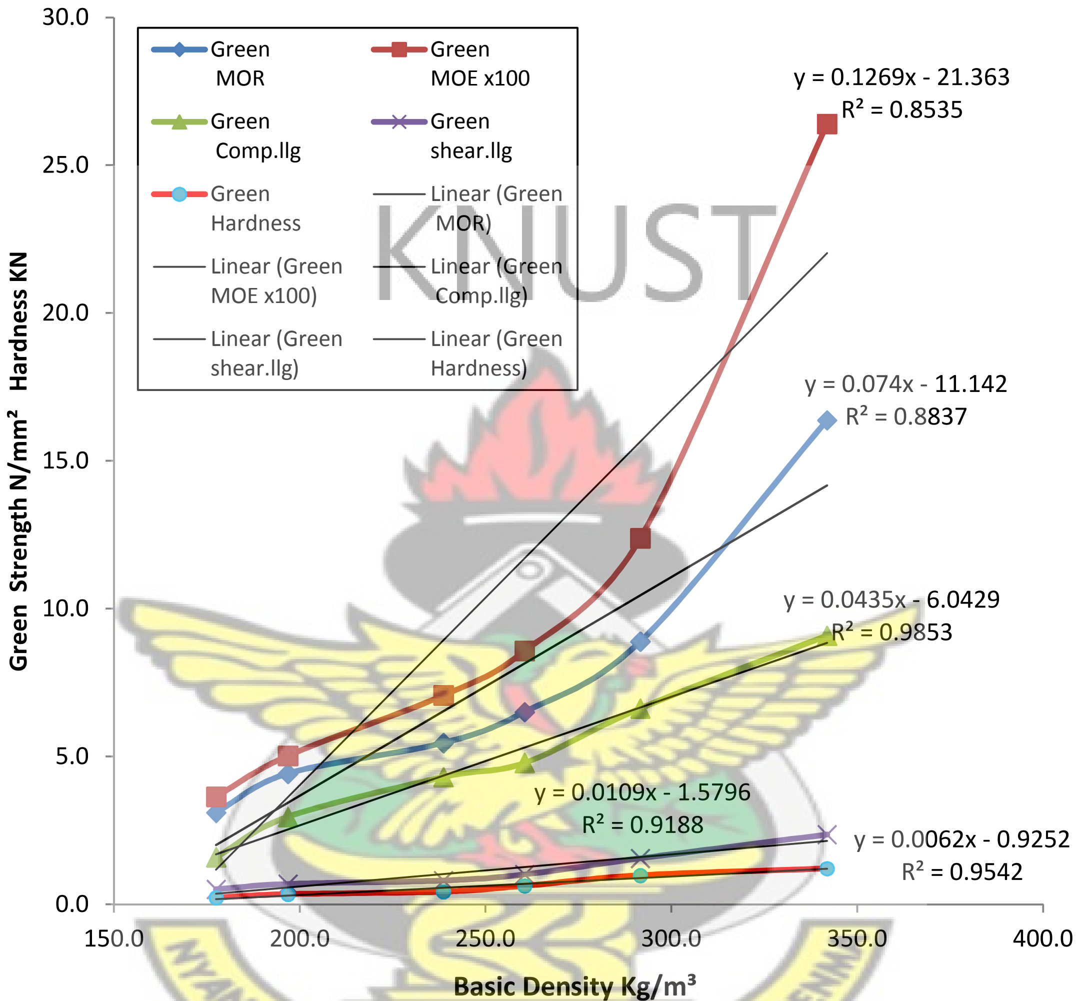

Figure 4.18: Relationship between Basic density and green strength - Central zone

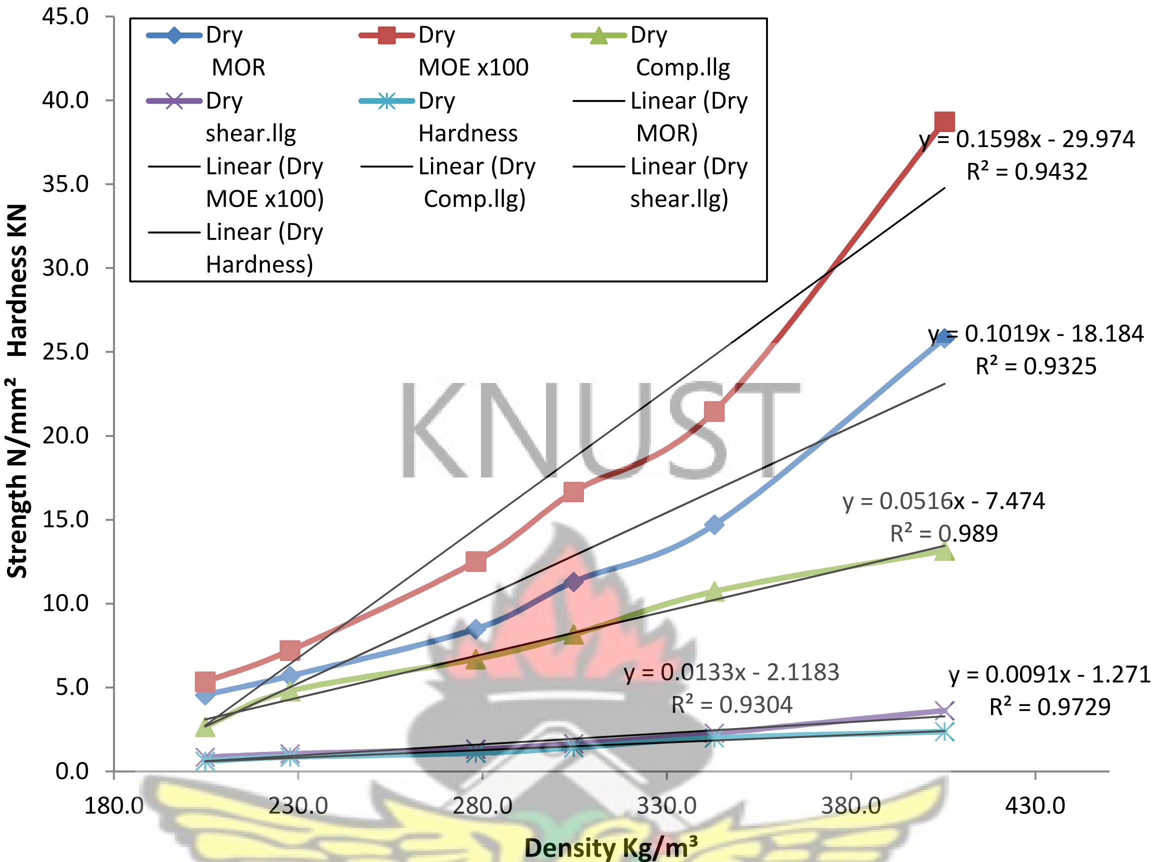

Figure 4.19: Relationship between density at 12% MC and strength at 12% MC – Central zone

Table 4.3: Functions relating mechanical properties to density (basic and 12% MC) of clear straight grain for the Central zones.

Mechanical Property	Green' wood Density (x) Strength (Y) Relationship	R^2	Wood at 12% MC Density (x) Strength (Y) Relationship	R^2
MOE (N/mm^2) x 100	Y = 0.126x - 21.36	$R^2 = 0.853$	Y = 0.159x - 29.97	$R^2 = 0.943$
MOR (N/mm^2)	Y = 0.074x - 11.14	$R^2 = 0.883$	Y = 0.101x - 18.18	$R^2 = 0.932$
Comp llg (N/mm^2)	Y = 0.043x - 6.042	$R^2 = 0.985$	Y = 0.051x - 7.474	$R^2 = 0.989$
Shear llg (N/mm^2)	Y = 0.010x - 1.579	$R^2 = 0.918$	Y = 0.013x - 2.118	$R^2 = 0.930$
Hardness KN	Y = 0.006x - 0.925	$R^2 = 0.954$	Y= 0.009x - 1.271	$R^2 = 0.972$

4.9.4 Relationship between Density and Mechanical Properties for the Bulge area.

Figures 4.20a to 4.20e present the scattered plots of the densities and the strength properties of the bulge area. From the graphs, it is generally apparent that the variations in the various mechanical properties of the individual trees with their coefficient of determinations (R^2) respectively 0.03, 0.23, 0.01, 0.60, and 0.25 for the MOE, MOR, Compression parallel to the grain, Shear parallel to the grain, and Hardness are weakly explained by the increase in density, except for the shear parallel to the grain, which is fairly strong. Mathematical models (Table 4.4) in the form Y= mx + c were derived from the linear regression for the density - mechanical properties relationship of the bulge area in the dry condition with R^2 values ranging between 0.01 – 0.60. For the dry wood, density was based on volume at 12% moisture content and oven dry weight.

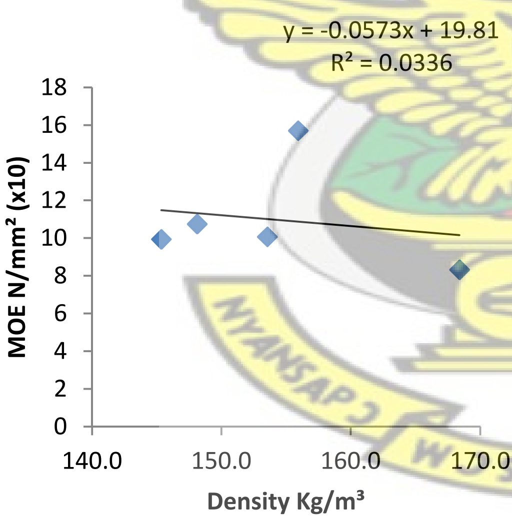

Figure 4.20a: Relationship between density at 12% MC and MOE at 12% MC-Bulge area

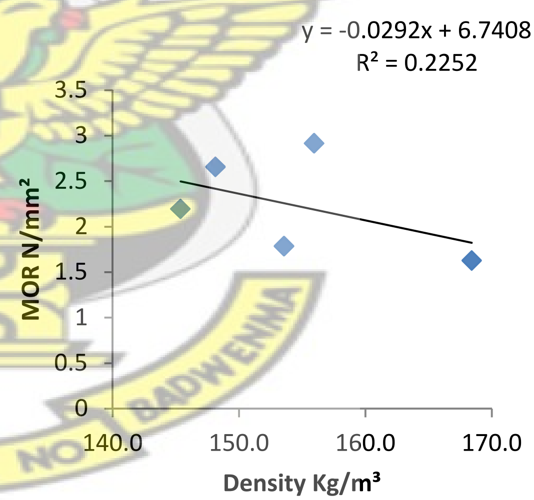

Figure 4.20b: Relationship between density at 12% MC and MOR at 12% MC-Bulge area

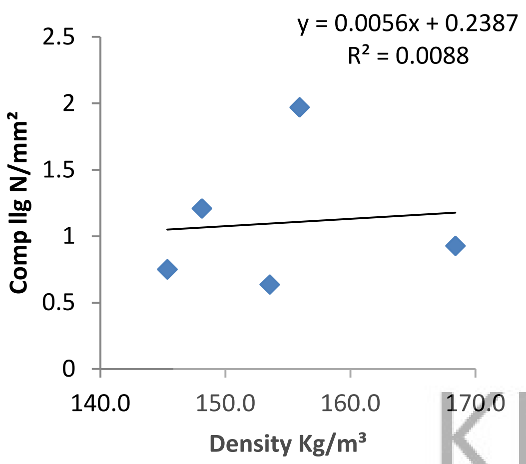

Figure 4.20c: Relationship between density at 12% MC and Comp llg at 12% MC-Bulge area

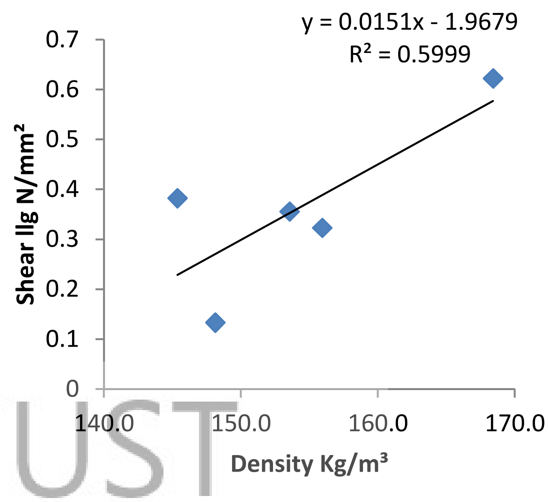

Figure 4.20d: Relationship between density at 12% MC and Shear llg at 12% MC-Bulge area

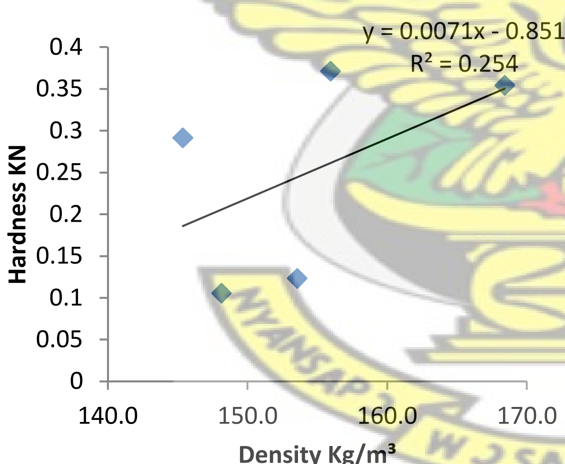

Figure 4.20e: Relationship between density at 12% MC and Hardness at 12% MC-Bulge area

Table 4.4: Functions relating mechanical properties to density 12% MC of clear straight grain for the Bulge area

Mechanical Property	Wood at 12% MC	
	Density (x) Strength (Y) Relationship	R^2
MOE (N/mm^2) x 100	$Y = -0.057x + 19.81$	$R^2 = 0.033$
MOR (N/mm^2)	$Y = -0.029x + 6.740$	$R^2 = 0.225$
Compression llg (N/mm^2)	$Y = 0.005x + 0.238$	$R^2 = 0.008$
Shear llg (N/mm^2)	$Y = 0.015x - 1.967$	$R^2 = 0.599$
Hardness KN	$Y = 0.007x - 0.851$	$R^2 = 0.254$

CHAPTER FIVE

5.0 Discussion

In general, all the five stems studied exhibited common characteristics: the dermal, sub-dermal and the central zones in their cross section. This zonal variation in *Borassus aethiopum* was also found in a study on wood characteristics and properties of *Cocos nucifera* (Odour and Githiomi, 2009). The analysis of variance (ANOVA) of the properties studied revealed that the variation between the various zones in each of the trees was highly significant at $P<0.05$ and rejected the null hypothesis that there is no significant difference between the zones of the individual trees for the physical, and mechanical properties studied.

5.1 Physical properties

5.1.1 Moisture Content

From Appendix 1A, the overall average green moisture content for each of the zones (dermal, sub-dermal, and central) in all the 5 trees were respectively 50%, 72%, and 168%. The mean green moisture content for each of the trees studied (Appendix 1B) were 112.5%, 98.8%, 87.8%, 91.3%, and 91.4% respectively for trees 1, 2, 3, 4, and 5. The overall average for the trees was 96% (Appendix 1A). It can be seen from the results that the mean green MC for the central zones recorded the highest MC followed by the sub-dermal zones and the dermal zones in that order. Results of the zonal variation in the mean green MC within the trees further revealed that the mean MC of the central zone comparatively had thrice as much water as that of the dermal zone and twice as that of the sub-dermal zones. Apparently, the highest green MC of the central zone recorded could in part be explained by the anatomical characteristics of the zone: as it is chiefly composed of ground tissues according to Eaia (1983). The relatively low moisture content recorded by the dermal zones may also be ascribed to higher proportion of vascular bundles that may be present at the peripheral zone of the stem which according to Butterfield and Meylan (1980) have fibres constituting over half the volume of each vascular bundle. The overall average MC for the bulge area was 246.2% (Appendix 14A). Comparatively, the MC of the bulge area recorded the highest MC of all the sections of the trees and this could be attributed to the presence of juvenile sclerenchyma fibres, and higher proportion of ground tissues as the tissues are very soft and spongy, Eaia (1983). The MC of the various sections in the trees increased in the following order: Dermal zone > Sub-dermal zone > Central > Bulge area. It is evident from Figure 4.1 that the mean MC for each of the 1.5m interval along the stem for each zone increased significantly at $P<0.05$ (Appendix 1C) from the bottom to top along the trees heights. Also, the mean MC values recorded for the trees for each interval increased from the periphery (the dermal zone), and to the sub-dermal zone through to the central zone.

5.1.2 Density

From Appendices 2A, 3A, 14A and 15A, the overall average basic density and [density at 12% MC] for each of the dermal zone, sub-dermal zone, central zone and the bulge area of the five trees were 636.0 Kg/m^3, 476.4 Kg/m^3, 251.2 Kg/m^3 and 134.7 Kg/m^3 [793.3 Kg/m^3, 579.1 Kg/m^3, 293.9 Kg/m^3 and 154.3 Kg/m^3] severally. Results of each of the mean basic density and density at 12% MC for trees 1 through to 5 were respectively 449.3Kg/m^3, 467.0 Kg/m^3, 478.7 Kg/m^3, 449.2 Kg/m^3 and 454.7 Kg/m^3, and [523.4 Kg/m^3, 548.0 Kg/m^3, 548.0 Kg/m^3, 587.1 Kg/m^3 and 549.0 Kg/m^3] (Appendices 2B and 3B). The mean basic density and density at 12% MC decreased significantly at $P<0.05$ from the bottom of the trees to the top of the trees (Appendix 2C and 3C). Regardless of the density values recorded for each 1.5m interval along the bole of the five trees, it was generally apparent that the mean basic density and density at 12% MC increased from the bulge area to the central zones to the sub-dermal zones and to the dermal zones as depicted in Appendices 2A, 3A, and 14A. According to Jane, 1970, wood from different parts of a tree is noted to show differences in density and this variation according to Panshin and de Zeeuw, (1980), exist horizontally, from the pith to the periphery and vertically, from the base to the crown of the tree. Results of the basic density and density at 12% MC exhibited similar patterns of variations. Donaldson *et al* (1995) also reported that density usually decreases with height in the stem of a tree. This is a general trend since wood density is usually higher at the bottom due to the higher compaction of the base tissues exerted by overlapping cells along the bole and tree crown (Ali, 2011). One explanation of the noticeable radial and axial change of density in *Borassus aethiopum* is likely to be associated with the presence of greater amount of extractives in the dermal zone than in the central zone. The Basic density and [density at 12% MC] ranged from a mean low of 127.7 kg/m^3 in the central zone to a mean high of 752.7 kg/m^3 in the dermal zone and [a mean low of 145.9 kg/m^3 in the central zone to a mean high of 957.7 kg/m^3 in the dermal zone] respectively. This range of density values further indicate the variability of the species studied. The relatively low Basic density and density at 12% MC recorded for the bulge area and the central zone and the relatively high Basic density and Density at 12% MC recorded for the dermal zone may in part be accounted for by higher proportion and frequency of vascular bundles in the dermal zone to that of the bulge area and the central zone which according to Eaia (1983), is primarily made up of ground tissues. FAO, (1985) found similar trend in *Cocos nucifera*, and pointed out that a typical stem at one meter height would have about ten bundles/cm^2 in the central portion and about 50 bundles/cm^2 near the outside or periphery. According to FAO, (1985) timber should be graded hard, intermediate or soft, corresponding to high, medium and low densities. The technical limits between the grades are: High density above 500 kg/m^3, Medium density between 500 and 350 kg/m^3 low density less that 350 kg/m^3 and added that only high density timber is acceptable for structural purposes. From the results of Appendices 3A and 14A, the wood of *Borassus aethiopum* can be classified as having a high to low density wood. Based on these ratings, the densities of the dermal zone and the sub-dermal can be graded as hard and that of the central zone and bulge area as soft.

5.2 Mechanical properties

5.2.1 Modulus of Elasticity (MOE)

The overall average green MOE and MOE at 12% MC (Appendices 4A, and 5A) for each of the three zones of the five trees were 14725.0 N/mm^2 [17127.3 N/mm^2], 5272.1 N/mm^2 [9704.12 N/mm^2], 1150.9 N/mm^2 [1698.6 N/mm^2] respectively. The overall MOE at 12% MC of the bulge area was 109.68 N/mm^2 (Appendix 14C). The mean static bending strength values for the MOE when green and at [12% MC] for each of the 5 trees were 6522.8N/mm^2 [8310.7 N/mm^2], 6387.9 N/mm^2 [8751.7 N/mm^2], 6480.8 [9810.2 N/mm^2], 8531.8 [10946.4 N/mm^2], and 7049.3 N/mm^2 [9731.1 N/mm^2] respectively (Appendices 4B and 5B). The MOE, which according to Shrivastava, (1997), measures the stiffness of a wood and is indispensable in the determination of the deflection of a beam under load, decreased significantly along the bole height from the bottom of the trees to the top of the trees at $P < 0.05$ for the green and dry state (Figures 4.4 and 4.5). The overall average green MOE and MOE at 12% MC for the trees were 6994.5 N/mm^2 and 9510.0 N/mm^2 in that order. In spite of the general significant difference between each of the three zones within a tree, the Analysis of Variance and the Tukey’s Multiple Comparison Test of the green and dry MOE for all the trees, however, revealed that there is no significant difference between the trees in terms of their stiffness (Appendices 4B, 4I, 5B and 5I) at P< (0.05). This insignificant difference between the trees could be ascribed to the trees densities as the post test, the Tukey's Multiple Comparison Test, revealed similar trends of insignificant differences at P< 0.05 between the trees for the basic density and the density at 12% MC (Appendices 2I and 3I). The mean green MOE and [MOE at 12% MC] ranged from a mean low of 118.7 N/mm^2 in the central zone to a mean high of 20563.8 N/mm^2 in the dermal zone and [a mean low of 206.5 N/mm^2 in the central zone to a mean high of 25871.8 N/mm^2 in the dermal zone] respectively.Upton and Attah (2003) and TEDB (1994) classified strength of species based on the MOE at 12% moisture content as follows: 'Very High'[19,000 N/mm^2 and more], 'High' [14,000-19,000N/mm^2], 'Medium' [11000-14,000 N/mm^2], 'Low/ Medium' [9,000-11,000 N/mm^2], and 'Low'[below 9,000 N/mm^2]. The above classification indicates that the strength of the species, disregarding the individual zones, is Low/Medium. Nonetheless, the various portions within the trees vary in terms of stiffness and the classification is 'High' in the dermal zone, 'low/Medium' in the sub-dermal zone, and 'Low' in the central zone and the bulge area. The overall order of decreasing MOE of the various sections of the five trees was as follows: Dermal zone > Sub-dermal zone > Central zone > Bulge area.

5.2.2 Modulus of Rupture (MOR)

Similarly, the mean static bending strength, the Modulus of Rupture (MOR), varied significantly at P<0.05 (Appendices 6C and 7C) from the base of the trees to the top of the trees for each zone. The mean MOR for each of the zones (dermal. Sub-dermal, and central zones) in the green and at 12% MC (Appendices 6A and 7A) was respectively 89.8 N/mm^2 [120.5 N/mm^2], 45.2 N/mm^2 [63.8 N/mm^2], and 7.5 N/mm^2 [11.9 N/mm^2]. However, the mean MOR (Appendices 6B and 7B) for each tree was respectively 45.8 N/mm^2 [60.6 N/mm^2], 45.6 N/mm^2 [63.2 N/mm^2], 45.2 N/mm^2 [69.7 N/mm^2], 54.4 N/mm^2 [69.3 N/mm^2], and 46.6 N/mm^2 [63.5 N/mm^2] for the green and at 12% MC. The overall averages for the green MOR and MOR at 12% MC were 47.5 N/mm^2 and 65.2 N/mm^2. The bending strength, MOR, of small clear specimen at 12% MC according to Farmer (1972), is rated very low when is under 50 N/mm^2, low if it ranges from 50 - 85 N/mm^2, medium if it ranges between 85-120 N/mm^2, high and very high if it ranges from 120-175 N/mm^2 and over 175 N/mm^2 respectively. Comparatively, the mean MOR at 12% MC obtained in this study is rated low in all the five trees in respect of Farmer's ratings. The preceding classification points out that the dermal zone is rated high, that of the sub-dermal zone is rated low, and very low in the case of the central zone. It is evident from the results that the mean MOR for the central zone accounts to a larger extent, the low rating of the species studied. Since density is an excellent index of the amount of wood substance contained in a piece of wood; it is a good index of mechanical properties as long as the wood is clear, straight grained, and free from defects (Forest Products Laboratory, 2010). Consequently, the high, low and very low maximum load-carrying capacity of the species in bending recorded for the dermal, sub-dermal and the central zones respectively is a function of their densities (Appendices 2A and 3A). The mean MOR at 12% MC of the bulged area for the five trees is 2.24 N/mm^2 (Appendix 15A). The strength value is extremely low compared to the other parts of the trees and could possibly be due to the presence of juvenile sclerenchyma fibres, and higher proportion of ground tissues as the tissues are very soft and spongy. The overall order of decreasing MOR of the various sections of the five trees was as follows: Dermal zone > Sub-dermal zone > Central zone > Bulge area.

5.2.3 Compression Parallel to the Grain

The mean maximum crushing strength for the dermal, sub-dermal and the central zones for the green and [at 12% MC] in all the five trees were 48.4 N/m^2 [62.9N/mm^2], 24.7 N/mm^2 [34.7 N/mm^2], and 4.9 N/mm^2 [7.7 N/mm^2] respectively. There was significant variation (Appendices 8Cand 9C) in mean Compression Strength Parallel to the Grain among sample heights in each of the three zones for the five *Borassus aethiopum* trees sampled. For each of the zones, the maximum crushing strength decreased significantly at $P<0.05$ along the bole from the base of the trees to the top of the trees. The mean Compression Strength Parallel to the Grain (Appendix 15A) at 12% MC for the Bulge area of the five trees was 1.1 N/mm^2. Evaluation of the mean maximum crushing strength for the five *Borassus aethiopum* trees indicated insignificant strength difference between the trees (Appendices 8I and 9I) and the Compression strength Parallel to the Grain were 26.9 N/mm^2 [35.6 N/mm^2], 29.7 N/mm^2 [39.6 N/mm^2], 24.6N/mm^2 [35.0 N/mm^2], 23.8N/mm^2 [33.4 N/mm^2] and 24.9 N/mm^2 [31.2 N/mm^2] respectively for each tree. The average Compression Strength Parallel to the Grain for all the five *Borassus aethiopum* trees was 26 N/mm^2 [35.1 N/mm^2]. The Compression strength Parallel to the Grain have been classified according to Farmer, (1972), as very low, low, medium, high, and vey high when the strength values are under 20 N/mm^2, ranging from 20-35N/mm^2, 35-55N/mm^2, 55-85 N/mm^2 and over 85N/mm^2 respectively. This classification consequently rates the dermal zone as high, low in the sub-dermal zone and very low in both the central zone and the bulge area. According to Desch and Dinwoodie (1996), the strength of a piece of wood in compression is closely related to its density.The very low Compression strength Parallel to the Grain recorded for the central zone and the bulge area was expected, as the samples from these regions easily buckled under relatively low stresses and could be explained by their densities. Overall order of decreasing Compression Strength Parallel to the Grain of the sections in the five trees was as follows: Dermal zone > Sub-dermal zone > Central zone > Bulge area.

5.2.4 Shear Parallel to the Grain

The overall average Shear strength Parallel to the Grain of the five *Borassus aethiopum* trees sampled in the green and at 12% MC (Appendices 10A and 11A) for the dermal, sub-dermal and the central zones were respectively 8.53 N/mm^2 [11.64 N/mm^2], 5.36 N/mm^2 [7.74 N/mm^2], and 1.15 N/mm^2 [1.80 (1.29) N/mm^2]. The mean shear strength parallel to the grain at 12% MC for the bulge area was also 0.25 N/mm^2 (Appendix 15A). The overall order of decreasing Shear strength Parallel to the Grain for the various sections in the five trees was as follows: Dermal zone > Sub-dermal zone > Central zone > Bulge area. The mean Shear strength Parallel to the Grain in the green and at 12% MC for the five trees were 3.9 N/mm^2 [6.6 N/mm^2], 5.1 N/mm^2 [7.1 N/mm^2], 5.4 N/mm^2 [7.3 N/mm^2], 5.4 N/mm^2 [7.1 N/mm^2], and 5.3 N/mm^2 [7.3 N/mm^2] respectively. The mean green Shear strength Parallel to the Grain varied significantly between the five trees at $P<0.05$ (Appendix 10B). The Tukey's Multiple Comparison Test (Appendix 10I), further, revealed that the significant difference in Shear Parallel to the Grain was actually between trees 1 and 3, and 1 and 4. The overall average Shear strength Parallel to the Grain for the five trees was 5.0 N/mm^2 and 7.1 N/mm^2 respectively for the green and at 12% MC. There was, however, no significant variation in the mean Shear strength Parallel to the Grain at 12% MC among the five trees sampled (Appendices 11B and 11I). Also, there was no significant Shear strength Parallel to the Grain variation among sample heights in the dermal zone for all the five *Borassus aethiopum* trees sampled (Appendices 10C, 10I, 11C and 11I).

5.2.5 Hardness

From (Appendices 12A, 13A and 15A) the overall average for the dermal zone, sub-dermal zone, central zone and the bulge area were 7.23[10.49] kN, 4.46[6.79] kN, 0.57[1.27] kN, and 0.25kN respectively. The overall order of decreasing side Hardness for the various sections in the five trees was as follows: Dermal zone > Sub-dermal zone > Central zone > Bulge area. The overall averages for each of the five trees in the green and at 12% MC were respectively 3.9 [6.2] kN, 4.6 [6.9] kN, 4.1 [6.0] kN, 3.7 [6.2] kN, and 4.2 [5.7] kN. For the average green and at [12% MC] side Hardness, there was no statistically significant difference at $P<0.05$ in average strength values among heights for all the five *Borassus aethiopum* trees (Appendices 12B and 13B). However, the average Hardness for each zone at a given height varied significantly along the bole and the hardness strength decreased from the butt of the trees through to the top of the trees. Evidently, these results demonstrate a stark difference in the ability of the various parts of the same tree to resist indentation. According to Meier (2011), the wood is so non-homogenous: the trunk varies between the strong fibro-vascular bundles, and the softer ground tissues. Toward the outer wall of the trunk, the density of the wood is the greatest, and gradually becomes lighter, softer, and weaker towards the soft core. The resistance of *Borassus aethiopum* to indentation was relatively very high at the dermal zone, fairly high at the sub-dermal, low at the central zone and very low at the bulge area. The average Hardness value, 10490N, for the dermal zone at 12% MC for this study compares favorably with the average Hardness value of 9920N reported by Meier (2011) for *Borassus flabellifer*.

5.3 Prediction of the Mechanical Properties of *Borassus aethiopum* from its Density.

Wood density is acknowledged to affect mechanical properties (Barnett and Jeronimidis 2003; Bowyer et al. 2003). Earlier studies examined the predictability of some wood mechanical properties from density on various hardwood species such *Hevea brasiliensis* (Gnanaharan and Dhamodaran 1992), *Eucalyptus globulus*, *E. nitens* and *E. regnans* (Yang and Evans 2003), *Celtis mildbraedii* and *Maesopsis eminii* (Zziwa et al. 2006). These studies reported density as a good estimator of mechanical properties in some timber species. However, in other species density was a poor predictor. The potential of *Borassus aethiopum* density as a predictor of its mechanical properties through simple linear regression is given in Tables 4.1 to 4.4 for the dermal zone, sub-dermal zone, central zone and the bulge area samples. As shown in Tables 4.1 to 4.3, the density of *Borassus aethiopum* in the green and at 12% MC for the dermal, sub-dermal, and central zones is a good estimator of measured mechanical properties. Hence, in almost all the evaluations, the coefficient of determination (R^2) was more than 90 %. For the dermal, sub-dermal and central zones, density alone accounted for approximately 93% of the variations in the mechanical properties studied. The density of the bulge area (Table 4.4) is however a poor predictor of its measured strength properties, except, for the Shear parallel to the grain which is comparatively good. The co-efficient of determination (R^2) was less than 26% in all the measured mechanical properties except for the Shear parallel to the grain strength in which density accounted for 59.9% of its variation. Poor predictability of some mechanical properties from density alone was reported for compression parallel to grain, MOE, and MOR for *H. brasiliensis*, *Celtis mildbraedii* and *Maesopsis eminii* (Gnanaharan and Dhamodaran 1992; Zziwa et al. 2006).

5.4 Comparison of the studied physical and mechanical properties of *Borassus aethiopum* to other species.

According to Ayarkwah (1997), the outer part of *Borassus aethiopum* has the following properties at 12% MC: density – 670kg/m^3, MOR – 104N/mm^2, MOE – 11300 N/mm^2, Compression Parallel to the grain – 58 N/mm^2, and Shear Parallel to the grain - 7.8 N/mm^2. However, the properties of the dermal zone at 12% MC for this study were as follows: density - 793.3 kg/m^3, MOE – 17127.3 N/mm^2, MOR – 120.2 N/mm^2, Compression Parallel to the grain – 62.9 N/mm^2, Shear Parallel to the grain - 11.64N/mm^2 and Side Hardness - 10.5kN. Comparatively, it is evident that the results obtained in this study are higher than that reported by Ayarkwah (1997). This difference could be attributed to several factors. Examples include tree species origin, growth conditions and anatomical differences. Bodig and Jayne (1982) indicated that because of the natural origin of wood, both physical and mechanical properties of wood frequently exhibit an unusually wide degree of variability. Bodig and Jayne (1982) also added that the natural variability of wood can be attributed to differences in genetic stock Dinwoodie (1989) reasserted this variability in wood and stated that "not only between different species of wood but also between trees of the same species, growing in different environments". Thus differences in the tree origin as well as its growing conditions are among the factors that these differences could be ascribed to.

Table 5.1**:** Range of mean mechanical and physical properties of *Borassus aethiopum* and *Cocos nucifera*

Species	MC %	Density (kg/m³)	MOR (N/mm²)	MOE (N/mm²)	Comp llg (N/mm²)	Shear llg (N/mm²)	Hardness kN
Borassus aethiopum	12%	145.9 - 957.7	2.1 – 217.1	206.5 – 25871.8	0.9 – 99.8	0.20 – 19.75	0.1 – 17.02
*Cocos nucifera**	12%	248.0 - 852.0	16.34 - 109.21	1982 – 12705.0	9.84 - 77.6	2.1 - 17.37	0.66 - 14.91

Source: Oduor and Githiomi, (2009)*

Table 5.1, juxtaposes the range of mean physical and mechanical properties at 12% MC of the dermal, sub-dermal and the central zones of *Borassus aethiopum* for this study and that of *Cocos nucifera* sourced from Oduor and Githiomi, (2009). It is evident from Table 5.1 that the range of mean physical and mechanical properties of *Borassus aethiopum* is superior to that of *Cocos nucifera*, although, *Borassus aethiopum* recorded least values in all the properties determined. Comparison of the mean mechanical properties determined for *Borassus aethiopum* (Dermal zone, Sub-dermal zone, Central zone and the Bulge area) to other commercially important timber species of Table 5.2 revealed that the mechanical properties of the dermal zone compares favourably with Afromosia (*Pericopsis elata*), Dahoma (*Pepdiniastrum africanum*), Kusia, Teak (*Tectona grandis*), and Sapele (*Entandrophragma cylindricum*), with the dermal zone having the highest MOE and the lowest strength in Shear parallel to the grain at 12% MC. The classifications of Upton and Attah (2003) and Farmer (1972) rate Afromosia and the Dermal zone as “High” in terms of their static bending strength; However, in terms of their Compression strength parallel to the grain, the Dermal zone and Afromosia are rated as “Medium” together with Dahoma, Kusia, Teak and Sapele.

Table 5.2**:** Comparison of the mean mechanical properties of *Borassus aethiopum* (Dermal zone, Sub-dermal zone, Central zone and the Bulge area) to other commercially important timber species.

	MC (12%)	MOR (N/mm^2)	MOE (N/mm^2)	Comp llg (N/mm^2)	Shear llg N/mm^2	Hard-ness kN
Dermal Zone	Green	89.8	13358.6	48.4	8.5	7.2
	12%	120.2	17127.3	62.9	11.6	10.5
Sub-dermal Zone	Green	45.2	6573.4	24.7	5.4	4.5
	12%	63.8	9704	34.7	7.7	6.8
Central Zone	Green	7.5	1051.5	4.9	1.2	1.3
	12%	11.8	1698.6	7.7	1.8	0.6
Bulge area	Green	-	-	-	-	-
	12%	2.24	109.68	1.1	0.4	0.3
Afromosia ** (*Pericopsis elata*)	Green	102	12,200	51.6	11.5	7.1
	12%	126.9	13,400	68.5	14.4	6.9
Balsa (*Ochroma pyramidale*) **	Green	-	-	-	-	-
	12%	21.6	3,400	14.9	2.1	-
Ceiba (*Ceiba pentandra*)**	Green	15.2	2,800	7.3	2.4	1
	12%	29.6	3,700	16.4	3.8	1.1
Dahoma*	Green	85.8	9,399	37	13.4	4.99
	12%	109.6	10,897	54.2	20.4	6.22
Kusia *	Green	91.3	10,389	40.9	15.1	5.34
	12%	109.6	11,708	57.8	22.2	6.87
Mahogany (Khaya spp.) **	Green	51	7,900	25.7	6.4	2.8
	12%	73.8	9,700	44.5	10.3	3.7
Obeche (Triplochiton scleroxylon) **	Green	35.2	5,000	17.7	4.6	1.9
	12%	51	5,900	27.1	6.8	1.9
Sapele(Entandrophragma cylindricum) **	Green	70.3	10,300	34.5	8.6	4.5
	12%	105.5	12,500	56.3	15.6	6.7
Teak (Tectona grandis)**	Green	80	9,400	41.1	8.9	4.1
	12%	100.7	10,700	58	13	4.4

*Source: (J. Ofori *et al,* 2009) and **(Forest Products Laboratory, 2010)

Also, from Table 5.2, the strength properties of the sub-dermal zone in terms of MOE, Compression parallel to the grain, and Hardness compare favourably with that of Mahogany (*Khaya spp*). Farmer (1972), rates the mechanical properties of the Central zone and the Bulge area as very low in terms of their MOE, MOR and Compression strength parallel to the grain. This same rating is used for Balsa (*Ochroma pyramidale),* Ceiba *(Ceiba pentandra)*, and Obeche (*Triplochiton scleroxylon*). Despite rating the Central zone, Bulge area, Balsa, Ceiba, and Obeche into the same class, the strength properties of the Central zone and the Bulge area are very low in respect of Balsa, Ceiba, and Obeche.

5.5 Basic Stresses of *Borassus aethiopum*

Analysis of Variance of Appendices (4B, 5B, 6B, 7B, 8B, 9B, 10B, 11B, 12B, and 13B) of the mechanical properties determined (MOE, MOR, Compression and Shear Parallel to the grain, and Hardness) for *Borassus aethiopum* revealed that there were significant difference between the dermal, sub-dermal and the central zones at $P<0.05$. Owing to the differences among the dermal zone, sub-dermal zone, and the central zone for the species studied, it is inexpedient to assign a single characteristic strength value for each of the mechanical properties for the species. From Appendices (4A, 5A, 6A, 7A, 8A, 9A, 10A, 11A, 12A and 13A), representing the strength properties of *Borassus aethiopum* with the overall means will turn to undermine the potentials of the dermal zone as the strength properties of the dermal zone is almost as twice as the strength properties of the overall means of *Borassus aethiopum*. Although a safe design is assured, if the overall means of the strength properties is used to represent the strength properties of the dermal zone in service. Using the overall means of the strength properties determined to represent the characteristic strength of the central zone, will turn to overemphasis the strength properties of the central zone which will lead to higher risk of failure in service. The strength properties of the sub-dermal zone almost reflect the strength properties of the overall means. Hence, a compromise must be reached between running too high a risk of failure occurring and yet making the best use of the potential strength available for all the zones. Basic stress of wood is that stress which can safely be sustained permanently by the wood containing no strength reducing characteristics (Mettem, 1986). Strength of wood is influenced by specimen size, rate of loading and duration of loading, and it is necessary to apply a safety factor to the characteristic strength value in order to accommodate the influence of the factors. However, the characteristic values for modulus of elasticity are not reduced to provide basic values (Desch and Dinwoodie, 1996). Mathematically, the basic stress is expressed as:

$$\text{Basic stress} = \frac{\text{mean} - 2.33S}{2.25(\text{or } 1.4)}$$

Where mean is the mean of strength property S = standard deviation, 2.25 is the safety factor for most strength properties except compression parallel to the grain, which is 1.4. Table 5.3 reveals the basic stress for *Borassus aethiopum* at 12% MC along the bole height (butt, middle and top sections) for the dermal zone, sub-dermal zone and the central zone. From Table 5.3, the Basic Stress was generally highest at the butt, followed by the middle and the top in that order.

Table 5.3 Basic Stress of *Borassus aethiopum* at 12% MC

Section (Zone)	Axial Direction	MOR N/mm²	MOE N/mm²	Comp llg N/mm²	Shear llg N/mm²	Hardness kN
	Buttt	50.25	22254.58	39.43	4.75	4.58
Dermal	Middle	40.53	17108.71	26.56	4.05	3.27
	Top	19.14	12018.61	14.47	2.35	1.94
	Buttt	22.98	14708.38	24.64	3.38	2.57
Sub-dermal	Middle	14.00	9473.46	11.34	1.73	2.11
	Top	4.44	4930.52	4.37	0.61	0.32
	Buttt	2.35	3009.60	3.20	0.46	0.44
Central	Middle	1.51	1458.65	0.75	0.44	0.30
	Top	0.28	627.62	0.17	0.09	0.02

The Butt represents distance from the stump height, the 1.5m mark to 3.2m, the Middle equals to 4.9m to 6.6m and the Top represents 8.3m to 10m.

CHAPTER SIX

6.0 Conclusion and Recommendation

6.1 Conclusion

Borassus aethiopum has three distinct zones: the dermal zone, sub-dermal zone and central zone, when cut transversely. Analysis of variance of the physical and mechanical properties of these zones indicate that there is significant difference at $P<0.05$ between the zones. The effect of stem height on "wood" physical properties and mechanical properties for each of the zones were significant at $P<0.05$. The physical and strength properties decreased significantly at $P<0.05$ from the butt of the trees to the top of the trees for each of the zones, except for the Moisture Content, which increased from the butt of the trees to the top of the trees within each zone. The range of mean basic density and density at 12% MC for the dermal, sub-dermal and the central zones were 480.4 - 752.7[582.5 - 957.7]kg/m^3, 229.2 - 652.5 [266.4 -814.9] kg/m^3, and 127.7 - 436.8 [145.9 - 525.7] kg/m^3 respectively. The mean green moisture content for the dermal, sub-dermal and the central zones range were 30% to 82%, 37% to 134%, and 69% to 290% respectively. The ranges of mean moisture content, basic density, and density at 12% MC for the bulge area were 200-298%, 78.43-163.3kg/m^3 and 89.0-187.7kg/m^3 respectively. The range of mean strength values in the green and [dry] conditions for the dermal zone, sub-dermal zone, and the central zone were as follows: Modulus of Elasticity: 2971.0 – 20563.8 N/mm^2 [5253.0 – 25871.8 N/mm^2], 1407.3 – 16661.2 N/mm^2 [18432 – 20323.1 N/mm^2], and 118.7 – 4669.9 N/mm^2 [206.0 – 5857.2 N/mm^2], Modulus of Rupture: 31.1-156.1 N/mm^2 [48.5 – 217.1 N/mm^2], 10.6 - 98.2 N/mm^2 [19.0 – 149.7 N/mm^2], and 1.3 – 22.9 N/mm^2 [2.1 – 31.9 N/mm^2], Compression parallel to the grain: 16.9-91.9 N/mm^2 [27.6 – 99.8 N/mm^2], 2.3-

61.5 N/mm^2 [3.2 – 71.8 N/mm^2], and 0.03-17.8 N/mm^2 [0.9 – 18.7 N/mm^2]. Shear parallel to the grain: 2.61-13.74 N/mm^2 [5.47 – 19.75 N/m^2], 0.43-10.40 N/m^2 [1.38 – 14.13 N/mm^2], and 0.09 -5.17 N/mm^2 [0.20 – 6.23 N/mm^2], Hardness: 2.74 -12.23 kN [5.07 – 17.02 kN], 0.66-10.12 kN [1.42 – 12.95 kN], and 0.04 -1.66 kN [0.1 – 3.13 kN]. The range of mean strength values for the MOE, MOR, Hardness, Compression and Shear Parallel to the grain for the bulge area were 70.27 – 188.46 N/mm^2, 1.15-3.30 N/mm^2, 0.09-0.44 kN, 0.47-2.34 N/mm^2 and 0.12-0.67 N/mm^2 respectively. The overall order of decreasing strength properties and density for the various sections of *Borassus aethiopum* was as follows: dermal zone > sub-dermal zone > central zone > bulge area. The overall order of decreasing Moisture Content of the various sections of the tree was as follows: bulge area > central zone > sub-dermal zone > dermal zone. According to the Upton and Attah (2003) and Farmer (1972) classifications, Strength is "High" in the dermal zone; low in the sub-dermal zone; and very low in the central zone and the bulge area. The ratio of strength increases associated with drying small clear specimens from the 'green' condition to 12 percent moisture content were generally greatest in the central zone (1.29-3.344); followed by sub-dermal zone (1.18-1.88); and least in the dermal zone (1.16-1.66). Density (X) and mechanical strength (Y) were highly correlated at 98.4% ~ 99.8%, 98.6% ~ 99.7%, and 92.4% ~ 99.8% respectively for the dermal, sub-dermal and the central zones for the 'green wood' and 97.1% ~ 99.9%, 94.9% ~99.7, 94.8% ~ 99.9% and 18.3%~89.3% respectively for the dermal zone, sub-dermal zone, central zone and the bulge area for wood dried to 12% moisture content. Regression equations in the form: Y = m*x*+ c were derived with R^2 values of 0.96 – 0.99, 0.95 – 0.99, 0.95 – 0.99 and 0.01 – 0.60 respectively for the dermal zone, sub-dermal zone, central zone and the bulge area. Density is a good predictor of the mechanical properties of the dermal zone, sub-dermal zone and central zone, with density accounting for approximately 93% of the variations in the mechanical properties studied. The density of the bulge area is however a poor predictor of its measured strength properties, except, for the Shear Parallel to the grain in which density accounted for 59.9% of its variation. The mechanical properties of the dermal zone compare favourably with Afromosia (*Pericopsis elata*), Dahoma (*Pepdiniastrum africanum*), Kusia, Teak (*Tectona grandis*), and Sapele (*Entandrophragma cylindricum*). While that of the sub-dermal zone compares favourably with Mahogany. Hence, an indication that this monocot giant, *Borassus aethiopum,* is a good substitute for these timber species. Portions with high basic density and density at 12% MC showed high strength values. "Wood" from the dermal zone and some portions of the sub-dermal zone are suitable for applications such as bridge construction, furniture, tool handles, rafters, and railway slippers. "Wood" from the central zone and the bulge area should not be tolerated in applications where strength is a prerequisite.

6.2 Recommendation

1. "Wood" from the dermal zone, and the first 6m height "wood" from the butt of the sub-dermal zone should be used in structural applications or heavy constructions, however "wood" from the central zone and the bulge area cannot be used in any structural application owing to their low mean strength values. Nonetheless, "wood" from the central zone and the bulge area could be suitable for packaging fragile articles, used as insulating material in cold stores and refrigerated ships and for modeling other novelties.
2. It is recommended that different drying schedules be employed for the dermal zone, sub-dermal zone, and central zone.

3. It is recommended that owing to the high variability within the species, it is always worth indicating in the general utility of the species, which zone and height is used for which application for efficient utilization and also to avoid risk of failure in service.
4. Very sharp tools and correct cutting angles are required to get clean cut. Circular bench saws with carbide-tipped saws or bandsaws with satellite-tipped blades may also give a clean cut.

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APPENDICES

Appendix 1A: Summary of the Basic Statistics of the Green Moisture Content of the 5 *Borassus aethiopum* tree species

Tree No		Mean	S.Dev.	Minimum	Maximum	Count	CL(95.0%)
Tree 1	Dermal	49.0	8.4	34.4	70.8	60	2.2
	Sub-dermal	85.7	27.0	41.5	134.2	60	7.0
	Central	202.9	41.9	123.1	279.7	60	10.8
Tree 2	Dermal	58.9	14.6	32.0	82.0	60	3.8
	Sub-dermal	76.5	21.3	41.8	129.6	60	5.5
	Central	161.0	52.7	68.6	290.0	60	13.6
Tree 3	Dermal	52.4	9.7	33.0	70.2	60	2.5
	Sub-dermal	64.3	13.1	40.5	100.0	60	3.4
	Central	146.9	36.2	83.3	242.9	60	9.3
Tree 4	Dermal	41.3	5.4	30.5	53.0	60	1.4
	Sub-dermal	65.6	17.6	36.9	92.7	60	4.6
	Central	167.1	53.0	75.2	274.3	60	13.7
Tree 5	Dermal	47.0	10.0	29.9	64.2	60	2.6
	Sub-dermal	66.4	23.8	41.3	123.8	60	6.2
	Central	160.7	47.4	76.7	283.3	60	12.3
ALL 5 Dermal		49.7	11.6	29.9	82.0	300	1.3
ALL 5 Sub-dermal		71.7	22.6	36.9	134.2	300	2.6
ALL 5 Central		167.7	50.0	68.6	290.0	300.0	5.7
ALL TREES		96.4	60.6	29.9	290	900	4.0

S.Dev. = Standard Deviation CL(95%) = 95% Confidence Level

Appendix 1B: Summary of the Analysis of variance (ANOVA) of the Mean Green Moisture Content of the (dermal, sub-dermal and the central zone) of the 5 *Borassus aethiopum* wood species

Tree No	Mean (± δ_{n-1})*	ANOVA between Individual Trees		
		Degrees of freedom	F-ratio	F-Critical
Tree 1	112.5±71.9	$F_{(2,177)}$	454.8	3.05
Tree 2	98.8±55.9	$F_{(2,177)}$	155.7	3.05
Tree 3	87.8±47.9	$F_{(2,177)}$	303.2	3.05
Tree 4	91.3±63.4	$F_{(2,177)}$	254.8	3.05
Tree 5	91.4±58.7	$F_{(2,177)}$	228.4	3.05
ALL 5 TREES	96.4± 60.6	$F_{(4,895)}$	4.9	2.38

Appendix 1C: Analysis of Variance (ANOVA) of the Green Moisture Content of all the 5 *Borassus aethiopum* Tree species.

Tree No	Zone	Degrees of freedom	F-ratio	F-Critical
	Dermal	F(5,54)	36.70	2.39
Tree 1	Sub-dermal	F(5,54)	68.56	2.39
	Central	F(5,54)	15.03	2.39
	Dermal	F(5,54)	84.3	2.39
Tree 2	Sub-dermal	F(5,54)	30.2	2.39
	Central	F(5,54)	14.6	2.39
	Dermal	F(5,54)	45.33	2.39
Tree 3	Sub-dermal	F(5,54)	13.95	2.39
	Central	F(5,54)	36.92	2.39
	Dermal	F(5,54)	20.29	2.39
Tree 4	Sub-dermal	F(5,54)	360.11	2.39
	Central	F(5,54)	20.99	2.39
	Dermal	F(5,54)	64.41	2.39
Tree 5	Sub-dermal	F(5,54)	71.19	2.39
	Central	F(5,54)	35.76	2.39
ALL 5 Dermal		F(4,295)	25.27	2.40
ALL 5 Sub-dermal		F(4,295)	11.45	2.40
ALL 5 Central		F(4,295)	12.15	2.40

Appendix 1D: Tukey's Multiple Comparison Test for the green MC of Tree 1

Height(m)	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	-2.1^{ns}					
4.9	-6.7^{s}	-5.8^{s}				
6.6	-9.6^{s}	-7.5^{s}	-1.7^{ns}			
8.3	-13.6^{s}	-10.4^{s}	-5.8^{s}	-4.1^{ns}		
10	-22.1^{s}	-20.0^{s}	-14.2^{s}	-12.5^{s}	-8.4^{s}	
Sub- dermal						
1.5						
3.2	-13.4^{ns}					
4.9	-33.8^{s}	-20.4^{s}				
6.6	-54.9^{s}	-41.6^{s}	-21.1^{s}			
8.3	-61.6^{s}	-48.2^{s}	-27.8^{s}	-6.6^{ns}		
10	-66.6^{s}	-53.2^{s}	-32.8^{s}	-11.6^{ns}	-0.5^{ns}	
Central						
1.5						
3.2	-35.6^{ns}					
4.9	-36.9^{ns}	-1.3^{ns}				
6.6	-75.1^{s}	-39.5^{s}	-38.1^{s}			
8.3	-82.6^{s}	-47^{s}	-45.6^{s}	-7.5^{ns}		
10	-89.0^{s}	-53.4^{s}	-52.1^{s}	-13.9^{ns}	-6.4^{ns}	

APPENDIX 1E: Tukey's Multiple Comparison Test for the green MC of TREE 2

Height(m)		1.5m	3.2m	4.9m	6.6m	8.3m	10m
Dermal							
	1.5						
	3.2	-9.3^{s}					
	4.9	-26.3^{s}	-17.0^{s}				
	6.6	-29.0^{s}	-19.7^{s}	-2.7^{ns}			
	8.3	-34.6^{s}	-25.3^{s}	-8.3^{s}	-5.6^{ns}		
	10	-37.7^{s}	-28.4^{s}	-11.4^{s}	-8.7^{s}	-3.1^{ns}	
Sub-dermal		1.5	3.2	4.9	6.6	8.3	10
	1.5						
	3.2	-15.7^{s}					
	4.9	-23.8^{s}	-8.1^{ns}				
	6.6	-27.8^{s}	-12.1^{ns}	-4^{ns}			
	8.3	-48.6^{s}	-32.9^{s}	-24.8^{s}	-20.8^{s}		
	10	-52.3^{s}	-36.6^{s}	-28.5^{s}	-24.5^{s}	-3.8^{ns}	
Central		1.5	3.2	4.9	6.6	8.3	10
	1.5						
	3.2	-51^{s}					
	4.9	-66.7^{s}	-15.7^{ns}				
	6.6	-78.1^{s}	-27.1^{ns}	-11.3^{ns}			
	8.3	-106.3^{s}	-55.2^{s}	-39.5^{ns}	-28.2^{ns}		
	10	-122.5^{s}	-71.5^{s}	-54.9^{s}	-44.4^{ns}	-16.3^{ns}	

APPENDIX 1F: Tukey's Multiple Comparison Test for the green MC of Tree 3

Height(m)	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	-10.7^{s}					
4.9	-14.8^{s}	-4.0^{ns}				
6.6	-16.5^{s}	-4.9^{ns}	-1.8^{ns}			
8.3	-21.3^{s}	-10.5^{s}	-6.5^{s}	-4.7^{ns}		
10	-27.7^{s}	-16.9^{s}	-12.9^{s}	-11.1^{s}	-6.4^{s}	
Sub-dermal						
1.5						
3.2	-3.4^{ns}					
4.9	-16.7^{s}	-13.4^{s}				
6.6	$-21.^{s}$	-17.9^{s}	-4.6^{ns}			
8.3	-22.8^{s}	-19.4^{s}	-6.1^{ns}	-1.4^{ns}		
10	-25.8^{s}	-22^{s}	-8.6^{ns}	-4^{ns}	-2.5^{ns}	
Central						
1.5						
3.2	-22.5^{ns}					
4.9	-29.4^{s}	-6.9^{ns}				
6.6	-51.8^{s}	-29.3^{s}	-22.4^{ns}			
8.3	-68.6^{s}	-46.2^{s}	-39.3^{s}	-16.9^{ns}		
10	-95.9^{s}	-73.4^{s}	-66.5^{s}	-44.1^{s}	-27.3^{s}	

APPENDIX 1G: Tukey's Multiple Comparison Test for the green MC of Tree 4

Height(m)	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	1.5^{ns}					
4.9	8.2^{s}	6.4^{s}				
6.6	9.8^{s}	7.9^{s}	1.5^{ns}			
8.3	10.4^{s}	8.6^{s}	2.2^{ns}	0.7^{ns}		
10	10.9^{s}	9.0^{s}	2.7^{ns}	1.1^{ns}	0.4^{ns}	
Sub-dermal						
1.5						
3.2	-12.2^{s}					
4.9	-17.1^{s}	-4.9^{s}				
6.6	-39.0^{s}	-26.7^{s}	-21.5^{s}			
8.3	-39.6^{s}	-27.4^{s}	-22.5^{s}	-0.6^{ns}		
10	-47.9^{s}	-35.7^{s}	-30.8^{s}	-8.9^{s}	-8.3^{s}	
Central						
1.5						
3.2	-42.1^{ns}					
4.9	-39.7^{s}	2.3^{ns}				
6.6	-73.2^{s}	-31.1^{ns}	-33.4^{ns}			
8.3	-97.1^{s}	-55^{s}	-57.4^{s}	-23.9^{ns}		
10	-131.7^{s}	-89.7^{s}	-92^{s}	-58.54^{s}	-34.6^{ns}	

Appendix 1H: Tukey's Multiple Comparison Test for the green MC of Tree 5

Height(m)	1.5m	3.2m	4.9m	6.6m	8.3m	10m
Dermal						
1.5						
3.2	-3.6^{ns}					
4.9	-17.1^{s}	-13.5^{s}				
6.6	-20^{s}	-16.4^{s}	-2.9^{ns}			
8.3	-21.1^{s}	-17.5^{s}	-4.1^{ns}	-1.1^{ns}		
10	-24.1^{s}	-20.5^{s}	-7.1^{s}	-4.1^{ns}	-3.0^{ns}	
Sub-dermal						
1.5						
3.2	-7.0^{ns}					
4.9	-10.9^{ns}	-4.0^{ns}				
6.6	-10.6^{ns}	-4.9^{ns}	-0.9^{ns}			
8.3	-28.8^{s}	-21.6^{s}	-16.7^{s}	-17.0^{s}		
10	-66.0^{s}	-59.0^{s}	-55.0^{s}	-54.1^{s}	-37.2^{s}	
Central						
1.5						
3.2	-25.3^{ns}					
4.9	-50.3^{s}	-25.7^{ns}				
6.6	-80.5^{s}	-55.2^{s}	-29.6^{ns}			
8.3	-104.5^{s}	-76.22^{s}	-53.5^{s}	-24.0^{ns}		
10	-114.3^{s}	-89.0^{s}	-63.4s	-33.8^{s}	-8.3^{ns}	

Appendix 1I: Tukey's Multiple Comparison Test for the green MC of All 5 Trees

	Tree 1 Dermal	Tree 2 Dermal	Tree 3 Dermal	Tree 4 Dermal	Tree 5 Dermal
Tree 1 Dermal					
Tree 2 Dermal	-9.9^{s}				
Tree 3 Dermal	-3.4^{ns}	6.6^{s}			
Tree 4 Dermal	7.7^{s}	17.6^{s}	11.1^{s}		
Tree 5 Dermal	1.9^{ns}	11.6^{s}	5.3^{s}	-5.7^{s}	
	Tree 1 Sub-dermal	Tree 2Sub-dermal	Tree 3 Sub-dermal	Tree 4 Sub-dermal	Tree 5 Sub-dermal
Tree 1 Sub-dermal					
Tree 2 Sub-dermal	9.2^{ns}				
Tree 3 Sub-dermal	21.4^{s}	12.2^{s}			
Tree 4 Sub-dermal	20.2^{s}	10.9^{s}	-1.3^{ns}		
Tree 5 Sub-dermal	19.4^{s}	10.1^{s}	-2.1^{ns}	-0.8^{ns}	
	Tree 1 Central	Tree 2 Central	Tree 3Central	Tree 4 Central	Tree 5 Central
Tree 1 Central					
Tree 2 Central	9.2^{ns}				
Tree 3 Central	21.4^{s}	12.2^{s}			
Tree 4 Central	20.2^{s}	10.9^{s}	-1.3^{ns}		
Tree 5 Central	19.4^{s}	10.1^{ns}	-2.1^{ns}	$-0.8n^{s}$	
	Tree 1	Tree 2	Tree 3	Tree 4	Tree 5
Tree 1					
Tree 2	13.7^{ns}				
Tree 3	24.7^{s}	11.0^{ns}			
Tree 4	21.2^{s}	7.5^{s}	-3.5^{ns}		
Tree 5	21.2^{s}	7.4^{s}	-3.5^{ns}	-0.1^{ns}	

Appendix 2A: Summary of the basic statistics of the Basic Density of the 5 *Borassus aethiopum*

Tree No	Zone	Mean	S.Dev.	Minimum	Maximum	Count	CL(95.0%)
Tree 1	Dermal	636.6	61.9	502.7	726.3	60.0	16.0
	Sub-dermal	425.1	98.4	271.4	623.8	60.0	25.4
	Central	226.3	46.5	152.3	327.6	60.0	12.0
Tree 2	Dermal	604.9	66.3	480.4	732.8	60.0	17.1
	Sub-dermal	488.3	90.5	314.0	635.7	60.0	23.4
	Central	254.8	77.9	147.1	436.8	60.0	20.1
Tree 3	Dermal	629.3	49.1	527.3	728.0	60.0	12.7
	Sub-dermal	504.7	53.1	366.7	583.3	60.0	13.7
	Central	263.9	76.1	127.7	390.8	60.0	19.7
Tree 4	Dermal	668.5	44.1	602.6	752.7	60.0	11.4
	Sub-dermal	501.2	73.0	343.6	605.9	60.0	18.9
	Central	266.3	50.1	194.9	399.6	60.0	12.9
Tree 5	Dermal	640.6	58.4	524.8	732.8	60.0	15.1
	Sub-dermal	462.4	104.3	229.2	652.2	60.0	26.9
	Central	244.6	67.3	134.3	416.7	60.0	17.4
ALL 5 Dermal		636.0	59.8	480.4	752.7	300.0	6.8
ALL 5 Sub-dermal		476.4	90.3	229.2	652.2	300.0	10.3
ALL 5 Central		251.2	66.1	127.7	436.8	300.0	7.5
ALL 5 TREES		454.5	174.1	127.7	752.7	900.0	11.4

S.Dev. = Standard Deviation CL(95%) = 95% Confidence Level

Appendix 2B: Summary of the ANOVA of the Mean Basic Density of the (dermal, sub-dermal, and the central zone) of the Individual Trees of the 5 *Borassus aethiopum* wood

Species No	Mean (± δ_{n-1})*	ANOVA between Individual Trees		
		Degrees of freedom	F	F-Critical
Tree 1	429.3±182.7	$F_{(2,177)}$	483.6	3.05
Tree 2	449.3±165.7	$F_{(2,177)}$	306.6	3.05
Tree 3	467.0±163.6	$F_{(2,177)}$	563.2	3.05
Tree 4	478.7±175.0	$F_{(2,177)}$	751.2	3.05
Tree 5	449.2±180.5	$F_{(2,177)}$	376.2	3.05
ALL 5 TREES	454.7 ±174.1	$F_{(4,895)}$	51.5	2.38

Appendix 2C: Analysis of Variance (ANOVA) of the Basic Density of all the 5 *Borassus aethiopum* Tree species.

Tree No	Zone	Degrees of freedom	F	F-Critical
Tree 1	Dermal	F(5,54)	112.02	2.39
	Sub-dermal	F(5,54)	184.42	2.39
	Central	F(5,54)	38.62	2.39
Tree 2	Dermal	F(5,54)	133.50	2.39
	Sub-dermal	F(5,54)	57.10	2.39
	Central	F(5,54)	94.80	2.39
Tree 3	Dermal	F(5,54)	90.82	2.39
	Sub-dermal	F(5,54)	17.46	2.39
	Central	F(5,54)	67.93	2.39
Tree 4	Dermal	F(5,54)	114.94	2.39
	Sub-dermal	F(5,54)	187.13	2.39
	Central	F(5,54)	51.02	2.39
Tree 5	Dermal	F(5,54)	182.20	2.39
	Sub-dermal	F(5,54)	71.20	2.39
	Central	F(5,54)	35.76	2.39
ALL 5 Dermal		F(4,295)	9.82	2.40
ALL 5 Sub-dermal		F(4,295)	8.90	2.40
ALL 5 Central		F(4,295)	3.81	2.40

Appendix 2D: Tukey's Multiple Comparison Test for the Basic Density of Tree 1

Height(m)	1.5m	3.2m	4.9m	6.6m	8.3m	10m
Dermal						
1.5						
3.2	14.2^{ns}					
4.9	48.3^{s}	34.2^{s}				
6.6	58.4^{s}	44.3^{s}	10.1^{ns}			
8.3	96.0^{s}	82.5^{s}	48.3^{s}	38.2^{s}		
10	176.6^{s}	162.5^{s}	128.3^{s}	118.2^{s}	80.0^{s}	
Sub-dermal						
1.5						
3.2	13.7^{s}					
4.9	191.6^{s}	57.0^{s}				
6.6	191.5^{s}	126.6^{s}	69.6^{ns}			
8.3	261.2^{s}	157.7^{s}	100.7^{s}	69.4^{s}		
10	292.4^{s}	0.2^{s}	100.7^{s}	100.6^{s}	31.1^{s}	
Central						
1.5						
3.2	60.1^{s}					
4.9	76.9^{s}	16.8^{ns}				
6.6	81.9^{s}	21.6^{ns}	5.1^{ns}			
8.3	118.7^{s}	58.7^{s}	41.6^{s}	36.8^{s}		
10	121.8^{s}	61.7^{s}	44.9^{s}	38.4^{s}	3.1^{ns}	

Appendix 2E: Tukey's Multiple Comparison Test for the Basic Density of Tree 2

Height(m)		1.5m	3.2m	4.9m	6.6m	8.3m	10m
Dermal							
	1.5						
	3.2	50.0^{s}					
	4.9	121.6^{s}	71.6^{s}				
	6.6	138.8^{s}	88.8^{s}	17.2^{ns}			
	8.3	158.9^{s}	108.9^{s}	37.3^{s}	20.1^{ns}		
	10	180.2^{s}	130.2^{s}	58.6^{s}	41.4^{s}	21.3^{ns}	
Sub-dermal							
	1.5						
	3.2	72.3^{s}					
	4.9	119.4^{s}	47.1^{ns}				
	6.6	135.4^{s}	63.1^{s}	15^{ns}			
	8.3	210.8^{s}	139.6^{s}	92.4^{s}	76.5^{s}		
	10	246.5^{s}	174.2^{s}	127.1^{s}	111.1^{s}	34.6^{ns}	
Central							
	1.5						
	3.2	66.9^{s}					
	4.9	128.1^{s}	61.2^{ns}				
	6.6	156.6^{s}	89.7^{s}	28.5^{ns}			
	8.3	196.3^{s}	129.4^{s}	68.2^{s}	39.8^{s}		
	10	209.1^{s}	142.2^{s}	81^{s}	52.5^{s}	12.8^{ns}	

Appendix 2F: Tukey's Multiple Comparison Test for the Basic Density of Tree 3

Height(m)	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	56.8^{s}					
4.9	80.8^{s}	23.9^{s}				
6.6	91.5^{s}	34.7^{s}	10.8^{ns}			
8.3	112.8^{s}	56^{s}	32^{s}	21.3^{ns}		
10	147.7^{s}	90.9^{s}	66.9^{s}	56.2^{s}	34.9^{s}	
Sub-dermal						
1.5						
3.2	23.3^{ns}					
4.9	48.3^{s}	24.9^{ns}				
6.6	54.6^{s}	31.3^{ns}	6.4^{ns}			
8.3	102.0^{s}	78.6^{s}	53.8^{s}	47.4^{s}		
10	118.7^{s}	95.3^{s}	70.4^{s}	64.1^{s}	16.7^{ns}	
Central						
1.5						
3.2	38.4^{ns}					
4.9	60.0^{s}	21.6^{ns}				
6.6	76.4^{s}	$38.0n^{s}$	16.3^{ns}			
8.3	167.2^{s}	128.8^{s}	107.2^{s}	90.8^{s}		
10	198.1^{s}	159.7^{s}	138.1^{s}	121.7^{s}	30.9^{ns}	

Appendix 2G: Tukey's Multiple Comparison Test for the Basic Density of Tree 4

Height(m)	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	1.5^{ns}					
4.9	8.2^{s}	6.4^{s}				
6.6	9.8^{s}	7.9^{s}	1.5^{ns}			
8.3	10.4^{s}	8.6^{s}	2.2^{ns}	0.7^{ns}		
10	10.9^{s}	9.0^{s}	2.7^{ns}	1.1^{ns}	0.4^{ns}	
Sub-dermal						
1.5						
3.2	12.2^{s}					
4.9	17.1^{s}	4.9^{s}				
6.6	39.0^{s}	26.7^{s}	21.5^{s}			
8.3	39.6^{s}	27.4^{s}	22.5^{s}	0.6^{ns}		
10	47.9^{s}	35.7^{s}	30.8^{s}	8.9^{s}	8.3^{s}	
Central						
1.5						
3.2	-42.1^{ns}					
4.9	-39.7^{ns}	2.3^{ns}				
6.6	-73.2^{s}	-31.1^{ns}	-33.4^{ns}			
8.3	-97.1^{s}	-55.0^{s}	-57.4^{s}	-23.9^{ns}		
10	-131.7^{s}	-89.7^{s}	-92.0^{s}	-58.5^{s}	-34.6^{ns}	

Appendix 2H: Tukey's Multiple Comparison Test for the Basic Density of Tree 5

Height(m)	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	3.6^{ns}					
4.9	17.1^{s}	13.5^{s}				
6.6	20^{s}	16.4^{s}	2.9^{ns}			
8.3	21.1^{s}	17.5^{s}	4.1^{ns}	1.1^{ns}		
10	24.1^{s}	20.5^{s}	7.1^{s}	4.1^{ns}	3.0^{ns}	
Sub-dermal						
1.5						
3.2	7.0^{ns}					
4.9	10.9^{ns}	4.0^{ns}				
6.6	10.6^{ns}	4.9^{ns}	0.9^{ns}			
8.3	28.8^{s}	21.6^{s}	16.7^{s}	17.0^{s}		
10	66.0^{s}	59.0^{s}	55.0^{s}	54.1^{s}	37.2^{s}	
Central						
1.5						
3.2	25.3^{ns}					
4.9	50.3^{s}	25.7^{ns}				
6.6	80.5^{s}	55.2^{s}	29.6^{ns}			
8.3	104.5^{s}	76.22^{s}	53.5^{s}	24.0^{ns}		
10	114.3^{s}	89.0^{s}	63.4^{s}	33.8^{s}	8.3^{ns}	

Appendix 2I: Tukey's Multiple Comparison Test for the Basic Density of All 5 Trees

	Tree 1 Dermal	Tree 2 Dermal	Tree 3 Dermal	Tree 4 Dermal	Tree 5 Dermal
Tree 1 Dermal					
Tree 2 Dermal	31.7^{s}				
Tree 3 Dermal	7.2^{ns}	-24.5^{ns}			
Tree 4 Dermal	-32^{s}	-63.7^{s}	-39.2^{s}		
Tree 5 Dermal	-4.1^{ns}	-35.78^{s}	-11.3^{ns}	27.9^{ns}	
	Tree 1 Sub-dermal	Tree 2Sub-dermal	Tree 3 Sub-dermal	Tree 4 Sub-dermal	Tree 5 Sub-dermal
Tree 1 Sub-dermal					
Tree 2 Sub-dermal	-63.1^{s}				
Tree 3 Sub-dermal	-79.6^{s}	-16.4^{ns}			
Tree 4 Sub-dermal	-76.1^{s}	-12.9^{ns}	3.5^{ns}		
Tree 5 Sub-dermal	-37.3^{ns}	25.9^{ns}	42.3^{ns}	38.8^{ns}	
	Tree 1 Central	Tree 2 Central	Tree 3Central	Tree 4 Central	Tree 5 Central
Tree 1 Central					
Tree 2 Central	-28.5^{ns}				
Tree 3 Central	-37.7^{s}	-9.1^{ns}			
Tree 4 Central	-40.1^{s}	-11.5^{ns}	-2.4^{ns}		
Tree 5 Central	-18.3^{ns}	10.3^{ns}	19.3^{ns}	21.8^{ns}	
	Tree 1	Tree 2	Tree 3	Tree 4	Tree 5
Tree 1					
Tree 2	-20^{ns}				
Tree 3	-36.7^{ns}	$-16.7n^{s}$			
Tree 4	-49.4^{ns}	-29.4^{ns}	-12.7^{ns}		
Tree 5	-19.9^{ns}	0.1^{ns}	16.8^{ns}	29.5^{ns}	

Appendix 3A: Summary of the basic statistics of the Density of the 5 *Borassus aethiopum* at 12% MC

Tree No	Zone	Mean	S.Dev.	Minimum	Maximum	Count	CL(95.0%)
	Dermal	794.1	85.1	611.9	919.7	60	22.0
Tree 1	Sub-dermal	512.8	128.2	317.6	775.6	60	33.1
	Central	263.3	56.3	174.8	387.1	60	14.5
	Dermal	750.6	91.4	582.5	929.0	60	23.6
Tree 2	Sub-dermal	594.8	119.2	370.1	792.0	60	30.8
	Central	298.6	95.6	168.6	525.7	60	24.7
	Dermal	783.8	68.1	644.6	922.1	60	17.6
Tree 3	Sub-dermal	615.3	70.0	436.1	720.1	60	18.1
	Central	309.7	92.6	145.9	466.7	60	23.9
	Dermal	838.2	62.1	746.4	957.7	60	16.0
Tree 4	Sub-dermal	611.2	96.5	407.1	751.0	60	24.9
	Central	312.0	61.6	225.3	477.9	60	15.9
	Dermal	799.7	81.2	641.2	929.0	60	21.0
Tree 5	Sub-dermal	561.4	136.3	266.4	814.9	60	35.2
	Central	285.9	82.0	153.7	499.8	60	21.2
ALL 5 Dermal		793.3	82.8	582.5	957.7	300	9.4
ALL 5 Sub-dermal		579.1	118.2	266.4	814.9	300	13.4
ALL 5 Central		293.9	80.7	145.9	525.7	300	9.2
ALL 5 TREES		555.4	225.8	145.9	957.7	900	14.8

S.Dev. = Standard Deviation CL(95%) = 95% Confidence Level

Appendix 3B: Summary of the ANOVA of the Mean Density of the (dermal, sub-dermal, and the central zone) of the Individual Trees of the 5 *Borassus aethiopum* wood at 12% MC

		ANOVA between Individual Trees		
Tree No	Mean ($\pm \delta_{n-1}$) *	Degrees of freedom	F-ratio	F-Critical
Tree 1	523.4±236.9	$F_{(2,177)}$	473.0	3.05
Tree 2	548.0±213.9	$F_{(2,177)}$	299.5	3.05
Tree 3	548.0±211.4	$F_{(2,177)}$	573.7	3.05
Tree 4	587.1±228.7	$F_{(2,177)}$	739.4	3.05
Tree 5	549.0±234.2	$F_{(2,177)}$	373.1	3.05
All 5 Trees	555.4±225.8	$F_{(4,895)}$	2.0	2.38

Appendix 3C: Analysis of Variance (ANOVA) of the Density of all the 5 *Borassus aethiopum* Tree species at 12% M.C

Tree No	Zone	Degrees of freedom	F	F-Critical
Tree 1	Dermal	F(5,54)	110.26	2.39
	Sub-dermal	F(5,54)	192.80	2.39
	Central	F(5,54)	38.94	2.39
Tree 2	Dermal	F(5,54)	137.8	2.39
	Sub-dermal	F(5,54)	57.9	2.39
	Central	F(5,54)	94.1	2.39
Tree 3	Dermal	F(5,54)	91.97	2.39
	Sub-dermal	F(5,54)	17.58	2.39
	Central	F(5,54)	66.63	2.39
Tree 4	Dermal	F(5,54)	117.23	2.39
	Sub-dermal	F(5,54)	191.59	2.39
	Central	F(5,54)	50.84	2.39
Tree 5	Dermal	F(5,54)	185.06	2.39
	Sub-dermal	F(5,54)	40.19	2.39
	Central	F(5,54)	21.54	2.39
ALL 5 Dermal		F(4,295)	9.70	2.40
ALL 5 Sub-dermal		F(4,295)	8.63	2.40
ALL 5 Central		F(4,295)	3.82	2.40

Appendix 3D: Tukey's Multiple Comparison Test for the Density of Tree 1 at 12% MC

Height (m)		1.5	3.2	4.9	6.6	8.3	10
Dermal							
	1.5						
	3.2	20.0^{ns}					
	4.9	68.0^{s}	48^{s}				
	6.6	82^{s}	62.0^{s}	14.1^{ns}			
	8.3	134.7^{s}	114.8^{s}	66.8^{s}	52.7^{s}		
	10	242.9^{s}	223.0^{s}	175.0^{s}	160.9^{s}	108.2^{s}	
Sub-dermal							
	1.5						
	3.2	180.3^{s}					
	4.9	254.0^{s}	73.7^{s}				
	6.6	254.3^{s}	74.0^{s}	0.2^{ns}			
	8.3	342.2^{s}	162.0^{s}	88.2^{s}	88.0^{s}		
	10	381.0^{s}	200.7^{s}	126.9^{s}	126.7^{s}	38.7^{ns}	
Central							
	1.5						
	3.2	73.4^{s}					
	4.9	93.8^{s}	20.4^{ns}				
	6.6	99.9^{s}	26.5^{ns}	6.1^{s}			
	8.3	143.9^{s}	70.5^{s}	50.1^{s}	44.0^{s}		
	10	147.6^{s}	74.2^{s}	53.8^{s}	47.7^{s}	3.7^{ns}	

Appendix 3E: Tukey's Multiple Comparison Test for the Density of Tree 2 at 12% MC

Height (m)	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	70.6^{s}					
4.9	169.6^{s}	99.0^{s}				
6.6	193.0^{s}	122.5^{s}	23.5^{ns}			
8.3	220.0^{s}	149.5^{s}	50.5^{s}	27.0^{ns}		
10	248.6^{s}	178.1^{s}	79.1^{s}	55.6^{s}	28.6^{ns}	
Sub-dermal						
1.5						
3.2	98.4^{s}					
4.9	161^{s}	62.6^{ns}				
6.6	181.4^{s}	83^{s}	20.4^{ns}			
8.3	281.4^{s}	183^{s}	120.3^{s}	100.0^{s}		
10	325.2^{s}	226.8^{s}	164.1^{s}	143.8^{s}	43.8^{ns}	
Central						
1.5						
3.2	83.9^{s}					
4.9	159.2^{s}	75.3^{s}				
6.6	193.7^{s}	109.8^{s}	34.5^{s}			
8.3	241.3^{s}	157.4^{s}	82.1^{s}	47.6^{s}		
10	256.4^{s}	172.5^{s}	97.3^{s}	62.8^{s}	15.2^{ns}	

Appendix 3F: Tukey's Multiple Comparison Test for the Density of Tree 3 at 12% MC

Height (m)	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	80.0^{s}					
4.9	113.3^{s}	33.3^{s}				
6.6	128.1^{s}	48.1^{s}	14.9^{ns}			
8.3	157.4^{s}	77.4^{s}	44.1^{s}	29.3^{ns}		
10	204.8^{s}	124.8^{s}	91.6^{s}	76.7^{s}	47.4^{s}	
Sub-dermal						
1.5						
3.2	31.4^{s}					
4.9	64.6^{s}	33.2^{ns}				
6.6	72.8^{s}	41.4^{ns}	8.2^{ns}			
8.3	135.1^{s}	103.6^{s}	70.5^{s}	62.3^{s}		
10	156.8^{s}	125.4^{s}	92.2^{s}	84.0^{s}	21.8^{ns}	
Central						
1.5						
3.2	48.1^{s}					
4.9	74.7^{s}	26.6^{ns}				
6.6	94.7^{s}	46.6^{ns}	20.0^{ns}			
8.3	204.6^{s}	156.5^{s}	129.9^{s}	109.9^{s}		
10	241.2^{s}	193.1^{s}	166.5^{s}	146.5^{s}	36.6^{ns}	

Appendix 3G: Tukey's Multiple Comparison Test for the Density of Tree 4 at 12% MC

Height (m)	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	31.7^{s}					
4.9	98.9^{s}	67.2^{s}				
6.6	137.3^{s}	105.6^{s}	38.5^{s}			
8.3	140.9^{s}	109.2^{s}	42.0^{s}	3.5^{ns}		
10	157.3^{s}	125.6^{s}	58.5^{s}	20.0^{ns}	16.4^{ns}	
Sub-dermal						
1.5						
3.2	43.2^{s}					
4.9	101.8^{s}	58.6^{s}				
6.6	173.4^{s}	130.1^{s}	71.6^{s}			
8.3	221.8^{s}	178.6^{s}	120.0^{s}	48.5^{s}		
10	258.6^{s}	215.4^{s}	156.9^{s}	85.3^{s}	36.8^{s}	
Central						
1.5						
3.2	60.1^{s}					
4.9	112.3^{s}	52.2^{s}				
6.6	123.8^{s}	63.7^{s}	11.5^{ns}			
8.3	148.7^{s}	88.6^{s}	36.4^{s}	24.9^{ns}		
10	161.4^{s}	101.3^{s}	49.1^{s}	37.6^{s}	12.7^{ns}	

Appendix 3H: Tukey's Multiple Comparison Test for the Density of Tree 5 at 12% MC

Height (m)	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	33.6^{s}					
4.9	123.2^{s}	89.7^{s}				
6.6	151.1^{s}	117.5^{s}	27.9^{s}			
8.3	171.0^{s}	137.4^{s}	47.8^{s}	19.9^{ns}		
10	226.5^{s}	193^{s}	103.3^{s}	75.5^{s}	55.6^{s}	
Sub-dermal						
1.5						
3.2	44.9^{s}					
4.9	149.8^{s}	104.9^{s}				
6.6	219.5^{s}	174.6^{s}	69.7^{ns}			
8.3	249.4^{s}	204.6^{s}	99.7^{s}	30.0^{s}		
10	350.8^{s}	305.9^{s}	201^{s}	131.3^{s}	101.3^{s}	
Central						
1.5						
3.2	46.8^{ns}					
4.9	63.2^{ns}	16.4^{ns}				
6.6	123.8^{s}	77.0^{s}	60.6^{ns}			
8.3	149.4^{s}	102.6^{s}	86.2^{s}	25.6^{ns}		
10	196.3^{s}	149.5^{s}	133.2^{s}	72.6^{s}	47.0^{ns}	

Appendix 3I: Tukey's Multiple Comparison Test for the Density of All 5 Trees at 12% MC

	Tree 1 Dermal	Tree 2 Dermal	Tree 3 Dermal	Tree 4 Dermal	Tree 5 Dermal
Tree 1 Dermal					
Tree 2 Dermal	43.6^{s}				
Tree 3 Dermal	10.4^{ns}	-33.2^{ns}			
Tree 4 Dermal	-44.1^{s}	-87.7^{s}	-54.5^{s}		
Tree 5 Dermal	-5.5^{ns}	-49.11^{s}	-15.9^{ns}	38.6^{ns}	

	Tree 1 Sub-dermal	Tree 2Sub-dermal	Tree 3 Sub-dermal	Tree 4 Sub-dermal	Tree 5 Sub-dermal
Tree 1 Sub-dermal					
Tree 2 Sub-dermal	-82^{s}				
Tree 3 Sub-dermal	-102.5^{s}	-20.5^{ns}			
Tree 4 Sub-dermal	-98.4^{s}	-16.4^{ns}	4.1^{ns}		
Tree 5 Sub-dermal	-48.7^{ns}	33.4^{ns}	53.8^{s}	49.8^{ns}	

	Tree 1 Central	Tree 2 Central	Tree 3Central	Tree 4 Central	Tree 5 Central
Tree 1 Central					
Tree 2 Central	-35.3^{ns}				
Tree 3 Central	-46.4^{s}	-11.1^{ns}			
Tree 4 Central	-48.7^{s}	-13.4^{ns}	-2.3^{n}		
Tree 5 Central	-22.6^{ns}	12.8^{ns}	23.8^{ns}	26.1^{ns}	

	Tree 1	Tree 2	Tree 3	Tree 4	Tree 5
Tree 1					
Tree 2	-24.6^{ns}				
Tree 3	-46.2^{ns}	-21.6^{ns}			
Tree 4	-63.7^{ns}	-39.2^{ns}	-17.6^{ns}		
Tree 5	-25.6^{ns}	-1.0^{ns}	20.6^{ns}	38.2^{ns}	

Appendix 4A: Summary of the basic statistics of the Green MOE of the 5 *Borassus aethiopum* species

Tree No	Zones	Mean	S.Dev.	Minimum	Maximum	Count	CL(95.0%)
Tree 1	Dermal	13708.4	4461.4	5282.2	19949.3	30.0	1665.9
	Sub-dermal	5000.9	2972.7	1545.5	11866.4	30.0	1110.0
	Central	859.2	574.1	292.3	2277.7	30.0	214.4
Tree 2	Dermal	11426.8	5505.6	2971.0	19515.1	30.0	2055.8
	Sub-dermal	6521.4	3610.3	1605.4	14064.0	30.0	1348.1
	Central	1215.5	910.2	390.8	3847.8	30.0	339.9
Tree 3	Dermal	11923.2	4142.4	5085.0	19998.7	30.0	1546.8
	Sub-dermal	6621.9	3872.9	1813.6	14504.4	30.0	1446.2
	Central	897.3	832.8	118.7	3196.5	30.0	311.0
Tree 4	Dermal	15009.6	3302.8	8888.4	20440.1	30.0	1233.3
	Sub-dermal	9451.0	4483.5	3581.0	16661.1	30.0	1674.2
	Central	1134.7	573.4	318.2	2646.8	30.0	214.1
Tree 5	Dermal	14725.0	3938.3	7627.4	20563.8	30.0	1470.6
	Sub-dermal	5272.1	2625.5	1407.3	9085.7	30.0	980.4
	Central	1150.9	1232.2	223.1	4669.9	30.0	460.1
ALL 5 Dermal		13358.6	4513.4	2971.0	20563.8	300.0	728.2
ALL 5 Sub-dermal		6573.4	3864.9	1407.3	16661.1	150.0	623.6
ALL 5 Central		1051.5	860.8	118.7	4669.9	150.0	138.9
ALL 5 TREES		6994.5	6111.6	118.7	20563.8	450.0	566.2

S.Dev. = Standard Deviation   CL(95%) = 95% Confidence Level

Appendix 4B: Summary of the ANOVA of the Green MOE of the Individual Trees (dermal, sub-dermal, and the central zone) of the 5 *Borassus aethiopum* wood.

Species No	Mean (± δ n-1)*	ANOVA between Individual Trees		
		Degrees of freedom	F-ratio	F-Critical
Tree 1	6522.82±6202.39	F(2,87)	133.16	3.10
Tree 2	6387.89±5654.81	F(2,87)	53.14	3.10
Tree 3	6480.82±5586.08	F(2,87)	83.30	3.10
Tree 4	8531.8±6563.9	F(2,87)	140.03	3.10
Tree 5	7049.33±6359.71	F(2,87)	182.21	3.10
ALL 5 TREES	6994.53±6111.62	F(4,445)	1.96	2.39

(± δ n-1)*= Standard Deviation

Appendix 4C: Analysis of Variance (ANOVA) of the Green MOE for the 5 *Borassus aethiopum* Tree species

Tree No	Zone	Degrees of freedom	F	F-Critical
Tree 1	Dermal	F(5,24)	29.32	2.62
	Sub-dermal	F(5,24)	53.31	2.62
	Central	F(5,24)	22.63	2.62
Tree 2	Dermal	F(5,24)	32.4	2.62
	Sub-dermal	F(5,24)	25.5	2.62
	Central	F(5,24)	53.0	2.62
Tree 3	Dermal	F(5,24)	17.81	2.62
	Sub-dermal	F(5,24)	85.80	2.62
	Central	F(5,24)	56.97	2.62
Tree 4	Dermal	F(5,24)	9.19	2.62
	Sub-dermal	F(5,24)	31.74	2.62
	Central	F(5,24)	36.42	2.62
Tree 5	Dermal	F(5,24)	19.70	2.62
	Sub-dermal	F(5,24)	24.16	2.62
	Central	F(5,24)	48.42	2.62
ALL 5 Dermal		F(4,145)	4.20	2.43
ALL 5 Sub-dermal		F(4,145)	7.31	2.43
ALL 5 Central		F(4,145)	1.06	2.43

Appendix 4D: T Tukey's Multiple Comparison Test for the green MOE of Tree 1

	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	919.1^{ns}					
4.9	1198.2^{ns}	279.0n^{s}				
6.6	5935.2^{s}	5016.1^{s}	4737.1^{ns}			
8.3	8981.2^{s}	8062.1^{s}	7783.1^{s}	3046.0^{ns}		
10	10253.3^{s}	9334.2^{s}	9055.1^{s}	4318.1^{s}	1272.0^{ns}	
Sub-dermal						
1.5						
3.2	3316.2^{s}					
4.9	5568.8^{s}	2252.6^{s}				
6.6	6237.7^{s}	2921.5^{s}	668.9n^{s}			
8.3	7379.5^{s}	4063.3^{s}	1810.6^{ns}	1141.8^{ns}		
10	8437.5^{s}	5121.3^{s}	2868.7^{s}	2199.8^{s}	1058.0^{ns}	
Central						
1.5						
3.2	1054.4^{s}					
4.9	1194.4^{s}	140.0^{ns}				
6.6	1240.1^{s}	185.7^{ns}	45.6^{ns}			
8.3	1448.4^{s}	394.0^{ns}	253.9^{ns}	208.3^{ns}		
10	1565.3^{s}	510.9^{ns}	370.9^{ns}	325.3^{ns}	117.0^{ns}	

Appendix 4E: Tukey's Multiple Comparison Test for the green MOE of Tree 2

	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	1043.7^{ns}					
4.9	4065.7^{ns}	3022.0^{ns}				
6.6	7011.6^{s}	5967.9^{s}	2945.9^{ns}			
8.3	10946.6^{s}	9902.8^{s}	6880.9^{s}	3935.0^{ns}		
10	14006.5^{s}	12962.7^{s}	9940.8^{s}	6994.9^{s}	3059.9^{ns}	
Sub-dermal						
1.5						
3.2	1141.6^{ns}					
4.9	4402.7^{s}	3261.0^{s}				
6.6	6929.2^{s}	5787.6^{s}	2526.5^{ns}			
8.3	7413.7^{s}	6272.0^{s}	3011.0^{ns}	484.4^{ns}		
10	8757.5^{s}	7615.9^{s}	4354.8^{s}	1828.3^{ns}	1343.9^{ns}	
Central						
1.5						
3.2	1890.9^{s}					
4.9	2107.7^{s}	216.8^{ns}				
6.6	2203.4^{s}	312.6^{ns}	95.8^{ns}			
8.3	2371.2^{s}	480.3^{ns}	263.5^{ns}	167.8^{ns}		
10	2572.8^{s}	682.0^{s}	465.2^{ns}	369.4^{ns}	201.6^{ns}	

Appendix 4F: Tukey's Multiple Comparison Test for the green MOE of Tree 3

	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	3886.3^{ns}					
4.9	5513.2^{s}	1626.9^{ns}				
6.6	7099.9^{s}	3213.6^{ns}	1586.8^{ns}			
8.3	9639.1^{s}	5752.7^{s}	4125.9^{s}	2539.1^{ns}		
10	10836.8^{s}	6950.5^{s}	5323.6^{s}	9736.8^{ns}	1197.7^{ns}	
Sub-dermal						
1.5						
3.2	4126.8^{s}					
4.9	6160.7^{s}	2033.9^{s}				
6.6	8427.5^{s}	4300.7^{s}	2266.8^{s}			
8.3	9697.8^{s}	5571.0^{s}	3537.1^{s}	1270.3^{ns}		
10	11025.6^{s}	6898.8^{s}	4864.9^{s}	2598.1^{s}	1327.8^{ns}	
Central						
1.5						
3.2	1197.3^{s}					
4.9	1789.8^{s}	592.6^{s}				
6.6	1959.0^{s}	761.7^{s}	169.2^{ns}			
8.3	2177.0^{s}	979.7^{s}	387.2^{ns}	218.0^{ns}		
10	2303.6^{s}	1106.4^{s}	513.8^{s}	344.7^{ns}	126.7^{ns}	

Appendix 4G: Tukey's Multiple Comparison Test for the green MOE of Tree 4

	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	1675.4^{ns}					
4.9	3631.1^{ns}	1955.7^{ns}				
6.6	3728.1^{ns}	2052.6^{ns}	96.9^{ns}			
8.3	5010.5^{s}	3335.1^{ns}	1379.3^{ns}	1282.4^{ns}		
10	8396.9^{s}	6721.4^{s}	4765.7^{s}	4668.9^{s}	3386.4^{ns}	
Sub-dermal						
1.5						
3.2	964.3^{ns}					
4.9	2739.9^{s}	1775.6^{ns}				
6.6	7443.1^{s}	6478.8^{s}	4703.2^{s}			
8.3	9489.7^{s}	8525.4^{s}	6749.8^{s}	2046.6^{ns}		
10	10378.2^{s}	9413.8^{s}	7638.2^{s}	2935.1^{ns}	888.5^{ns}	
Central						
1.5						
3.2	773.6^{s}					
4.9	990.0^{s}	216.4^{ns}				
6.6	1213.8^{s}	440.2^{s}	223.8^{ns}			
8.3	1447.8^{s}	674.3^{s}	457.9^{s}	234.1^{ns}		
10	1622.8^{s}	849.3^{s}	632.9^{s}	409.1^{ns}	175.0^{ns}	

Appendix 4H: Tukey's Multiple Comparison Test for the green MOE of Tree 5

	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	1077.2^{ns}					
4.9	4043.5^{s}	2966.3^{ns}				
6.6	4917.8^{s}	3840.6^{s}	874.4^{ns}			
8.3	8002.6^{s}	6925.4^{s}	3959.1^{s}	3084.7^{ns}		
10	9775.8^{s}	8698.6^{s}	5732.3^{s}	4857.9^{s}	1773.2^{ns}	
Sub-dermal						
1.5						
3.2	1343.3^{ns}					
4.9	1871.8^{ns}	528.5^{ns}				
6.6	3777.1^{s}	2433.8^{ns}	1905.3^{ns}			
8.3	5555.8^{s}	4212.5^{s}	3684.0^{s}	1778.8^{ns}		
10	6667.2^{s}	5323.9^{s}	4795.4^{s}	2890.1^{s}	1111.4^{ns}	
Central						
1.5						
3.2	2091.0^{s}					
4.9	2831.1^{s}	740.1^{ns}				
6.6	3049.8^{s}	958.8^{s}	218.6^{ns}			
8.3	3244.0^{s}	1153.0^{s}	412.8^{ns}	194.2^{ns}		
10	3316.2^{s}	1225.2^{s}	485.1^{ns}	266.4^{ns}	72.3^{ns}	

Appendix 4I: Tukey's Multiple Comparison Test for the green MOE of All 5 Trees

	Tree 1 Dermal	Tree 2 Dermal	Tree 3 Dermal	Tree 4 Dermal	Tree 5 Dermal
Tree 1 Dermal					
Tree 2 Dermal	2281.6^{ns}				
Tree 3 Dermal	1785.1^{ns}	-496.4^{ns}			
Tree 4 Dermal	-1301.2^{ns}	-3582.8^{s}	-3086.4^{ns}		
Tree 5 Dermal	-1016.6^{ns}	-3298.1^{s}	-2801.7^{ns}	284.7^{ns}	
	Tree 1 Sub-dermal	**Tree 2Sub-dermal**	**Tree 3 Sub-dermal**	**Tree 4 Sub-dermal**	**Tree 5 Sub-dermal**
Tree 1 Sub-dermal					
Tree 2 Sub-dermal	-1520.5^{ns}				
Tree 3 Sub-dermal	-1621.0^{ns}	-100.25^{ns}			
Tree 4 Sub-dermal	-4450.2^{s}	-2929.7^{s}	-2829.2^{s}		
Tree 5 Sub-dermal	-271.2^{ns}	1249.3^{ns}	1349.8^{ns}	4178.95^{s}	
	Tree 1 Central	**Tree 2 Central**	**Tree 3 Central**	**Tree 4 Central**	**Tree 5 Central**
Tree 1 Central					
Tree 2 Central	-356.3^{ns}				
Tree 3 Central	-38.1^{ns}	318.2^{ns}			
Tree 4 Central	-275.5^{ns}	80.7^{ns}	-237.4^{ns}		
Tree 5 Central	-291.7^{ns}	64.5^{ns}	-253.6^{ns}	-16.2^{ns}	
	Tree 1	**Tree 2**	**Tree 3**	**Tree 4**	**Tree 5**
Tree 1					
Tree 2	134.9^{ns}				
Tree 3	42.0^{ns}	-92.9^{ns}			
Tree 4	-2009.0^{ns}	-2143.9^{ns}	-2050.9^{ns}		
Tree 5	-526.5^{ns}	-661.4^{ns}	-586.5^{ns}	1482.5^{ns}	

Appendix 5A: Summary of the basic statistics of the MOE of the 5 *Borassus aethiopum* at 12% MC.

Tree No	Zone	Mean	S.Dev.	Minimum	Maximum	Count	CL(95.0%)
Tree 1	Dermal	15965.59	5578.73	8330.02	24330.46	30.0	2083.13
	Sub-dermal	7696.21	4848.50	1843.18	19184.70	30.0	1810.46
	Central	1270.42	1033.63	357.61	3549.84	30.0	385.97
Tree 2	Dermal	14848.76	6409.94	5252.99	24401.45	30.0	2393.51
	Sub-dermal	9318.76	4697.89	2906.58	18090.10	30.0	1754.22
	Central	2087.59	1405.95	496.71	5857.17	30.0	524.99
Tree 3	Dermal	17621.85	4857.16	9353.09	25871.79	30.0	1813.69
	Sub-dermal	10304.32	5464.23	2484.74	20323.06	30.0	2040.38
	Central	1504.43	1194.34	206.46	3900.68	30.0	445.97
Tree 4	Dermal	18828.43	4513.98	9906.97	25631.90	30.0	1685.55
	Sub-dermal	11887.68	4447.42	4820.47	19088.80	30.0	1660.70
	Central	2122.93	1029.53	819.33	4069.70	30.0	384.43
Tree 5	Dermal	18371.87	3362.33	11071.99	25272.90	30.0	1255.51
	Sub-dermal	9313.62	4046.22	2952.23	15720.07	30.0	1510.88
	Central	1507.72	1283.87	298.27	5174.02	30.0	479.41
ALL 5 Dermal		17127..30	5203.16	5252.99	25871.79	150.0	839.48
ALL 5 Sub-dermal		9704.12	4860.37	1843.18	20323.06	150.0	784.18
ALL 5 Central		1698.62	1231.25	206.46	5857.17	150.0	198.65
ALL 5 TREES		9510.01	7556.97	206.46	25871.79	450.0	700.10

S.Dev. = Standard Deviation CL(95%) = 95% Confidence Level

Appendix 5B: Summary of the ANOVA of the MOE of the Individual Trees (dermal, sub-dermal, and the central zone) of the 5 *Borassus aethiopum* wood at 12% MC

Tree No	Mean (± δ_{n-1}) *	ANOVA between Individual Trees		
		Degrees of freedom	F-ratio	F-Critical
Tree 1	8310.74±7398.3	F(2,87)	87.69	3.10
Tree 2	8751.71±6988.01	F(2,87)	56.59	3.10
Tree 3	9810.19±7860.41	F(2,87)	106.81	3.10
Tree 4	10946.35±7804.66	F(2,87)	153.8	3.10
Tree 5	9731.07±7587.89	F(2,87)	218.6	3.10
All 5 Trees	9510.01±7556.97	F(4,445)	1.7	2.39

Appendix 5C: Analysis of Variance (ANOVA) of the MOE for the 5 *Borassus aethiopum* Tree species at 12% M.C

Tree No	Zone	Degrees of freedom	F	F-Critical
Tree 1	Dermal	F(5,24)	50.86	2.62
	Sub-dermal	F(5,24)	55.69	2.62
	Central	F(5,24)	267.33	2.62
Tree 2	Dermal	F(5,24)	198.8	2.62
	Sub-dermal	F(5,24)	16.3	2.62
	Central	F(5,24)	39.0	2.62
Tree 3	Dermal	F(5,24)	18.19	2.62
	Sub-dermal	F(5,24)	95.51	2.62
	Central	F(5,24)	114.13	2.62
Tree 4	Dermal	F(5,24)	14.60	2.62
	Sub-dermal	F(5,24)	50.17	2.62
	Central	F(5,24)	53.52	2.62
Tree 5	Dermal	F(5,24)	7.21	2.62
	Sub-dermal	F(5,24)	17.00	2.62
	Central	F(5,24)	48.43	2.62
ALL 5 Dermal		F(4,145)	3.30	2.43
ALL 5 Sub-dermal		F(4,145)	3.18	2.43
ALL 5 Central		F(4,145)	3.08	2.43

Appendix 5D: Tukey's Multiple Comparison Test for the MOE of Tree 1 at 12% MC

Height (m)	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	3074.5^{ns}					
4.9	4972.2^{s}	1897.7^{ns}				
6.6	9572.5^{s}	6498.0^{s}	4600.3^{s}			
8.3	12528.8^{s}	9454.3^{s}	7556.6^{s}	2956.3^{ns}		
10	14789.4^{s}	11714.9^{s}	9817.2^{s}	5217.0^{s}	2260.6^{ns}	
Sub-dermal						
1.5						
3.2	3446^{s}					
4.9	5862^{s}	2415^{ns}				
6.6	9876^{s}	6430^{s}	4014s			
8.3	11520^{s}	8070^{s}	5655^{s}	1640^{ns}		
10	12860^{s}	9414^{s}	6998^{s}	2984^{s}	1344^{ns}	
Central						
1.5						
3.2	1844.7^{s}					
4.9	2010.3^{s}	165.6^{ns}				
6.6	2621.6^{s}	776.9^{s}	611.3^{s}			
8.3	2915.0^{s}	1070.2^{s}	904.6^{s}	293.3^{ns}		
10	2925.4^{s}	1080.7^{s}	915.1^{s}	303.8^{s}	10.5^{ns}	

Appendix 5E: Tukey's Multiple Comparison Test for the MOE of Tree 2 at 12% MC

Height (m)	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	1532.9^{ns}					
4.9	7427.3^{s}					
6.6	10311.5^{s}	5894.4^{s}	15526.4^{s}			
8.3	14350^{s}	8778.5^{s}	2884.1^{s}	4038.5^{s}		
10	17059.3^{s}	12817^{s}	6922.6^{s}	6747.8^{s}	2709.3^{s}	
Sub-dermal						
1.5						
3.2	3117.1^{ns}					
4.9	4061.0^{ns}	943.8^{ns}				
6.6	9114.2^{s}	5997.0^{s}	5053.2^{s}			
8.3	9629.7^{s}	6512.5^{s}	5568.7^{s}	515.5^{ns}		
10	11315.8^{s}	8198.6^{s}	7254.8^{s}	2201.6^{ns}	1686.1^{ns}	
Central						
1.5						
3.2	2503.1^{s}					
4.9	2670.8^{s}	167.7^{ns}				
6.6	3038.3^{s}	535.2^{ns}	367.5^{ns}			
8.3	3632.5^{s}	1129.4^{s}	961.7^{ns}	594.2^{ns}		
10	4080.6^{s}	1577.5^{s}	1409.8^{s}	1042.3^{s}	448.1^{ns}	

Appendix 5F: Tukey's Multiple Comparison Test for the MOE of Tree 3 at 12% MC

Height (m)	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	3625.2^{ns}					
4.9	6375.1^{s}	2749.9^{ns}				
6.6	6778.1^{s}	3153^{ns}	403.1^{ns}			
8.3	10472.8^{s}	6847.7^{s}	4097.8^{ns}	3694.7^{ns}		
10	12990.9^{s}	9365.8^{s}	6615.9^{s}	6212.8^{s}	2518.1^{ns}	
Sub-dermal						
1.5						
3.2	4783^{s}					
4.9	8990^{s}	4206^{s}				
6.6	10930^{s}	6145^{s}	1939^{ns}			
8.3	12250^{s}	7467^{s}	3261^{s}	1322^{ns}		
10	16210^{s}	11420^{s}	7217^{s}	5278^{s}	3956^{s}	
Central						
1.5						
3.2	1193.8^{s}					
4.9	1968^{s}	774.1^{s}				
6.6	2705.1^{s}	1511.3^{s}	737.1^{s}			
8.3	3104.9^{s}	1911.1^{s}	1137^{s}	399.8^{ns}		
10	3256.6^{s}	2062.8^{s}	1288.7^{s}	551.546^{s}	151.7^{ns}	

Appendix 5G: Tukey's Multiple Comparison Test for the MOE of Tree 4 at 12% MC

Height (m)	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	3012.2^{ns}					
4.9	5534.6^{s}	2522.4^{ns}				
6.6	6234.7^{s}	3222.5^{ns}	700.1^{ns}			
8.3	7565.6^{s}	4553.4^{ns}	203.1^{ns}	1330.9^{ns}		
10	12444.7^{s}	9432.5^{ns}	6910.1^{s}	6210.0^{s}	4879.1^{s}	
Sub-dermal						
1.5						
3.2	2598.1^{ns}					
4.9	4632.4^{s}	2034.3^{ns}				
6.6	7837.4^{s}	5239.3^{s}	3205.0^{s}			
8.3	9779.3^{s}	7181.2^{s}	5146.9^{s}	1941.9^{ns}		
10	12145.4^{s}	9547.3^{s}	7513.0^{s}	4308.0^{s}	2366.1^{ns}	
Central						
1.5						
3.2	1022.9^{s}					
4.9	1613.5^{s}	590.6^{ns}				
6.6	1881.8^{s}	858.9^{s}	268.3^{ns}			
8.3	2642.0^{s}	1619.1^{s}	1028.5^{s}	760.2^{s}		
10	2870.5^{s}	1847.6^{s}	1257.0^{s}	988.7^{s}	228.6^{ns}	

Appendix 5H: Tukey's Multiple Comparison Test for the MOE of Tree 5 at 12% MC

Height (m)	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	2867.5^{ns}					
4.9	3337.7^{ns}	470.2^{ns}				
6.6	5027.3^{s}	2159.8^{ns}	1689.6^{ns}			
8.3	6325^{s}	3457.5^{ns}	2987.3^{ns}	1297.7^{ns}		
10	7945.3^{s}	5077.9^{s}	4607.7^{s}	2918.1^{ns}	1620.4^{ns}	
Sub-dermal						
1.5						
3.2	3085.3^{ns}					
4.9	3368.8^{ns}	283.5^{ns}				
6.6	4709.7^{s}	1624.4^{ns}	1340.9^{ns}			
8.3	8776.7^{s}	5691.4^{s}	5407.9^{s}	4067.0^{ns}		
10	10328.2^{s}	7242.9^{s}	6959.4^{s}	5618.5^{s}	1551.5^{ns}	
Central						
1.5						
3.2	2075.5^{s}					
4.9	2773.5^{s}	698.1^{ns}				
6.6	2866.5^{s}	791.1^{ns}	93.0^{ns}			
8.3	3469.4^{s}	1393.9^{s}	695.8^{ns}	602.8^{ns}		
10	3562.9^{s}	1487.4^{s}	789.4^{ns}	696.4^{ns}	93.5^{ns}	

Appendix 5I: Tukey's Multiple Comparison Test for the MOE of All 5 Trees at 12% MC

	Tree 1 Dermal	Tree 2 Dermal	Tree 3 Dermal	Tree 4 Dermal	Tree 5 Dermal
Tree 1 Dermal					
Tree 2 Dermal	1116.8^{ns}				
Tree 3 Dermal	-1656.3^{ns}	-2773.1^{ns}			
Tree 4 Dermal	-2862.8^{ns}	-3979.7^{s}	-1206.6^{ns}		
Tree 5 Dermal	-2406.3^{ns}	-3523.1^{ns}	-750.0^{ns}	-456.6^{ns}	
	Tree 1 Sub-dermal	**Tree 2Sub-dermal**	**Tree 3 Sub-dermal**	**Tree 4 Sub-dermal**	**Tree 5 Sub-dermal**
Tree 1 Sub-dermal					
Tree 2 Sub-dermal	-1622.6^{ns}				
Tree 3 Sub-dermal	-2608.1^{ns}	-985.6^{ns}			
Tree 4 Sub-dermal	-4191.5^{s}	-2568.9^{ns}	-1583.4^{ns}		
Tree 5 Sub-dermal	-1617.4^{ns}	-5.1^{ns}	990.7^{ns}	2574.1^{ns}	
	Tree 1 Central	**Tree 2 Central**	**Tree 3 Central**	**Tree 4 Central**	**Tree 5 Central**
Tree 1 Central					
Tree 2 Central	-817.2^{ns}				
Tree 3 Central	-234.0^{ns}	583.2^{ns}			
Tree 4 Central	-852.5^{ns}	-35.3^{ns}	-618.5^{ns}		
Tree 5 Central	-237.3^{ns}	579.9^{ns}	-3.3^{ns}	615.2^{ns}	
	Tree 1	**Tree 2**	**Tree 3**	**Tree 4**	**Tree 5**
Tree 1					
Tree 2	-441.0^{ns}				
Tree 3	-1499.5^{ns}	-1058.5^{ns}			
Tree 4	-2635.6^{ns}	-2194.6^{ns}	-1136.2^{ns}		
Tree 5	-1420.3^{ns}	-979.4^{ns}	79.1^{ns}	1215.3^{ns}	

Appendix 6A: Summary of the basic statistics of the green MOR of the 5 *Borassus aethiopum* species

Tree No		Mean	S.Dev.	Minimum	Maximum	Count	CL(95.0%)
	Dermal	94.6	27.1	50.0	156.1	30.0	10.1
Tree 1	Sub-dermal	36.0	19.1	12.8	70.8	30.0	7.1
	Central	6.8	3.8	2.3	14.9	30.0	1.4
	Dermal	85.2	35.7	31.1	132.4	30.0	13.3
Tree 2	Sub-dermal	44.1	19.9	15.0	74.6	30.0	7.4
	Central	7.6	4.2	3.2	17.6	30.0	1.6
	Dermal	79.4	31.4	39.0	139.1	30.0	11.7
Tree 3	Sub-dermal	49.5	25.2	18.0	98.2	30.0	9.4
	Central	6.7	4.7	1.7	18.2	30.0	1.7
	Dermal	93.9	17.8	62.6	128.0	30.0	6.7
Tree 4	Sub-dermal	60.6	25.7	29.6	97.5	30.0	9.6
	Central	8.7	4.0	2.5	17.2	30.0	1.5
	Dermal	96.2	22.1	57.8	149.1	30.0	8.2
Tree 5	Sub-dermal	36.1	14.3	10.6	57.6	30.0	5.3
	Central	7.5	6.4	1.3	22.9	30.0	2.4
ALL 5 Dermal		89.8	28.0	31.1	156.1	150.0	4.5
ALL 5 Sub-dermal		45.2	22.9	10.6	98.2	150.0	3.7
ALL 5 Central		7.5	4.7	1.3	22.9	150.0	0.8
ALL 5 TREES		47.5	39.7	1.3	156.1	450.0	3.7

S.Dev. = Standard Deviation CL(95%) = 95% Confidence Level

Appendix 6B: Summary of the ANOVA of the green MOR of the (dermal, sub-dermal, and the central zone) of the Individual trees of the 5 *Borassus aethiopum* wood.

Tree No	Mean ($\pm \delta_{n-1}$)*	ANOVA between Individual Trees		
		Degrees of freedom	F-ratio	F-Critical
Tree 1	45.8±41.4	F(2,87)	161.6	3.10
Tree 2	45.6±39.5	F(2,87)	80.4	3.10
Tree 3	45.2±37.9	F(2,87)	73.2	3.10
Tree 4	54.4±39.6	F(2,87)	166.6	3.10
Tree 5	46.6±40.3	F(2,87)	251.4	3.10
All 5 Trees	47.5±39.7	F(4,445)	0.9	2.39

Appendix 6C: Analysis of Variance (ANOVA) of the Green MOR for the 5 *Borassus aethiopum* Tree species

Tree No	Zone	Degrees of freedom	F	F-Critical
Tree 1	Dermal	F(5,24)	11.56	2.62
	Sub-dermal	F(5,24)	159.89	2.62
	Central	F(5,24)	23.26	2.62
Tree 2	Dermal	F(5,24)	143.0	2.62
	Sub-dermal	F(5,24)	380.5	2.62
	Central	F(5,24)	267.2	2.62
Tree 3	Dermal	F(5,24)	115.10	2.62
	Sub-dermal	F(5,24)	260.30	2.62
	Central	F(5,24)	74.76	2.62
Tree 4	Dermal	F(5,24)	7.45	2.62
	Sub-dermal	F(5,24)	158.91	2.62
	Central	F(5,24)	251.35	2.62
Tree 5	Dermal	F(5,24)	23.92	2.62
	Sub-dermal	F(5,24)	32.03	2.62
	Central	F(5,24)	199.20	2.62
ALL 5 Dermal		F(4,145)	2.08	2.43
ALL 5 Sub-dermal		F(4,145)	7.04	2.43
ALL 5 Central		F(4,145)	0.88	2.43

APPENDIX 6D: Tukey's Multiple Comparison Test for the green MOR of Tree 1

		1.5	3.2	4.9	6.6	8.3	10
Dermal							
	1.5						
	3.2	17.6^{ns}					
	4.9	27.8^{ns}	10.1^{ns}				
	6.6	29.4^{ns}	11.8^{ns}	1.6^{ns}			
	8.3	49.7^{s}	32.1^{s}	21.9^{ns}	20.3^{ns}		
	10	70.1^{s}	52.5^{s}	42.3^{s}	40.7^{s}	20.4^{ns}	
Sub-dermal							
	1.5						
	3.2	10.9^{s}					
	4.9	29.1^{s}	18.1^{s}				
	6.6	38.1^{s}	27.2^{s}	9.0^{s}			
	8.3	46.8^{s}	35.9^{s}	17.7^{s}	8.7^{s}		
	10	50.9^{s}	40.0^{s}	21.9^{s}	12.8^{s}	4.2^{ns}	
Central							
	1.5						
	3.2	6.7^{s}					
	4.9	7.9^{s}	1.15^{ns}				
	6.6	8.9^{s}	2.2^{ns}	1.0^{ns}			
	8.3	9.7^{s}	2.9^{ns}	1.8^{ns}	0.8^{ns}		
	10	10.2^{s}	3.4^{s}	2.3^{ns}	1.2^{ns}	0.5^{ns}	

Appendix 6E: Tukey's Multiple Comparison Test for the green MOR of TREE 2

	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	11.6^{ns}					
4.9	18.6^{s}	7.0^{ns}				
6.6	41.4^{s}	29.8^{s}	22.9^{s}			
8.3	79.4^{s}	67.8^{s}	60.8^{s}	38.0^{s}		
10	92.2^{s}	80.6^{s}	73.6^{s}	50.8^{s}	12.8^{ns}	
Sub-dermal						
1.5						
3.2	8.1^{s}					
4.9	20.5^{s}	12.4^{s}				
6.6	35.5^{s}	27.3^{s}	14.9^{s}			
8.3	45.6^{s}	37.5^{s}	25.1^{s}	10.1^{s}		
10	53.8^{s}	45.6^{s}	33.2^{s}	18.3^{s}	8.2^{s}	
Central						
1.5						
3.2	7.8^{s}					
4.9	9.3^{s}	1.5^{s}				
6.6	10.1^{s}	2.3^{s}	0.7^{ns}			
8.3	11.4^{s}	3.6^{s}	2.1^{s}	1.3^{s}		
10	12.7^{s}	4.9^{s}	3.4^{s}	2.7^{s}	1.3^{s}	

Appendix 6F: Tukey's Multiple Comparison Test for the green MOR of TREE 3

	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	36.4^{s}					
4.9	51.9^{s}	15.5^{s}				
6.6	69.8^{s}	33.4^{s}	17.9^{s}			
8.3	81.5^{s}	45.1^{s}	29.6^{s}	11.7^{ns}		
10	89.2^{s}	52.9^{s}	37.3^{s}	19.4^{s}	7.7^{ns}	
Sub-dermal						
1.5						
3.2	34.8^{s}					
4.9	43.7^{s}	8.9^{s}				
6.6	60.9^{s}	26.0^{s}	17.1^{s}			
8.3	64.7^{s}	29.8^{s}	20.9^{s}	3.8^{ns}		
10	74.4^{s}	39.6^{s}	30.7^{s}	13.5^{s}	9.7^{s}	
Central						
1.5						
3.2	6.5^{s}					
4.9	10.2^{s}	3.7^{s}				
6.6	10.8^{s}	4.4^{s}	0.7^{ns}			
8.3	11.3^{s}	4.9^{s}	1.2^{ns}	0.5^{ns}		
10	13.6^{s}	7.1^{s}	3.4^{s}	2.7^{s}	2.2^{ns}	

Appendix 6G: Tukey's Multiple Comparison Test for the green MOR of TREE 4

	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	19.5^{ns}					
4.9	24.0^{ns}	4.5^{ns}				
6.6	29.9^{s}	10.4^{ns}	5.9^{ns}			
8.3	34.7^{s}	15.2^{ns}	10.7^{ns}	4.7^{ns}		
10	43.7^{s}	24.2^{s}	19.7^{ns}	13.7^{ns}	9.0^{ns}	
Sub-dermal						
1.5						
3.2	8.7^{ns}					
4.9	26.3^{s}	17.5^{s}				
6.6	52.5^{s}	43.8^{s}	26.2^{s}			
8.3	58.3^{s}	49.6^{s}	32.1^{s}	5.9^{ns}		
10	64.7^{s}	56.0^{s}	38.4^{s}	12.2^{s}	6.3^{ns}	
Central						
1.5						
3.2	7.0^{s}					
4.9	7.7^{s}	0.7^{ns}				
6.6	8.9^{s}	2.0^{ns}	1.2^{ns}			
8.3	9.8^{s}	2.8^{s}	2.1^{ns}	0.8^{ns}		
10	12.0^{s}	5.0^{s}	4.3^{s}	3.0^{s}	2.2^{ns}	

Appendix 6H: Tukey's Multiple Comparison Test for the green MOR of TREE 5

	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	20.9^{s}					
4.9	30.7^{s}	9.8^{ns}				
6.6	43.6^{s}	22.8^{s}	13.0^{ns}			
8.3	44.9^{s}	24.0^{s}	14.2^{ns}	1.2^{ns}		
10	62.4^{s}	41.5^{s}	31.7^{s}	18.7^{ns}	17.5^{ns}	
Sub-dermal						
1.5						
3.2	10.1^{ns}					
4.9	11.9^{s}	1.7^{ns}				
6.6	13.4^{s}	3.3^{ns}	1.6^{ns}			
8.3	28.3^{s}	18.1^{s}	16.4^{s}	14.8^{s}		
10	40.1^{s}	29.9^{s}	28.2^{s}	26.6^{s}	11.8^{s}	
Central						
1.5						
3.2	9.5^{s}					
4.9	14.3^{s}	4.8^{s}				
6.6	15.8^{s}	6.3^{s}	1.5^{ns}			
8.3	17.6^{s}	8.1^{s}	3.4^{s}	1.5^{ns}		
10	17.9^{s}	8.5^{s}	3.7^{s}	2.2^{s}	0.3^{ns}	

Appendix 6I: Tukey's Multiple Comparison Test for the green MOR of All 5 Trees

	Tree 1 Dermal	Tree 2 Dermal	Tree 3 Dermal	Tree 4 Dermal	Tree 5 Dermal
Tree 1 Dermal					
Tree 2 Dermal	28.6^{s}				
Tree 3 Dermal	34.4^{s}	5.8^{ns}			
Tree 4 Dermal	19.9^{ns}	-8.7^{ns}	-14.5^{ns}		
Tree 5 Dermal	17.6^{ns}	-11.0^{ns}	-16.8^{ns}	-2.2^{ns}	

	Tree 1 Sub-dermal	Tree 2Sub-dermal	Tree 3 Sub-dermal	Tree 4 Sub-dermal	Tree 5 Sub-dermal
Tree 1 Sub-dermal					
Tree 2 Sub-dermal	-8.2^{ns}				
Tree 3 Sub-dermal	-13.5^{ns}	-5.3^{ns}			
Tree 4 Sub-dermal	-24.6^{s}	-16.4^{s}	-11.1^{ns}		
Tree 5 Sub-dermal	-0.1^{ns}	8.0^{ns}	13.4^{ns}	24.5^{s}	

	Tree 1 Central	Tree 2 Central	Tree 3 Central	Tree 4 Central	Tree 5 Central
Tree 1 Central					
Tree 2 Central	-0.8^{ns}				
Tree 3 Central	0.1^{ns}	0.9^{ns}			
Tree 4 Central	-1.9^{ns}	-1.1^{ns}	-2.0^{ns}		
Tree 5 Central	-0.7^{ns}	0.1^{ns}	-0.7^{ns}	1.2^{ns}	

	Tree 1	Tree 2	Tree 3	Tree 4	Tree 5
Tree 1					
Tree 2	-2.7^{ns}				
Tree 3	-9.2^{ns}	-6.5^{ns}			
Tree 4	-8.8^{ns}	-6.1^{ns}	-0.4^{ns}		
Tree 5	-3.0^{ns}	-0.2^{ns}	-6.3^{ns}	5.8^{ns}	

Appendix 7A: Summary of the basic statistics of the MOR of the 5 *Borassus aethiopum* at 12% MC.

Tree No	Zone	Mean	S.Dev.	Minimum	Maximum	Count	CL (95.0%)
Tree 1	Dermal	116.9	33.0	62.7	175.0	30.0	12.3
	Sub-dermal	55.0	29.8	19.0	103.5	30.0	11.1
	Central	9.6	6.3	4.0	24.5	30.0	2.3
Tree 2	Dermal	115.2	42.6	48.5	181.1	30.0	15.9
	Sub-dermal	61.1	30.2	21.3	149.7	30.0	11.3
	Central	13.3	7.8	5.4	29.5	30.0	2.9
Tree 3	Dermal	124.4	41.2	67.3	217.1	30.0	15.4
	Sub-dermal	73.3	32.2	26.8	139.1	30.0	12.0
	Central	11.5	7.6	2.1	24.6	30.0	2.8
Tree 4	Dermal	121.9	22.3	70.2	165.6	30.0	8.3
	Sub-dermal	71.2	24.5	34.9	126.9	30.0	9.2
	Central	14.8	7.7	6.6	31.9	30.0	2.9
Tree 5	Dermal	122.6	29.7	83.2	180.8	30.0	11.1
	Sub-dermal	58.2	25.3	28.6	108.1	30.0	9.4
	Central	9.6	7.6	2.1	25.7	30.0	2.8
ALL 5 Dermal		120.2	34.3	48.5	217.1	150.0	5.5
ALL 5 Sub-dermal		63.8	29.1	19.0	149.7	150.0	4.7
ALL 5 Central		11.8	7.6	2.1	31.9	150.0	1.2
ALL 5 TREES		65.2	51.5	2.1	217.1	450.0	4.8

S.Dev. = Standard Deviation CL(95%) = 95% Confidence Level

Appendix 7B: Summary of the ANOVA of the MOR of the (dermal, sub-dermal, and the central zone) of the Individual trees of the 5 *Borassus aethiopum* wood at 12% MC.

Tree No	Mean ($\pm \delta_{n-1}$)*	ANOVA between Individual Trees		
		Degrees of freedom	F-ratio	F-Critical
Tree 1	60.6±51.1	F(2,87)	129.857	3.10
Tree 2	63.2±51.6	F(2,87)	83.8135	3.10
Tree 3	69.7±55.4	F(2,87)	103.253	3.10
Tree 4	69.3±48.1	F(2,87)	222.969	3.10
Tree 5	63.5±51.8	F(2,87)	182.901	3.10
All 5 Trees	65.2±51.5	F(4,445)	0.55813	2.39

Appendix 7C: Analysis of Variance (ANOVA) of the MOR for the 5 *Borassus aethiopum* Tree species at 12% M.C

Tree No	Zone	Degrees of freedom	F	F-Critical
	Dermal	F(5,24)	135.03	2.62
Tree 1	Sub-dermal	F(5,24)	629.02	2.62
	Central	F(5,24)	481.52	2.62
	Dermal	F(5,24)	446.0	2.62
Tree 2	Sub-dermal	F(5,24)	25.0	2.62
	Central	F(5,24)	785.4	2.62
	Dermal	F(5,24)	30.64	2.62
Tree 3	Sub-dermal	F(5,24)	189.79	2.62
	Central	F(5,24)	315.04	2.62
	Dermal	F(5,24)	43.06	2.62
Tree 4	Sub-dermal	F(5,24)	127.93	2.62
	Central	F(5,24)	152.08	2.62
	Dermal	F(5,24)	418.96	2.62
Tree 5	Sub-dermal	F(5,24)	483.24	2.62
	Central	F(5,24)	1487.11	2.62
ALL 5 Dermal		F(4,145)	0.39	2.43
ALL 5 Sub-dermal		F(4,145)	2.39	2.43
ALL 5 Central		F(4,145)	3.33	2.43

Appendix 7D: Tukey's Multiple Comparison Test for the MOR of TREE 1 at 12% MC

Height(m)	1.5m	3.2m	4.9m	6.6m	8.3m	10m
Dermal						
1.5						
3.2	22.0^{s}					
4.9	37.1^{s}	15.1^{s}				
6.6	52.1^{s}	30.1^{s}	15.1^{s}			
8.3	75.5^{s}	53.6^{s}	38.5^{s}	23.4^{s}		
10	95.1^{s}	73.1^{s}	58.0^{s}	42.9^{s}	19.5^{s}	
Sub-dermal						
1.5						
3.2	20.4^{s}					
4.9	43.0^{s}	22.5^{s}				
6.6	61.9^{s}	41.5^{s}	18.9^{s}			
8.3	73.6^{s}	53.2^{s}	30.6^{s}	11.7^{s}		
10	82.3^{s}	61.8^{s}	39.3^{s}	20.4^{s}	8.7^{s}	
Central						
1.5						
3.2	11.8^{s}					
4.9	12.9^{s}	1.1^{ns}				
6.6	16.0^{s}	4.2^{s}	3.1^{s}			
8.3	17.6^{s}	5.8^{s}	4.7^{s}	1.6^{s}		
10	18.1^{s}	6.3^{s}	5.2^{s}	2.1^{s}	0.5^{ns}	

Appendix 7E: Tukey's Multiple Comparison Test for the MOR of TREE 2 at 12% MC

Height (m)	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	22.2^{s}					
4.9	55.1^{s}	32.9^{s}				
6.6	68.1^{s}	45.9^{s}	13.0^{s}			
8.3	95.7^{s}	73.5^{s}	40.6^{s}	27.5^{s}		
10	123.5^{s}	101.3^{s}	68.5^{s}	55.4^{s}	27.9^{s}	
Sub-dermal						
1.5						
3.2	14.5^{ns}					
4.9	41.9^{s}	27.3^{s}				
6.6	56.4^{s}	41.9^{s}	14.6^{ns}			
8.3	58.7^{s}	44.2^{s}	16.8^{ns}	2.3^{ns}		
10	79.9^{s}	65.4^{s}	38.0^{s}	23.5^{ns}	21.2^{ns}	
Central						
1.5						
3.2	13.2^{s}					
4.9	16.4^{s}	3.2^{s}				
6.6	18.7^{s}	5.4^{s}	2.2^{s}			
8.3	21.5^{s}	8.2^{s}	5.0^{s}	2.8^{s}		
10	23.0^{s}	9.7^{s}	6.6^{s}	4.3^{s}	1.5^{s}	

Appendix 7F: Tukey's Multiple Comparison Test for the MOR of TREE 3 at 12% MC

Height (m)	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	32.9^{s}					
4.9	59.6^{s}	26.7^{ns}				
6.6	70.3^{s}	37.4^{s}	10.7^{ns}			
8.3	91.4^{s}	58.5^{s}	31.8^{ns}	21.1^{ns}		
10	115.5^{s}	82.7^{s}	56.0^{s}	45.2^{s}	24.1^{ns}	
Sub-dermal						
1.5						
3.2	39.8^{s}					
4.9	51.2^{s}	11.4^{s}				
6.6	71.3^{s}	31.5^{s}	20.1^{s}			
8.3	79.5^{s}	39.7^{s}	28.3^{s}	8.2^{ns}		
10	96.7^{s}	56.9^{s}	45.6^{s}	25.5^{s}	17.3^{s}	
Central						
1.5						
3.2	5.9^{s}					
4.9	12.0^{s}	6.1^{s}				
6.6	16.5^{s}	10.6^{s}	4.5^{s}			
8.3	18.9^{s}	13.0^{s}	6.9^{s}	2.4^{s}		
10	20.8^{s}	14.9^{s}	8.8^{s}	4.3^{s}	1.9^{ns}	

Appendix 7G: Tukey's Multiple Comparison Test for the MOR of TREE 4 at 12% MC

Height (m)	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	22.2^{s}					
4.9	26.0^{s}	3.9^{ns}				
6.6	35.7^{s}	13.5^{ns}	9.7^{ns}			
8.3	45.6^{s}	23.4^{s}	19.6^{s}	9.9^{ns}		
10	67.3^{s}	45.1^{s}	41.2^{s}	31.6^{s}	21.7^{s}	
Sub-dermal						
1.5						
3.2	30.0^{s}					
4.9	42.5^{s}	12.5^{s}				
6.6	49.4^{s}	19.5^{s}	7.0^{ns}			
8.3	61.8^{s}	31.9^{s}	19.3^{s}	12.4^{s}		
10	73.9^{s}	43.9^{s}	31.4^{s}	24.4^{s}	12.1^{s}	
Central						
1.5						
3.2	11.7^{s}					
4.9	14.2^{s}	2.5^{ns}				
6.6	17.9^{s}	6.2^{s}	3.7^{s}			
8.3	21.1^{s}	9.4^{s}	6.9^{s}	3.2^{s}		
10	22.2^{s}	10.6^{s}	8.1^{s}	4.4^{s}	1.2^{ns}	

Appendix 7H: Tukey's Multiple Comparison Test for the MOR of TREE 5 at 12% MC

Height (m)	1.5 m	3.2 m	4.9 m	6.6 m	8.3 m	10 m
Dermal						
1.5						
3.2	39.6^{s}					
4.9	54.1^{s}	14.5^{s}				
6.6	69.8^{s}	30.2^{s}	15.7^{s}			
8.3	74.0^{s}	34.4^{s}	19.9^{s}	4.2^{ns}		
10	90.0^{s}	50.4^{s}	35.8^{s}	20.2^{s}	16.0^{s}	
Sub-dermal						
1.5						
3.2	34.7^{s}					
4.9	45.4^{s}	10.7^{s}				
6.6	51.8^{s}	17.1^{s}	6.4^{s}			
8.3	70.4^{s}	35.6^{s}	25.0^{s}	18.6^{s}		
10	74.3^{s}	39.5^{s}	28.9^{s}	22.5^{s}	3.9^{ns}	
Central						
1.5						
3.2	12.9^{s}					
4.9	17.1^{s}	4.1^{s}				
6.6	17.6^{s}	4.7^{s}	0.5^{ns}			
8.3	21.6^{s}	8.7^{s}	4.5^{s}	4.0^{s}		
10	22.2^{s}	9.3^{s}	5.1^{s}	4.6^{s}	0.6^{ns}	

Appendix 7I: Tukey's Multiple Comparison Test for the MOR of All 5 TREES at 12% MC

	Tree 1 Dermal	Tree 2 Dermal	Tree 3 Dermal	Tree 4 Dermal	Tree 5 Dermal
Tree 1 Dermal					
Tree 2 Dermal	1.7^{ns}				
Tree 3 Dermal	-7.5^{ns}	-9.2^{ns}			
Tree 4 Dermal	-5.0^{ns}	-6.7^{ns}	2.5^{ns}		
Tree 5 Dermal	-5.7^{ns}	-7.4^{ns}	1.8^{ns}	-0.7^{ns}	

	Tree 1 Sub-dermal	Tree 2Sub-dermal	Tree 3 Sub-dermal	Tree 4 Sub-dermal	Tree 5 Sub-dermal
Tree 1 Sub-dermal					
Tree 2 Sub-dermal	-6.1^{ns}				
Tree 3 Sub-dermal	-18.3^{ns}	-12.1^{ns}			
Tree 4 Sub-dermal	-16.2^{ns}	-10.1^{ns}	2.1^{ns}		
Tree 5 Sub-dermal	-3.2^{ns}	2.9^{ns}	15.1ns	13ns	

	Tree 1 Central	Tree 2 Central	Tree 3 Central	Tree 4 Central	Tree 5 Central
Tree 1 Central					
Tree 2 Central	-3.7^{ns}				
Tree 3 Central	-1.9^{ns}	-1.9^{ns}			
Tree 4 Central	-5.2^{ns}	-1.5^{ns}	-3.3^{ns}		
Tree 5 Central	-0.01^{ns}	-3.7^{ns}	-1.9^{ns}	-5.2^{ns}	

	Tree 1	Tree 2	Tree 3	Tree 4	Tree 5
Tree 1					
Tree 2	-2.7^{ns}				
Tree 3	-9.2^{ns}	-6.5^{ns}			
Tree 4	-8.8^{ns}	-6.1^{ns}	0.4^{ns}		
Tree 5	-3.0^{ns}	-0.2^{ns}	6.3^{ns}	5.8^{ns}	

Appendix 8A: Summary of the basic statistics of the green Compression Parallel to the Grain of the 5 *Borassus aethiopum* species

Tree No	Zone	Mean	S.Dev.	Minimum	Maximum	Count	CL(95.0%)
Tree 1	Dermal	54.4	16.2	18.9	80.6	30.0	6.0
	Sub-dermal	22.9	16.4	2.4	47.6	30.0	6.1
	Central	3.4	2.6	0.03	9.1	30.0	1.0
Tree 2	Dermal	55.5	16.2	35.5	91.9	30.0	6.1
	Sub-dermal	28.1	17.5	4.9	61.5	30.0	6.5
	Central	5.4	4.1	0.5	12.6	30.0	1.5
Tree 3	Dermal	50.3	17.4	16.9	81.8	30.0	6.5
	Sub-dermal	20.0	16.3	2.3	51.5	30.0	6.1
	Central	3.6	2.3	0.1	9.2	30.0	0.9
Tree 4	Dermal	40.9	10.9	25.7	64.6	30.0	4.1
	Sub-dermal	22.8	5.7	10.8	32.4	30.0	2.1
	Central	7.9	3.8	1.0	17.8	30.0	1.4
Tree 5	Dermal	40.8	14.1	19.9	67.1	30.0	5.3
	Sub-dermal	29.7	11.4	11.2	48.7	30.0	4.3
	Central	4.2	2.7	1.3	10.7	30.0	1.0
ALL 5 Dermal		48.4	16.2	16.9	91.9	150.0	2.6
ALL 5 Sub-dermal		24.7	14.4	2.3	61.5	150.0	2.3
ALL 5 Central		4.9	3.6	0.03	17.8	150.0	0.6
ALL 5 TREES		26.0	21.8	0.03	91.9	450.0	2.0

S.Dev. = Standard Deviation

CL(95%) = 95% Confidence Level

Appendix 8B: Summary of the ANOVA of the green Compression Parallel to the Grain of the (dermal, sub-dermal, and the central zone) of the Individual trees of the 5 *Borassus aethiopum* wood.

Tree No	Mean (± δ_{n-1})*	ANOVA between Individual Trees		
		Degrees of freedom	F-ratio	F-Critical
Tree 1	26.9±24.9	$F_{(2,87)}$	110.9	3.10
Tree 2	29.7±24.8	$F_{(2,87)}$	96.6	3.10
Tree 3	24.6±23.8	$F_{(2,87)}$	88.2	3.10
Tree 4	23.8±15.4	$F_{(2,87)}$	147.8	3.10
Tree 5	24.9±18.6	$F_{(2,87)}$	94.5	3.10
All 5 Trees	26.0±21.8	$F_{(2,87)}$	1	2.39

Appendix 8C: Analysis of Variance (ANOVA) of the Green Compression Parallel to the grain for the 5 *Borassus aethiopum* Tree species

Tree No	Zone	Degrees of freedom	F	F-Critical
	Dermal	F(5,24)	44.93	2.62
Tree 1	Sub-dermal	F(5,24)	397.50	2.62
	Central	F(5,24)	4.37	2.62
	Dermal	F(5,24)	23.74	2.62
Tree 2	Sub-dermal	F(5,24)	12.37	2.62
	Central	F(5,24)	23.74	2.62
	Dermal	F(5,24)	9.64	2.62
Tree 3	Sub-dermal	F(5,24)	194.14	2.62
	Central	F(5,24)	62.17	2.62
	Dermal	F(5,24)	85.91	2.62
Tree 4	Sub-dermal	F(5,24)	24.64	2.62
	Central	F(5,24)	7.78	2.62
	Dermal	F(5,24)	41.83	2.62
Tree 5	Sub-dermal	F(5,24)	52.63	2.62
	Central	F(5,24)	27.22	2.62
ALL 5 Dermal		F(4,145)	6.70	2.43
ALL 5 Sub-dermal		F(4,145)	2.44	2.43
ALL 5 Central		F(4,145)	9.92	2.43

Appendix 8D: Tukey's Multiple Comparison Test for the green Compression Parallel to the Grain of TREE 1

Height (m)	1.5m	3.2m	4.9m	6.6m	8.3m	10m
Dermal						
1.5						
3.2	6.8^{ns}					
4.9	16.6^{s}	9.8^{ns}				
6.6	22.8^{s}	16.0^{s}	6.2^{ns}			
8.3	29.3^{s}	22.5^{s}	12.7^{s}	6.6^{ns}		
10	46.2^{s}	39.4^{s}	29.6^{s}	23.4^{s}	16.9^{s}	
Sub-dermal						
1.5						
3.2	3.2^{s}					
4.9	22.2^{s}	19.0^{s}				
6.6	29.1^{s}	25.9^{s}	6.9^{s}			
8.3	38.0^{s}	34.8^{s}	15.8^{s}	8.9^{s}		
10	42.0^{s}	38.8^{s}	19.8^{s}	12.9^{s}	4.0^{s}	
Central						
1.5						
3.2	0.5^{ns}					
4.9	1.0^{ns}	0.5^{ns}				
6.6	1.5^{ns}	1.0^{ns}	0.5^{ns}			
8.3	4.1^{s}	3.6^{ns}	3.1^{ns}	2.6^{ns}		
10	4.6^{s}	4.1^{s}	3.6^{ns}	3.1^{ns}	0.5^{ns}	

Appendix 8E: Tukey's Multiple Comparison Test for the green Compression Parallel to the Grain of TREE 2

Height (m)	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	22.4^{s}					
4.9	22.6^{s}	0.2^{ns}				
6.6	33.3^{s}	10.9^{ns}	10.7^{ns}			
8.3	38.8^{s}	16.4^{s}	16.2^{s}	5.5^{ns}		
10	44.9^{s}	22.5^{s}	22.3^{s}	11.6^{ns}	6.1^{ns}	
Sub-dermal						
1.5						
3.2	10.4^{ns}					
4.9	20.5^{s}	10.1^{ns}				
6.6	30.9^{s}	20.5^{s}	10.4^{ns}			
8.3	36.2^{s}	25.8^{s}	15.7^{ns}	5.3^{ns}		
10	41.5^{s}	31.13^{s}	21.0^{s}	10.6^{ns}	5.3^{ns}	
Central						
1.5						
3.2	0.3^{ns}					
4.9	6.1^{s}	5.8^{s}				
6.6	7.3^{s}	7.0^{s}	1.3^{ns}			
8.3	8.1^{s}	7.9^{s}	2.1^{ns}	0.9^{ns}		
10	9.0^{s}	8.7^{s}	2.9^{ns}	1.6^{ns}	0.8^{ns}	

Appendix 8F: Tukey's Multiple Comparison Test for the green Compression Parallel to the Grain of TREE 3

Height (m)	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	10.7 ^{ns}					
4.9	16.1^{ns}	5.4^{ns}				
6.6	20.8^{ns}	10.1^{ns}	4.7^{ns}			
8.3	21.7^{s}	11^{ns}	5.6^{ns}	0.9^{ns}		
10	45.9^{s}	35.2^{s}	29.8^{s}	25.1^{s}	24.2^{s}	
Sub-dermal						
1.5						
3.2	10.5^{s}					
4.9	24.1^{s}	13.6^{s}				
6.6	34.2^{s}	23.7^{s}	10.1^{s}			
8.3	40.9^{s}	30.4^{s}	16.8^{s}	6.7^{s}		
10	43.0^{s}	32.6^{s}	19.0^{s}	8.8^{s}	2.1^{ns}	
Central						
1.5						
3.2	2.2^{s}					
4.9	3.9^{s}	1.7^{s}				
6.6	4.2^{s}	2.0^{s}	0.3^{ns}			
8.3	4.9^{s}	2.7^{s}	1.1^{ns}	0.7^{ns}		
10	7.1^{s}	4.8^{s}	3.2^{s}	2.9^{s}	2.1^{s}	

Appendix 8G: Tukey's Multiple Comparison Test for the green Compression Parallel to the Grain of TREE 4

	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	8.3^{s}					
4.9	16.8^{s}	8.4^{s}				
6.6	22.1^{s}	13.8^{s}	5.4^{ns}			
8.3	27.1^{s}	18.8^{s}	10.4^{s}	5.0^{ns}		
10	29.6^{s}	21.3^{s}	12.8^{s}	7.4^{s}	2.5^{ns}	
Sub-dermal						
1.5						
3.2	3.2^{s}					
4.9	5.3^{s}	2.1^{ns}				
6.6	8.4^{s}	5.2^{s}	3.1^{ns}			
8.3	11.7^{s}	8.5^{s}	6.4^{s}	3.2^{ns}		
10	15.4^{s}	12.2^{s}	10.1^{s}	7.0^{s}	3.7^{ns}	
Central						
1.5						
3.2	4.7^{ns}					
4.9	5.8^{ns}	1.1^{ns}				
6.6	7.3^{s}	2.6^{ns}	1.6^{ns}			
8.3	6.9^{s}	2.2^{ns}	1.1^{ns}	-0.5^{ns}		
10	9.5^{s}	4.8^{ns}	3.7^{ns}	2.1^{ns}	2.6^{ns}	

Appendix 8H: Tukey's Multiple Comparison Test for the green Compression Parallel to the Grain of TREE 5

	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	11.7^{s}					
4.9	22.9^{s}	11.2^{s}				
6.6	25.3^{s}	13.6^{s}	2.5^{ns}			
8.3	34.2^{s}	22.5^{s}	11.3^{s}	8.8^{ns}		
10	38.7^{s}	27.1^{s}	15.9^{s}	13.4^{s}	4.6^{ns}	
Sub-dermal						
1.5						
3.2	5.8^{ns}					
4.9	12.1^{s}	6.2^{ns}				
6.6	19.3^{s}	13.5^{s}	7.2^{s}			
8.3	27.1^{s}	21.3^{s}	15.0^{s}	7.8^{s}		
10	29.6^{s}	23.8^{s}	17.6^{s}	10.3^{s}	2.5^{ns}	
Central						
1.5						
3.2	4.7^{s}					
4.9	4.9^{s}	0.2^{ns}				
6.6	4.9^{s}	0.2^{ns}	0.1^{ns}			
8.3	7.0^{s}	2.3^{s}	2.1^{ns}	2.1^{ns}		
10	7.5^{s}	2.8^{s}	2.6^{s}	2.6^{s}	0.5^{ns}	

Appendix 8I: Tukey's Multiple Comparison Test for the green Compression Parallel to the Grain of All 5 Trees

	Tree 1 Dermal	Tree 2 Dermal	Tree 3 Dermal	Tree 4 Dermal	Tree 5 Dermal
Tree 1 Dermal					
Tree 2 Dermal	-1.1^{ns}				
Tree 3 Dermal	4.0^{ns}	5.1^{ns}			
Tree 4 Dermal	13.5^{s}	14.6^{s}	9.5^{ns}		
Tree 5 Dermal	13.6^{s}	14.7^{s}	9.6^{ns}	0.1^{ns}	
	Tree 1 Sub-dermal	Tree 2Sub-dermal	Tree 3 Sub-dermal	Tree 4 Sub-dermal	Tree 5 Sub-dermal
Tree 1 Sub-dermal					
Tree 2 Sub-dermal	-5.2^{ns}				
Tree 3 Sub-dermal	2.9^{ns}	8.1^{ns}			
Tree 4 Sub-dermal	0.1^{ns}	5.4^{ns}	-2.7^{ns}		
Tree 5 Sub-dermal	-6.8^{ns}	-1.5^{ns}	-9.6^{ns}	-6.9^{ns}	
	Tree 1 Central	Tree 2 Central	Tree 3 Central	Tree 4 Central	Tree 5 Central
Tree 1 Central					
Tree 2 Central	-2.0^{ns}				
Tree 3 Central	-0.2^{ns}	1.8^{ns}			
Tree 4 Central	-4.5^{s}	-2.5^{s}	-4.3^{s}		
Tree 5 Central	-0.7^{ns}	1.3^{ns}	-0.5^{ns}	3.7^{s}	
	Tree 1	Tree 2	Tree 3	Tree 4	Tree 5
Tree 1					
Tree 2	-2.8^{ns}				
Tree 3	2.2^{ns}	5.0^{ns}			
Tree 4	3.1^{ns}	5.8^{ns}	0.8^{ns}		
Tree 5	2.0^{ns}	4.8^{ns}	-0.2^{ns}	-1.0^{ns}	

Appendix 9A: Summary of the basic statistics of the Compression Parallel to the Grain of the 5 *Borassus aethiopum* at 12% MC

Tree No	Zone	Mean	S.Dev.	Minimum	Maximum	Count	CL (95.0%)
	Dermal	68.5	14.8	43.4	90.5	30.0	5.5
Tree 1	Sub-dermal	32.4	20.7	7.6	60.4	30.0	7.7
	Central	6.1	2.7	1.8	9.9	30.0	1.0
	Dermal	70.6	18.0	41.8	99.8	30.0	6.7
Tree 2	Sub-dermal	40.4	16.3	14.5	67.1	30.0	6.1
	Central	7.7	4.1	2.7	14.7	30.0	1.5
	Dermal	68.3	17.0	33.2	94.5	30.0	6.3
Tree 3	Sub-dermal	30.4	20.0	3.2	71.8	30.0	7.5
	Central	6.2	3.7	0.9	14.2	30.0	1.4
	Dermal	56.3	15.8	31.0	85.9	30.0	5.9
Tree 4	Sub-dermal	31.8	11.8	13.7	52.3	30.0	4.4
	Central	12.0	4.4	4.1	18.7	30.0	1.6
	Dermal	51.0	18.6	27.6	86.2	30.0	6.9
Tree 5	Sub-dermal	38.4	11.5	16.7	54.5	30.0	4.3
	Central	6.5	3.9	2.1	14.6	30.0	1.5
ALL 5 Dermal		62.9	18.4	27.6	99.8	150.0	3.0
ALL 5 Sub-dermal		34.7	16.8	3.2	71.8	150.0	2.7
ALL 5 Central		7.7	4.4	0.9	18.7	150.0	0.7
ALL 5 TREES		35.1	26.9	0.9	99.8	450.0	2.5

S.Dev. = Standard Deviation CL(95%) = 95% Confidence Level

Appendix 9B: Summary of the ANOVA of the Compression Parallel to the Grain of the (dermal, sub-dermal, and the central zone) of the Individual trees of the 5 *Borassus aethiopum* wood at 12% MC.

Tree No	Mean (± δ_{n-1}) *	ANOVA between Individual Trees		
		Degrees of freedom	F-ratio	F-Critical
Tree 1	35.6±29.6	$F_{(2,87)}$	135	3.10
Tree 2	39.6±29.4	$F_{(2,87)}$	147.3	3.10
Tree 3	35.0±29.8	$F_{(2,87)}$	125.8	3.10
Tree 4	33.4±21.6	$F_{(2,87)}$	108.7	3.10
Tree 5	31.2±22.8	$F_{(2,87)}$	95.8	3.10
All 5 Trees	35.1±26.9	$F_{(4,445)}$	1	2.39

Appendix 9C: Analysis of Variance (ANOVA) of the Compression Parallel to the grain for the 5 *Borassus aethiopum* Tree species at 12% MC

Tree No	Zone	Degrees of freedom	F	F-Critical
	Dermal	F(5,24)	535.89	2.62
Tree 1	Sub-dermal	F(5,24)	3634.45	2.62
	Central	F(5,24)	209.29	2.62
	Dermal	F(5,24)	407.10	2.62
Tree 2	Sub-dermal	F(5,24)	187.34	2.62
	Central	F(5,24)	280.94	2.62
	Dermal	F(5,24)	271.95	2.62
Tree 3	Sub-dermal	F(5,24)	119.56	2.62
	Central	F(5,24)	37.67	2.62
	Dermal	F(5,24)	54.26	2.62
Tree 4	Sub-dermal	F(5,24)	33.14	2.62
	Central	F(5,24)	60.78	2.62
	Dermal	F(5,24)	66.70	2.62
Tree 5	Sub-dermal	F(5,24)	164.80	2.62
	Central	F(5,24)	134.70	2.62
ALL 5 Dermal		F(4,145)	8.05	2.43
ALL 5 Sub-dermal		F(4,145)	2.15	2.43
ALL 5 Central		F(4,145)	12.96	2.43

Appendix 9D: Tukey's Multiple Comparison Test for the Compression Parallel to the Grain of TREE 1 at 12% MC

Height (m)	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	11.6^{s}					
4.9	16.2^{s}	4.7^{s}				
6.6	21.8^{s}	10.2^{s}	5.6^{s}			
8.3	34.2^{s}	22.6^{s}	18^{s}	12.4^{s}		
10	44.2^{s}	32.7^{s}	28^{s}	22.5^{s}	10.1^{s}	
Sub-dermal						
1.5						
3.2	1.1^{ns}					
4.9	30.4^{s}	29.3^{s}				
6.6	36.8^{s}	35.7^{s}	6.4^{s}			
8.3	45.8^{s}	44.7^{s}	15.4^{s}	9.0^{s}		
10	51.8^{s}	50.7^{s}	21.4^{s}	15.0^{s}	6.0^{s}	
Central						
1.5						
3.2	1.2^{s}					
4.9	1.9^{s}	0.7^{ns}				
6.6	4.0^{s}	2.8^{s}	2.1^{s}			
8.3	5.9^{s}	4.7^{s}	4.0^{s}	2.0^{s}		
10	7.4^{s}	6.2^{s}	5.5^{s}	3.5^{s}	1.5^{s}	

Appendix 9E: Tukey's Multiple Comparison Test for the Compression Parallel to the Grain of TREE 2 at 12% MC

Height (m)	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	16.8^{s}					
4.9	23.3^{s}	6.4^{s}				
6.6	30.5^{s}	13.7^{s}	7.2^{s}			
8.3	41.0^{s}	24.2^{s}	17.8^{s}	10.5^{s}		
10	55.3^{s}	38.4^{s}	32.0^{s}	24.8^{s}	14.2^{s}	
Sub-dermal						
1.5						
3.2	11.3^{s}					
4.9	19.0^{s}	7.8^{s}				
6.6	31.8^{s}	20.5^{s}	12.7^{s}			
8.3	38.9^{s}	27.6^{s}	19.8^{s}	7.1^{s}		
10	45.5^{s}	34.2^{s}	26.4^{s}	13.7^{s}	6.6^{s}	
Central						
1.5						
3.2	1.2^{s}					
4.9	6.4^{s}	5.2^{s}				
6.6	8.3^{s}	7.1^{s}	1.9^{s}			
8.3	9.0^{s}	7.8^{s}	2.6^{s}	0.7^{ns}		
10	10.6^{s}	9.4^{s}	4.3^{s}	2.3^{s}	1.6^{s}	

Appendix 9F: Tukey's Multiple Comparison Test for the Compression Parallel to the Grain of TREE 3 at 12% MC

Height (m)	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	13^{s}					
4.9	23.4^{s}	10.4^{s}				
6.6	29.2^{s}	16.2^{s}	5.8^{s}			
8.3	30.4^{s}	17.4^{s}	7.0^{s}	1.2^{s}		
10	53.8^{s}	40.8^{s}	30.4^{s}	24.6^{s}	23.4^{s}	
Sub-dermal						
1.5						
3.2	14.7^{s}					
4.9	33.5^{s}	18.9^{s}				
6.6	37.7^{s}	23.0^{s}	4.1^{ns}			
8.3	47.7^{s}	33.0^{s}	14.1^{s}	10.0^{s}		
10	56.9^{s}	42.2^{s}	23.3^{s}	19.2^{s}	9.2^{s}	
Central						
1.5						
3.2	2.6^{ns}					
4.9	3.8^{s}	1.2^{ns}				
6.6	6.5^{s}	3.8^{s}	2.7^{ns}			
8.3	8.2^{s}	5.6^{s}	4.4^{s}	1.7^{s}		
10	10.2^{s}	7.6^{s}	6.4^{s}	3.7^{s}	2.0^{ns}	

Appendix 9G: Tukey's Multiple Comparison Test for the Compression Parallel to the Grain of TREE 4 at 12% MC

Height (m)	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	14.8^{s}					
4.9	18.2^{s}	3.4^{ns}				
6.6	29.9^{s}	15.1^{s}	11.7^{s}			
8.3	33.9^{s}	19.1^{s}	15.7^{s}	4.0^{ns}		
10	46.3^{s}	31.4^{s}	28.0^{s}	16.3^{s}	12.3^{s}	
Sub-dermal						
1.5						
3.2	5.2^{s}					
4.9	8.3^{s}	3.1^{ns}				
6.6	8.5^{s}	3.3^{ns}	0.2^{ns}			
8.3	14.4^{s}	9.2^{s}	6.1^{s}	5.9^{s}		
10	15.4^{s}	10.2^{s}	7.1^{s}	6.9^{s}	1.0^{ns}	
Central						
1.5						
3.2	3.1^{s}					
4.9	5.8^{s}	2.7^{s}				
6.6	6.1^{s}	3.0^{s}	0.3^{ns}			
8.3	8.4^{s}	5.4^{s}	2.7^{s}	2.4^{ns}		
10	13.2^{s}	10.2^{s}	7.4^{s}	7.2^{s}	4.8^{s}	

Appendix 9H: Tukey's Multiple Comparison Test for the Compression Parallel to the Grain of TREE 5 at 12% MC

Height (m)	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	17.3^{s}					
4.9	31.4^{s}	14.1^{s}				
6.6	38.8^{s}	21.5^{s}	7.3^{ns}			
8.3	46.3^{s}	29.0^{s}	14.9^{s}	7.5^{ns}		
10	51.5^{s}	34.2^{s}	20.1^{s}	12.7^{s}	5.3^{s}	
Sub-dermal						
1.5						
3.2	5.3^{s}					
4.9	11.3^{s}	6.0^{s}				
6.6	16.2^{s}	10.9^{s}	4.9^{s}			
8.3	24.0^{s}	18.7^{s}	12.7^{s}	7.8^{s}		
10	33.3^{s}	28.0^{s}	22.0^{s}	17.1^{s}	9.3^{s}	
Central						
1.5						
3.2	4.1^{s}					
4.9	7.2^{s}	3.0^{s}				
6.6	7.6^{s}	3.5^{s}	0.4^{ns}			
8.3	10.4^{s}	6.3^{s}	3.2^{s}	2.8^{s}		
10	11.1^{s}	6.9^{s}	3.9^{s}	3.5^{s}	0.6^{ns}	

Appendix 9I: Tukey's Multiple Comparison Test for the Compression Parallel to the Grain of All 5 TREES at 12% MC

	Tree 1 Dermal	Tree 2 Dermal	Tree 3 Dermal	Tree 4 Dermal	Tree 5 Dermal
Tree 1 Dermal					
Tree 2 Dermal	-2.1^{ns}				
Tree 3 Dermal	0.1^{ns}	2.3^{ns}			
Tree 4 Dermal	12.2^{s}	14.3^{s}	12^{ns}		
Tree 5 Dermal	17.5^{s}	19.6^{s}	17.4^{s}	5.4^{ns}	
	Tree 1 Sub-dermal	**Tree 2Sub-dermal**	**Tree 3 Sub-dermal**	**Tree 4 Sub-dermal**	**Tree 5Sub-dermal**
Tree 1 Sub-dermal					
Tree 2 Sub-dermal	-8.1^{ns}				
Tree 3 Sub-dermal	1.9^{ns}	10.0^{ns}			
Tree 4 Sub-dermal	0.5^{ns}	8.6^{ns}	-1.4^{ns}		
Tree 5 Sub-dermal	-6^{ns}	2.0^{ns}	-8^{ns}	-6.6^{ns}	
	Tree 1 Central	**Tree 2 Central**	**Tree 3 Central**	**Tree 4 Central**	**Tree 5 Central**
Tree 1 Central					
Tree 2 Central	-1.6^{ns}				
Tree 3 Central	-0.1^{ns}	1.5^{ns}			
Tree 4 Central	-6^{s}	-4.3^{s}	-5.8^{s}		
Tree 5 Central	-0.5^{ns}	1.1^{ns}	-0.3^{ns}	5.5^{s}	
	Tree 1	**Tree 2**	**Tree 3**	**Tree 4**	**Tree 5**
Tree 1					
Tree 2	-3.9^{ns}				
Tree 3	0.6^{ns}	4.6^{ns}			
Tree 4	2.2^{ns}	6.2^{ns}	1.6^{ns}		
Tree 5	3.7^{ns}	7.6^{ns}	3.0^{ns}	1.4^{ns}	

Appendix 10A: Summary of the basic statistics of the green Shear Parallel to the Grain of the 5 *Borassus aethiopum* species

Tree No	Zone	Mean	S.Dev.	Minimum	Maximum	Count	CL (95.0%)
	Dermal	7.38	2.71	2.84	12.54	30.00	1.01
Tree 1	Sub-dermal	3.63	2.22	0.43	7.92	30.00	0.83
	Central	0.56	0.30	0.14	1.14	30.00	0.11
	Dermal	8.75	2.67	2.61	13.50	30.00	1.00
Tree 2	Sub-dermal	5.47	2.31	1.25	10.13	30.00	0.86
	Central	1.08	0.54	0.34	2.37	30.00	0.20
	Dermal	8.67	2.13	4.71	12.41	30.00	0.79
Tree 3	Sub-dermal	7.01	2.27	3.49	10.40	30.00	0.85
	Central	0.65	0.63	0.09	2.03	30.00	0.42
	Dermal	8.85	2.23	4.82	13.66	30.00	0.83
Tree 4	Sub-dermal	5.19	2.36	1.46	8.98	30.00	0.88
	Central	2.19	1.14	0.80	5.17	30.00	0.24
	Dermal	9.01	2.81	3.81	13.74	30.00	1.05
Tree 5	Sub-dermal	5.51	2.75	1.04	10.29	30.00	1.03
	Central	1.30	0.96	0.40	3.23	30.00	0.36
ALL 5 Dermal		8.53	2.56	2.61	13.74	150.00	0.41
ALL 5 Sub-dermal		5.36	2.59	0.43	10.40	150.00	0.42
ALL 5 Central		1.15	0.96	0.09	5.17	150.00	0.16
ALL 5 TREES		5.02	3.72	0.09	13.74	450.00	0.34

S.Dev. = Standard Deviation CL(95%) = 95% Confidence Level

Appendix 10B: Summary of the ANOVA of the green Shear Parallel to the Grain of the (dermal, sub-dermal, and the central zone) of the Individual trees of the 5 *Borassus aethiopum* wood.

Tree No	Mean ($\pm \delta_{n-1}$)*	ANOVA between Individual Trees		
		Degrees of freedom	F-ratio	F-Critical
Tree 1	3.9±3.4	$F_{(2,87)}$	85.4	3.10
Tree 2	5.1±3.8	$F_{(2,87)}$	104.5	3.10
Tree 3	5.4±3.9	$F_{(2,87)}$	160.5	3.10
Tree 4	5.4±3.8	$F_{(2,87)}$	84.7	3.10
Tree 5	5.3±3.9	$F_{(2,87)}$	81.7	3.10
All 5 Trees	5.0±3.7	$F_{(4,445)}$	2.9	2.39

Appendix 10C: Analysis of Variance (ANOVA) of the Green Shear Parallel to the grain for the 5 *Borassus aethiopum* Tree species

Tree No	Zone	Degrees of freedom	F	F-Critical
Tree 1	Dermal	F(5,24)	36.07	2.62
	Sub-dermal	F(5,24)	91.73	2.62
	Central	F(5,24)	48.81	2.62
Tree 2	Dermal	F(5,24)	21.15	2.62
	Sub-dermal	F(5,24)	61.19	2.62
	Central	F(5,24)	19.56	2.62
Tree 3	Dermal	F(5,24)	72.19	2.62
	Sub-dermal	F(5,24)	26.42	2.62
	Central	F(5,24)	46.01	2.62
Tree 4	Dermal	F(5,24)	29.85	2.62
	Sub-dermal	F(5,24)	120.22	2.62
	Central	F(5,24)	18.91	2.62
Tree 5	Dermal	F(5,24)	44.52	2.62
	Sub-dermal	F(5,24)	39.61	2.62
	Central	F(5,24)	147.35	2.62
ALL 5 Dermal		F(4,145)	2.02	2.43
ALL 5 Sub-dermal		F(4,145)	7.59	2.43
ALL 5 Central		F(4,145)	21.52	2.43

Appendix 10D: Tukey's Multiple Comparison Test for the green Shear Parallel to the Grain of TREE 1 zone

Height (m)	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	2.6^{s}					
4.9	4.7^{s}	2.1^{s}				
6.6	5.7^{s}	3.1^{s}	1.0^{ns}			
8.3	6.9^{s}	4.3^{s}	2.2^{s}	1.2^{ns}		
10	7.0^{s}	4.4^{s}	2.3^{s}	1.3^{ns}	0.1^{ns}	
Sub-dermal						
1.5						
3.2	0.9^{ns}					
4.9	2.6^{s}	1.6^{s}				
6.6	3.4^{s}	2.5^{s}	0.8^{ns}			
8.3	5.1^{s}	4.1^{s}	2.5^{s}	1.7^{s}		
10	6.0^{s}	5.1^{s}	3.5^{s}	2.6^{s}	0.9^{ns}	
Central						
1.5						
3.2	0.2^{s}					
4.9	0.4^{s}	0.2^{ns}				
6.6	0.6^{s}	0.4^{s}	0.2^{ns}			
8.3	0.7^{s}	0.5^{s}	0.3^{s}	0.1^{ns}		
10	0.8^{s}	0.6^{s}	0.4^{s}	0.2^{s}	0.1^{ns}	

Appendix 10E: Tukey's Multiple Comparison Test for the green Shear Parallel to the Grain of TREE 2

Height (m)	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	2.3^{ns}					
4.9	3.5^{s}	1.2^{ns}				
6.6	4.3^{s}	2.0^{ns}	0.8^{ns}			
8.3	5.1^{s}	2.8^{s}	1.6^{ns}	0.7^{ns}		
10	7.6^{s}	5.4^{s}	4.2^{s}	3.4^{s}	2.6^{s}	
Sub-dermal						
1.5						
3.2	1.5^{ns}					
4.9	3.0^{s}	1.5^{s}				
6.6	4.1^{s}	2.5^{s}	1.1^{ns}			
8.3	4.7^{s}	3.3^{s}	1.7^{s}	0.7^{ns}		
10	6.7^{s}	5.3^{s}	3.7^{s}	2.7^{s}	2.0^{s}	
Central						
1.5						
3.2	0.4^{ns}					
4.9	0.7^{s}	0.3^{ns}				
6.6	1.0^{s}	0.6^{s}	0.3^{ns}			
8.3	1.1^{s}	0.7^{s}	0.4^{ns}	0.1^{ns}		
10	1.5^{s}	1.1^{s}	0.7^{s}	0.5^{ns}	0.4^{ns}	

Appendix 10F: Tukey's Multiple Comparison Test for the green Shear Parallel to the Grain of TREE 3

Height (m)	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	1.5^{s}					
4.9	2.6^{s}	1.2^{s}				
6.6	3.1^{s}	1.7^{s}	0.5^{ns}			
8.3	5.0^{s}	3.5^{s}	2.3^{s}	1.8^{s}		
10	6.0^{s}	4.6^{s}	3.4^{s}	2.9^{s}	1.1^{ns}	
Sub-dermal						
1.5						
3.2	1.2^{s}					
4.9	2.8^{s}	1.6^{ns}				
6.6	3.2^{s}	2.0^{s}	0.4^{ns}			
8.3	4.8^{s}	3.6^{s}	1.9^{s}	1.5^{ns}		
10	6.1^{s}	4.9^{s}	3.3^{s}	2.9^{s}	1.4^{ns}	
Central						
1.5						
3.2	0.2^{ns}					
4.9	1.1^{s}	0.9^{s}				
6.6	1.3^{s}	1.1^{s}	0.2^{ns}			
8.3	1.4^{s}	1.2^{s}	0.3^{ns}	0.1^{ns}		
10	1.5^{s}	1.3^{s}	0.4^{ns}	0.1^{ns}	0.1^{ns}	

Appendix 10G: Tukey's Multiple Comparison Test for the green Shear Parallel to the Grain of TREE 4

Height (m)	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	1.9^{s}					
4.9	2.8^{s}	0.9^{ns}				
6.6	4.0^{s}	2.1^{s}	1.2^{ns}			
8.3	4.4^{s}	2.5^{s}	1.6^{ns}	0.4^{ns}		
10	6.4^{s}	4.6^{s}	3.6^{s}	2.5^{s}	2.1^{s}	
Sub-dermal						
1.5						
3.2	1.0^{s}					
4.9	2.4^{s}	1.4^{s}				
6.6	4.5^{s}	3.5^{s}	2.1^{s}			
8.3	5.1^{s}	4.1^{s}	2.8^{s}	0.6^{ns}		
10	6.4^{s}	5.4s	4.0^{s}	1.9^{s}	1.3^{s}	
Central						
1.5						
3.2	2.3^{s}					
4.9	2.5^{s}	0.2^{ns}				
6.6	2.5^{s}	0.2^{ns}	0^{ns}			
8.3	2.7^{s}	0.5^{ns}	0.3^{ns}	0.3^{ns}		
10	3.0^{s}	0.7^{ns}	0.6^{ns}	0.5^{ns}	0.3^{ns}	

Appendix 10H: Tukey's Multiple Comparison Test for the green Shear Parallel to the Grain of TREE 5

Height (m)	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	2.2^{s}					
4.9	3.2^{s}	0.9^{ns}				
6.6	4.0^{s}	1.8^{ns}	0.9^{ns}			
8.3	6.4^{s}	4.1^{s}	3.2^{s}	2.3^{s}		
10	8.0^{s}	5.8^{s}	4.8^{s}	4.0^{s}	1.7^{ns}	
Sub-dermal						
1.5						
3.2	1.3^{ns}					
4.9	3.5^{s}	2.2^{s}				
6.6	3.7^{s}	2.4^{s}	0.2^{s}			
8.3	6.6^{s}	5.3^{s}	3.1^{s}	2.9^{s}		
10	7.0^{s}	5.7^{ns}	3.5^{s}	3.3^{s}	0.4^{ns}	
Central						
1.5						
3.2	0.9^{s}					
4.9	2.0^{s}	1.1^{s}				
6.6	2.4^{s}	1.5^{s}	0.4^{ns}			
8.3	2.4^{s}	1.5^{s}	0.4^{s}	0^{ns}		
10	$2.^{5s}$	1.6^{s}	0.5^{s}	0.1^{ns}	0.1^{ns}	

Appendix 10I: Tukey's Multiple Comparison Test for the green Shear Parallel to the Grain of All 5 TREES

	Tree 1 Dermal	Tree 2 Dermal	Tree 3 Dermal	Tree 4 Dermal	Tree 5 Dermal
Tree 1 Dermal					
Tree 2 Dermal	-1.4^{ns}				
Tree 3 Dermal	-1.3^{ns}	0.1^{ns}			
Tree 4 Dermal	-1.5^{ns}	-0.1^{ns}	-0.2^{ns}		
Tree 5 Dermal	-1.6^{ns}	-0.3^{ns}	-0.3^{ns}	-0.2^{ns}	
	Tree 1 Sub-dermal	**Tree 2Sub-dermal**	**Tree 3 Sub-dermal**	**Tree 4 Sub-dermal**	**Tree 5 Sub-dermal**
Tree 1 Sub-dermal					
Tree 2 Sub-dermal	-1.8^{s}				
Tree 3 Sub-dermal	-3.4^{s}	-1.5^{ns}			
Tree 4 Sub-dermal	-1.6^{ns}	0.3^{ns}	1.8^{s}		
Tree 5 Sub-dermal	-1.9^{s}	-0.1^{ns}	1.5^{ns}	-0.3^{ns}	
	Tree 1 Central	**Tree 2 Central**	**Tree 3 Central**	**Tree 4 Central**	**Tree 5 Central**
Tree 1 Central					
Tree 2 Central	-0.5^{ns}				
Tree 3 Central	-0.1^{ns}	0.4^{ns}			
Tree 4 Central	-1.6^{s}	-1.1^{s}	-1.5^{s}		
Tree 5 Central	0.7^{s}	-0.2^{ns}	-0.7^{s}	0.9^{s}	
	Tree 1	**Tree 2**	**Tree 3**	**Tree 4**	**Tree 5**
Tree 1					
Tree 2	-1.2^{ns}				
Tree 3	-1.6^{s}	-0.3^{ns}			
Tree 4	-1.6^{s}	-0.3^{ns}	0.2^{ns}		
Tree 5	-1.4^{ns}	-0.2^{ns}	0.2^{ns}	0.1^{ns}	

Appendix 11A: Summary of the basic statistics of the Shear Parallel to the Grain of the 5 *Borassus aethiopum* at 12% MC.

Tree No		Mean	S.Dev.	Minimum	Maximum	Count	CL(95.0%)
Tree 1	Dermal	12.22	3.87	7.06	19.47	30.00	1.44
	Sub-dermal	6.83	3.00	1.38	10.90	30.00	1.12
	Central	0.82	0.41	0.30	1.65	30.00	0.15
Tree 2	Dermal	11.60	4.00	5.47	19.75	30.00	1.49
	Sub-dermal	7.67	2.54	3.51	12.11	30.00	0.95
	Central	1.97	1.06	0.41	4.00	30.00	0.39
Tree 3	Dermal	11.46	2.78	7.83	17.46	30.00	1.04
	Sub-dermal	9.23	2.82	4.96	14.13	30.00	1.05
	Central	1.08	0.94	0.20	2.91	30.00	0.35
Tree 4	Dermal	11.42	2.88	6.41	17.18	30.00	1.07
	Sub-dermal	6.85	3.02	2.36	11.71	30.00	1.13
	Central	2.93	1.41	1.77	6.23	30.00	0.52
Tree 5	Dermal	11.48	3.74	5.82	17.99	30.00	1.40
	Sub-dermal	8.11	3.35	3.83	13.88	30.00	1.25
	Central	2.18	1.18	1.03	5.12	30.00	0.44
ALL 5 Dermal		11.64	3.46	5.47	19.75	150.00	0.56
ALL 5 Sub-dermal		7.74	3.05	1.38	14.13	150.00	0.49
ALL 5 Central		1.80	1.29	0.20	6.23	150.00	0.21
ALL 5 TREES		7.06	4.90	0.20	19.75	450.00	0.45

Appendix 11B: Summary of the ANOVA of the Shear Parallel to the Grain of the (dermal, sub-dermal, and the central zone) of the Individual trees of the 5 *Borassus aethiopum* wood at 12% MC.

Tree No	Mean (± δ_{n-1})*	ANOVA between Individual Trees		
		Degrees of freedom	F-ratio	F-Critical
Tree 1	6.6±5.5	F(2,87)	121.321	3.10
Tree 2	7.1±4.8	F(2,87)	89.62	3.10
Tree 3	7.3±5.0	F(2,87)	162.628	3.10
Tree 4	7.1±4.3	F(2,87)	83.9293	3.10
Tree 5	7.3±4.9	F(2,87)	74.9534	3.10
All 5 Trees	7.1±4.9	F(4,445)	0.2	2.39

Appendix 11C: Analysis of Variance (ANOVA) of the Shear Parallel to the grain for the 5 *Borassus aethiopum* Tree species at 12% MC

Tree No	Zone	Degrees of freedom	F	F-Critical
	Dermal	F(5,24)	135.35	2.62
Tree 1	Sub-dermal	F(5,24)	90.49	2.62
	Central	F(5,24)	79.74	2.62
	Dermal	F(5,24)	160.85	2.62
Tree 2	Sub-dermal	F(5,24)	99.77	2.62
	Central	F(5,24)	72.01	2.62
	Dermal	F(5,24)	120.79	2.62
Tree 3	Sub-dermal	F(5,24)	23.97	2.62
	Central	F(5,24)	113.55	2.62
	Dermal	F(5,24)	78.30	2.62
Tree 4	Sub-dermal	F(5,24)	110.57	2.62
	Central	F(5,24)	503.73	2.62
	Dermal	F(5,24)	287.96	2.62
Tree 5	Sub-dermal	F(5,24)	73.26	2.62
	Central	F(5,24)	52.00	2.62
ALL 5 Dermal		F(4,145)	0.28	2.43
ALL 5 Sub-dermal		F(4,145)	3.42	2.43
ALL 5 Central		F(4,145)	19.82	2.43

Appendix 11D: Tukey's Multiple Comparison Test for the Shear Parallel to the Grain of TREE 1 at 12% MC

Height (m)	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	2.5^{s}					
4.9	6.3^{s}	3.7^{s}				
6.6	7.8^{s}	5.3^{s}	1.6^{ns}			
8.3	9.5^{s}	6.9^{s}	3.2^{s}	1.6^{ns}		
10	10.4^{s}	7.9^{s}	4.2^{s}	2.6^{s}	0.9^{ns}	
Sub-dermal						
1.5						
3.2	1.0^{ns}					
4.9	2.4^{s}	1.4^{ns}				
6.6	4.0^{s}	3.0^{s}	1.6^{s}			
8.3	6.3^{s}	5.3^{s}	3.9^{s}	2.3^{s}		
10	8.2^{s}	7.2^{s}	5.8^{s}	4.2^{s}	1.9^{s}	
Central						
1.5						
3.2	0.4^{s}					
4.9	0.6^{s}	0.2^{s}				
6.6	0.9^{s}	0.5^{s}	0.3^{s}			
8.3	1.0^{s}	0.6^{s}	0.4^{s}	0.1^{ns}		
10	1.1^{s}	0.7^{s}	0.5^{s}	0.3^{s}	0.1^{ns}	

Appendix 11E: Tukey's Multiple Comparison Test for the Shear Parallel to the Grain of TREE 2 at 12% MC

Height (m)	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	4.2^{s}					
4.9	5.9^{s}	1.7^{s}				
6.6	7.3^{s}	3.1^{s}	1.4^{ns}			
8.3	10.1^{s}	5.9^{s}	4.2^{s}	2.8^{s}		
10	11.8^{s}	7.6^{s}	5.9^{s}	4.6^{s}	1.7^{s}	
Sub-dermal						
1.5						
3.2	1.9^{s}					
4.9	2.6^{s}	0.7^{ns}				
6.6	4.4^{s}	2.5^{s}	1.8^{s}			
8.3	5.8^{s}	3.9^{s}	3.3^{s}	1.5^{s}		
10	7.2^{s}	5.3^{s}	4.7^{s}	2.9^{s}	1.4^{s}	
Central						
1.5						
3.2	1.2^{s}					
4.9	1.7^{s}	0.5^{ns}				
6.6	2.0^{s}	0.8^{s}	0.3^{ns}			
8.3	2.6^{s}	1.4^{s}	0.9^{s}	0.5^{s}		
10	3.1^{s}	1.9^{s}	1.4^{s}	1.1^{s}	0.6^{ns}	

Appendix 11F: Tukey's Multiple Comparison Test for the Shear Parallel to the Grain of TREE 3 at 12% MC

Height (m)	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	3.5^{s}					
4.9	5.3^{s}	1.8^{s}				
6.6	5.9^{s}	2.4^{s}	0.6^{ns}			
8.3	7.3^{s}	3.8^{s}	2^{s}	1.4^{s}		
10	8.1^{s}	4.7^{s}	2.9^{s}	2.3^{s}	0.9^{ns}	
Sub-dermal						
1.5						
3.2	1.4^{ns}					
4.9	3.0^{s}	1.6^{ns}				
6.6	4.0^{s}	2.5^{s}	0.9^{ns}			
8.3	6.0^{s}	4.6^{s}	3.0^{s}	2.1^{ns}		
10	7.4^{s}	6.0^{s}	4.4^{s}	3.4^{s}	1.4^{ns}	
Central						
1.5						
3.2	0.6^{s}					
4.9	1.9^{s}	1.2^{s}				
6.6	2.1^{s}	1.5^{s}	0.2^{ns}			
8.3	2.3^{s}	1.7^{s}	0.4^{s}	0.2^{ns}		
10	2.4^{s}	1.8^{s}	0.5^{s}	0.3^{ns}	0.1^{ns}	

Appendix 11G: Tukey's Multiple Comparison Test for the Shear Parallel to the Grain of TREE 4 at 12% MC

Height (m)	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	3.1^{s}					
4.9	4.4^{s}	1.2^{ns}				
6.6	5.6^{s}	2.5^{s}	1.3^{s}			
8.3	6.7^{s}	3.6^{s}	2.4^{s}	1.1^{ns}		
10	8.6^{s}	5.5^{s}	4.3^{s}	3.0^{s}	1.9^{s}	
Sub-dermal						
1.5						
3.2	1.4^{s}					
4.9	4.0^{s}	2.6^{s}				
6.6	6.1^{s}	4.7^{s}	2.1^{s}			
8.3	6.8^{s}	5.4^{s}	2.8^{s}	0.7^{ns}		
10	8.1^{s}	6.6^{s}	4.1^{s}	2.0^{s}	1.2^{ns}	
Central						
1.5						
3.2	3.0^{s}					
4.9	3.2^{s}	0.2^{ns}				
6.6	3.6^{s}	0.6^{s}	0.3^{s}			
8.3	3.9^{s}	0.9^{s}	0.7^{s}	0.3^{s}		
10	4.1^{s}	1.1^{s}	0.8^{s}	0.5^{s}	0.1^{ns}	

Appendix 11H: Tukey's Multiple Comparison Test for the Shear Parallel to the Grain of TREE 5 at 12% MC

	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	3.9^{s}					
4.9	5.4^{s}	1.5^{s}				
6.6	7.1^{s}	3.1^{s}	1.6^{s}			
8.3	9.4^{s}	5.5^{s}	4.0^{s}	2.4^{s}		
10	11.2^{s}	7.2^{s}	5.7^{s}	4.1^{s}	1.7^{s}	
Sub-dermal						
1.5						
3.2	2.5^{s}					
4.9	5.3^{s}	2.7^{s}				
6.6	6.0^{s}	3.4^{s}	0.7^{ns}			
8.3	8.6^{s}	6.0^{s}	3.3^{s}	2.6^{s}		
10	9.1^{s}	6.5^{s}	3.8^{s}	3.1^{s}	0.5^{ns}	
Central						
1.5						
3.2	1.4^{s}					
4.9	2.3^{s}	0.9^{s}				
6.6	2.8^{s}	1.4^{s}	0.5^{ns}			
8.3	3.0^{s}	1.6^{s}	0.7^{ns}	0.2^{ns}		
10	3.1^{s}	1.7^{s}	0.8^{s}	0.3^{ns}	0.1^{ns}	

Appendix 11I: Tukey's Multiple Comparison Test for the Shear Parallel to the Grain of All 5 TREES at 12% MC

	Tree 1 Dermal	Tree 2 Dermal	Tree 3 Dermal	Tree 4 Dermal	Tree 5 Dermal
Tree 1 Dermal					
Tree 2 Dermal	0.6^{ns}				
Tree 3 Dermal	0.8^{ns}	0.1^{ns}			
Tree 4 Dermal	0.8^{ns}	0.2^{ns}	0.03^{ns}		
Tree 5 Dermal	0.7^{ns}	0.1^{ns}	0.02^{ns}	0.1^{ns}	
	Tree 1 Sub-dermal	Tree 2Sub-dermal	Tree 3 Sub-dermal	Tree 4 Sub-dermal	Tree 5 Sub-dermal
Tree 1 Sub-dermal					
Tree 2 Sub-dermal	0.8^{ns}				
Tree 3 Sub-dermal	2.4^{s}	1.6^{ns}			
Tree 4 Sub-dermal	0.02^{ns}	0.8^{ns}	2.4^{s}		
Tree 5 Sub-dermal	1.3^{ns}	0.4^{ns}	1.1^{ns}	1.3^{ns}	
	Tree 1 Central	Tree 2 Central	Tree 3 Central	Tree 4 Central	Tree 5 Central
Tree 1 Central					
Tree 2 Central	1.1^{s}				
Tree 3 Central	0.3^{ns}	0.9^{s}			
Tree 4 Central	2.1^{s}	1.0^{s}	1.8^{s}		
Tree 5 Central	1.4^{s}	0.2^{ns}	1.1^{s}	0.7^{ns}	
	Tree 1	Tree 2	Tree 3	Tree 4	Tree 5
Tree 1					
Tree 2	-0.5^{ns}				
Tree 3	-0.6^{ns}	-0.2^{ns}			
Tree 4	-0.4^{ns}	0.0^{ns}	0.2^{ns}		
Tree 5	-0.6^{ns}	-0.2^{ns}	0.0^{ns}	-0.2^{ns}	

Appendix 12A: Summary of the basic statistics of the green Hardness of the 5 *Borassus aethiopum* species

Tree No		Mean	S.Dev.	Minimum	Maximum	Count	CL(95.0%)
	Dermal	7.88	0.48	5.17	11.57	18.00	1.01
Tree 1	Sub-dermal	3.34	1.97	0.66	6.61	18.00	0.98
	Central	0.36	0.23	0.12	0.83	18.00	0.11
	Dermal	8.00	0.67	2.74	11.91	18.00	1.41
Tree 2	Sub-dermal	5.09	3.22	0.92	10.12	18.00	1.60
	Central	0.67	0.32	0.31	1.42	18.00	0.16
	Dermal	6.53	0.58	3.53	10.08	18.00	1.22
Tree 3	Sub-dermal	5.35	2.22	1.97	8.06	18.00	1.11
	Central	0.41	0.45	0.04	1.26	18.00	0.22
	Dermal	6.03	0.38	2.86	8.82	18.00	0.80
Tree 4	Sub-dermal	4.29	2.32	1.19	8.01	18.00	1.15
	Central	0.73	0.45	0.14	1.66		0.22
	Dermal	7.72	0.66	3.41	12.23	18.00	1.39
Tree 5	Sub-dermal	4.23	1.66	0.94	6.55	18.00	0.83
	Central	0.66	0.42	0.16	1.44	18.00	0.21
ALL 5 Dermal		7.23	2.47	2.74	12.23	90.00	0.52
ALL 5 Sub-dermal		4.46	2.39	0.66	10.12	90.00	0.50
ALL 5 Central		0.57	0.40	0.04	1.66	90.00	0.08
ALL 5 TREES		4.09	3.39	0.04	12.23	270.00	0.41

S.Dev. = Standard Deviation CL(95%) = 95% Confidence Level

Appendix 12B: Summary of the ANOVA of the green Hardness of the (dermal, sub-dermal, and the central zone) of the Individual trees of the 5 *Borassus aethiopum* wood.

Tree No	Mean ($\pm \delta_{n-1}$)*	ANOVA between Individual Trees		
		Degrees of freedom	F-ratio	F-Critical
Tree 1	3.9±3.5	$F_{(2,51)}$	96.432	3.18
Tree 2	4.6±3.9	$F_{(2,51)}$	39.76	3.18
Tree 3	4.1±3.3	$F_{(2,51)}$	51.14	3.18
Tree 4	3.7±2.8	$F_{(2,51)}$	48.35	3.18
Tree 5	4.2±3.5	$F_{(2,51)}$	62.66	3.18
All 5 Trees	4.1±3.4	$F_{(4,265)}$	0.56	2.41

Appendix 12C: Analysis of Variance (ANOVA) of the Green Hardness for the 5 *Borassus aethiopum* Tree species

Tree No	Zone	Degrees of freedom	F	F-Critical
	Dermal	F(5,24)	276.78	2.62
Tree 1	Sub-dermal	F(5,24)	253.20	2.62
	Central	F(5,24)	49.28	2.62
	Dermal	F(5,24)	209.78	2.62
Tree 2	Sub-dermal	F(5,24)	634.81	2.62
	Central	F(5,24)	47.30	2.62
	Dermal	F(5,24)	168.20	2.62
Tree 3	Sub-dermal	F(5,24)	166.74	2.62
	Central	F(5,24)	307.68	2.62
	Dermal	F(5,24)	25.13	2.62
Tree 4	Sub-dermal	F(5,24)	68.46	2.62
	Central	F(5,24)	136.29	2.62
	Dermal	F(5,24)	604.43	2.62
Tree 5	Sub-dermal	F(5,24)	157.72	2.62
	Central	F(5,24)	100.06	2.62
ALL 5 Dermal		F(4,145)	2.52	2.43
ALL 5 Sub-dermal		F(4,145)	2.07	2.43
ALL 5 Central		F(4,145)	3.39	2.43

Appendix 12D: Tukey's Multiple Comparison Test for the green Hardness of TREE 1

	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	2.2^{s}					
4.9	3.0^{s}	0.8^{s}				
6.6	4.3^{s}	2.1^{s}	1.3^{s}			
8.3	4.8^{s}	2.6^{s}	1.8^{s}	0.5^{ns}		
10	6.0^{s}	3.9^{s}	3.1^{s}	1.8^{s}	1.2^{s}	
Sub-dermal						
1.5						
3.2	1.5^{s}					
4.9	2.9^{s}	1.4^{s}				
6.6	3.8^{s}	2.3^{s}	0.8^{s}			
8.3	4.8^{s}	3.2^{s}	1.8^{s}	1.0^{s}		
10	5.6^{s}	4.1^{s}	2.7^{s}	1.9^{s}	0.9^{s}	
Central						
1.5						
3.2	0.3^{s}					
4.9	0.5^{s}	0.2^{s}				
6.6	0.5^{s}	0.3^{s}	0.02^{ns}			
8.3	0.6^{s}	0.3^{s}	0.1^{ns}	0.03^{ns}		
10	0.6^{s}	0.4^{s}	0.1^{ns}	0.1^{ns}	0.1^{ns}	

Appendix 12E: Tukey's Multiple Comparison Test for the green Hardness of TREE 2

Height (m)	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	1.8^{s}					
4.9	2.3^{s}	0.5^{ns}				
6.6	3.2^{s}	1.4^{s}	0.9^{ns}			
8.3	5.2^{s}	3.4^{s}	2.9^{s}	2.0^{s}		
10	8.5^{s}	6.7^{s}	6.3^{s}	5.3^{s}	3.3^{s}	
Sub-dermal						
1.5						
3.2	2.2^{s}					
4.9	4.0^{s}	1.8^{s}				
6.6	6.1^{s}	3.8^{s}	2.0^{s}			
8.3	7.8^{s}	5.6^{s}	3.8^{s}	1.8^{s}		
10	9.0^{s}	6.7^{s}	4.9^{s}	2.9^{s}	1.1^{s}	
Central						
1.5						
3.2	0.3^{s}					
4.9	0.6^{s}	0.3^{s}				
6.6	0.7^{s}	0.4^{s}	0.2^{ns}			
8.3	0.8^{s}	0.5^{s}	0.3^{ns}	0.1^{ns}		
10	0.9^{s}	0.1^{s}	0.1^{s}	0.2^{ns}	0.1^{ns}	

Appendix12F: Tukey's Multiple Comparison Test for the green Hardness of TREE 3

Height m	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	1.2^{s}					
4.9	2.2^{s}	1.0^{s}				
6.6	4.7^{s}	3.5^{s}	2.5^{s}			
8.3	5.8^{s}	4.6^{s}	3.6^{s}	1.1^{s}		
10	6.3^{s}	5.1^{s}	4.1^{s}	1.6^{s}	0.5^{ns}	
Sub-dermal						
1.5						
3.2	0.4^{ns}					
4.9	1.5^{s}	1.0^{s}				
6.6	3.6^{s}	3.2^{s}	2.2^{s}			
8.3	4.7^{s}	4.3^{s}	3.3^{s}	1.1^{s}		
10	5.6^{s}	5.2^{s}	4.2^{s}	2.0^{s}	0.9^{s}	
Central						
1.5						
3.2	0.4^{s}					
4.9	1.0^{s}	0.6^{s}				
6.6	1.1^{s}	0.7^{s}	0.1^{s}			
8.3	1.1^{s}	0.7^{s}	0.2^{s}	0.02^{ns}		
10	1.1^{s}	0.7^{s}	0.2^{s}	0.1^{ns}	0.03^{ns}	

Appendix 12G: Tukey's Multiple Comparison Test for the green Hardness of TREE 4

Height m	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	1.3^{ns}					
4.9	2.0^{s}	0.8^{ns}				
6.6	2.2^{s}	0.9^{ns}	0.2^{ns}			
8.3	3.3^{s}	2.1^{s}	3.5^{ns}	1.3^{ns}		
10	4.7^{s}	3.4^{s}	0.2^{s}	2.7^{s}	1.4^{ns}	
Sub-dermal						
1.5						
3.2	1.3^{ns}					
4.9	3.2^{s}	1.8^{s}				
6.6	3.6^{s}	2.4^{s}	0.6^{ns}			
8.3	5.6^{s}	4.3^{s}	2.6^{s}	2.0^{s}		
10	6.3^{s}	5.0^{s}	3.3^{s}	2.7^{s}	0.7^{ns}	
Central						
1.5						
3.2	0.7^{s}					
4.9	0.9^{s}	0.2^{ns}				
6.6	1.0^{s}	0.3^{s}	0.1^{ns}			
8.3	1.1^{s}	0.4^{s}	0.2^{s}	0.1^{ns}		
10	1.4^{s}	0.7^{s}	0.5^{s}	0.4^{s}	0.3^{s}	

Appendix 12H: Tukey's Multiple Comparison Test for the green Hardness of TREE 5

Height m	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	2.0^{s}					
4.9	4.7^{s}	2.7^{s}				
6.6	5.3^{s}	3.4^{s}	0.7^{s}			
8.3	6.0^{s}	4.1^{s}	1.4^{s}	0.7^{s}		
10	8.3^{s}	6.3^{s}	3.6^{s}	3.0^{s}	2.3^{s}	
Sub-dermal						
1.5						
3.2	1.1^{s}					
4.9	1.6^{s}	0.4^{ns}				
6.6	2.2^{s}	1.1^{s}	0.6^{ns}			
8.3	3.1^{s}	2.0^{s}	1.6^{s}	0.9^{s}		
10	5.1^{s}	3.9^{s}	3.5^{s}	2.9^{s}	1.9^{s}	
Central						
1.5						
3.2	0.2^{ns}					
4.9	0.7^{s}	0.5^{s}				
6.6	0.8^{s}	0.6^{s}	0.2^{ns}			
8.3	0.9^{s}	0.8^{s}	0.3^{s}	0.1^{ns}		
10	1.1^{s}	0.9^{s}	0.4^{s}	0.3^{s}	0.2^{ns}	

Appendix 12I: Tukey's Multiple Comparison Test for the green Hardness of All 5 TREES

	Tree 1 Dermal	Tree 2 Dermal	Tree 3 Dermal	Tree 4 Dermal	Tree 5 Dermal
Tree 1 Dermal					
Tree 2 Dermal	-0.1^{ns}				
Tree 3 Dermal	1.3^{ns}	1.5^{ns}			
Tree 4 Dermal	1.9^{ns}	2.0^{ns}	0.5^{ns}		
Tree 5 Dermal	0.2^{ns}	0.3^{ns}	-1.2^{ns}	-1.7^{ns}	
	Tree 1 Sub-dermal	**Tree 2Sub-dermal**	**Tree 3 Sub-dermal**	**Tree 4 Sub-dermal**	**Tree 5 Sub-dermal**
Tree 1 Sub-dermal					
Tree 2 Sub-dermal	-1.8^{ns}				
Tree 3 Sub-dermal	-2.1^{ns}	-0.2^{ns}			
Tree 4 Sub-dermal	-1.0^{ns}	0.9^{ns}	1.1^{ns}		
Tree 5 Sub-dermal	-0.9^{ns}	0.9^{ns}	1.1^{ns}	0.04^{ns}	
	Tree 1 Central	**Tree 2 Central**	**Tree 3 Central**	**Tree 4 Central**	**Tree 5 Central**
Tree 1 Central					
Tree 2 Central	-0.3^{ns}				
Tree 3 Central	-0.04^{ns}	0.3^{ns}			
Tree 4 Central	-0.4^{s}	-0.1^{ns}	-0.3^{ns}		
Tree 5 Central	-0.3^{ns}	0.1ns	-0.3^{ns}	0.1^{ns}	
	Tree 1	**Tree 2**	**Tree 3**	**Tree 4**	**Tree 5**
Tree 1					
Tree 2	-0.7^{ns}				
Tree 3	-0.2^{ns}	0.5^{ns}			
Tree 4	0.2^{ns}	0.9^{ns}	0.4^{ns}		
Tree 5	-0.3^{ns}	0.4^{ns}	-0.1^{ns}	-0.5^{ns}	

Appendix 13A: Summary of the basic statistics of the Hardness of the 5 *Borassus aethiopum* at 12% MC.

Tree No		Mean	S.Dev.	Minimum	Maximum	Count	CL (95.0%)
	Dermal	11.15	2.39	6.86	14.42	18.00	1.19
Tree 1	Sub-dermal	6.12	2.78	1.42	10.12	18.00	1.38
	Central	1.25	0.46	0.54	1.93	18.00	0.23
	Dermal	11.34	3.68	5.49	17.02	18.00	1.83
Tree 2	Sub-dermal	7.91	3.51	2.31	12.95	18.00	1.75
	Central	1.44	0.82	0.70	3.13	18.00	0.41
	Dermal	9.47	2.98	5.07	13.56	18.00	1.48
Tree 3	Sub-dermal	6.86	2.33	3.63	10.54	18.00	1.16
	Central	0.97	0.66	0.10	2.24	18.00	0.33
	Dermal	9.72	2.40	5.79	13.88	18.00	1.19
Tree 4	Sub-dermal	7.08	1.91	3.59	9.61	18.00	0.95
	Central	1.37	0.57	0.79	2.42	18.00	0.28
	Dermal	10.76	2.85	6.92	15.01	18.00	1.42
Tree 5	Sub-dermal	5.97	1.98	2.20	7.96	18.00	0.98
	Central	1.31	0.76	0.36	2.60	18.00	0.38
ALL 5 Dermal		10.49	2.93	5.07	17.02	90.00	0.61
ALL 5 Sub-dermal		6.79	2.61	1.42	12.95	90.00	0.55
ALL 5 Central		1.27	0.67	0.10	3.13	90.00	0.14
ALL 5 TREES		6.18	4.43	0.10	17.02	270.00	0.53

S.Dev. = Standard Deviation CL(95%) = 95% Confidence Level

Appendix 13B: Summary of the ANOVA of the Hardness of the (dermal, sub-dermal, and the central zone) of the Individual trees of the 5 *Borassus aethiopum* wood at 12% MC.

Tree No	Mean ($\pm \delta_{n-1}$)*	ANOVA between Individual Trees		
		Degrees of freedom	F-ratio	F-Critical
Tree 1	6.2±4.6	$F_{(2,51)}$	96.9	3.18
Tree 2	6.9±5.1	$F_{(2,51)}$	51.5	3.18
Tree 3	5.7±4.2	$F_{(2,51)}$	69.6	3.18
Tree 4	6.1±3.9	$F_{(2,51)}$	100.9	3.18
Tree 5	6.0±4.4	$F_{(2,51)}$	101.6	3.18
All 5 Trees	6.2±4.4	$F_{(4,265)}$	0.5	2.41

Appendix 13C: Analysis of Variance (ANOVA) of the Hardness for the 5 *Borassus aethiopum* Tree species at 12% MC

Tree No	Zone	Degrees of freedom	F	F-Critical
Tree 1	Dermal	F(5,24)	195.833	2.62
	Sub-dermal	F(5,24)	202.12	2.62
	Central	F(5,24)	391.22	2.62
Tree 2	Dermal	F(5,24)	288.92	2.62
	Sub-dermal	F(5,24)	706.41	2.62
	Central	F(5,24)	225.87	2.62
Tree 3	Dermal	F(5,24)	344.41	2.62
	Sub-dermal	F(5,24)	343.57	2.62
	Central	F(5,24)	216.24	2.62
Tree 4	Dermal	F(5,24)	128.41	2.62
	Sub-dermal	F(5,24)	69.59	2.62
	Central	F(5,24)	231.66	2.62
Tree 5	Dermal	F(5,24)	244.26	2.62
	Sub-dermal	F(5,24)	239.73	2.62
	Central	F(5,24)	233.18	2.62
ALL 5 Dermal		F(4,145)	1.53	2.43
ALL 5 Sub-dermal		F(4,145)	1.68	2.43
ALL 5 Central		F(4,145)	1.34	2.43

Appendix 13D: Tukey's Multiple Comparison Test for the Hardness of Tree 1 at 12% MC

Height (m)	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	1.2^{s}					
4.9	1.9^{s}	0.7^{ns}				
6.6	3.5^{s}	2.3^{s}	1.6^{s}			
8.3	4.8^{s}	3.7^{s}	2.9^{s}	1.3^{s}		
10	6.9^{s}	5.7^{s}	5.0^{s}	3.3^{s}	2.0^{s}	
Sub-dermal						
1.5						
3.2	1.4^{s}					
4.9	2.5^{s}	1.1^{s}				
6.6	4.4^{s}	3.0^{s}	1.9^{s}			
8.3	5.4^{s}	4.0^{s}	2.9^{s}	1.0^{ns}		
10	8.1^{s}	6.7^{s}	5.6^{s}	3.7^{s}	2.7^{s}	
Central						
1.5						
3.2	0.3^{s}					
4.9	0.6^{s}	0.4^{s}				
6.6	0.7^{s}	0.5^{s}	0.1^{ns}			
8.3	$1,0^{s}$	0.7^{s}	0.4^{s}	0.3^{s}		
10	1.4^{s}	1.1^{s}	0.7^{s}	0.6^{s}	0.4^{s}	

Appendix 13E: Tukey's Multiple Comparison Test for the Hardness of TREE 2 at 12% MC

Height (m)		1.5	3.2	4.9	6.6	8.3	10
Dermal							
	1.5						
	3.2	2.4^{s}					
	4.9	3.9^{s}	1.5^{s}				
	6.6	6.0^{s}	3.6^{s}	2.1^{s}			
	8.3	8.2^{s}	5.8^{s}	4.2^{s}	2.2^{s}		
	10	10.7^{s}	8.3^{s}	6.7^{s}	4.7^{s}	2.5^{s}	
Sub-dermal							
	1.5						
	3.2	1.7^{s}					
	4.9	4.0^{s}	2.3^{s}				
	6.6	6.0^{s}	4.3^{s}	2.0^{s}			
	8.3	7.1^{s}	5.4^{s}	3.1^{s}	1.1^{s}		
	10	10.2^{s}	8.5^{s}	6.2^{s}	4.2^{s}	3.1^{s}	
Central							
	1.5						
	3.2	1.3^{s}					
	4.9	1.7^{s}	0.5^{s}				
	6.6	2.0^{s}	0.7^{s}	0.3^{s}			
	8.3	2.2^{s}	1.0^{s}	0.5^{s}	0.2^{s}		
	10	2.3^{s}	1.1^{s}	0.6^{s}	0.3^{ns}	0.1^{s}	

Appendix 13F: Tukey's Multiple Comparison Test for the Hardness of TREE 3 at 12% MC

Height (m)	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	1.1^{s}					
4.9	2.6^{s}	1.5^{s}				
6.6	5.4^{s}	4.4^{s}	2.9^{s}			
8.3	6.2^{s}	5.1^{s}	3.6^{s}	0.8^{ns}		
10	8.0^{s}	7.0^{s}	5.5^{s}	2.6^{s}	1.9^{s}	
Sub-dermal						
1.5						
3.2	1.8^{s}					
4.9	2.9^{s}	1.1^{s}				
6.6	4.4^{s}	2.6^{s}	1.5^{s}			
8.3	5.7^{s}	3.9^{s}	2.8^{s}	1.3^{s}		
10	6.6^{s}	4.8^{s}	3.7^{s}	2.2^{s}	0.9^{s}	
Central						
1.5						
3.2	0.6^{s}					
4.9	1.1^{s}	0.5^{s}				
6.6	1.3^{s}	0.7^{s}	0.2^{s}			
8.3	1.6^{s}	1.0^{s}	0.5^{s}	0.3^{ns}		
10	1.9^{s}	1.4^{s}	0.8^{s}	0.6^{s}	0.3^{s}	

Appendix 13G: Tukey's Multiple Comparison Test for the Hardness of TREE 4 at 12% MC

Height (m)	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	2.4^{s}					
4.9	3.3^{s}	0.9^{ns}				
6.6	4.5^{s}	2.1^{s}	1.2^{s}			
8.3	5.2^{s}	2.8^{s}	1.9^{s}	0.7^{ns}		
10	7.4^{s}	5.0^{s}	4.1^{s}	3.0^{s}	2.2^{s}	
Sub-dermal						
1.5						
3.2	0.6^{s}					
4.9	1.3^{s}	0.8^{s}				
6.6	2.3^{s}	1.7^{s}	0.9^{s}			
8.3	3.5^{s}	2.9^{s}	2.1^{s}	1.2^{s}		
10	5.4^{s}	4.8^{s}	4.1^{s}	3.1^{s}	1.9^{s}	
Central						
1.5						
3.2	0.7^{s}					
4.9	1.2^{s}	0.5^{s}				
6.6	1.3^{s}	0.7^{s}	0.2^{ns}			
8.3	1.5^{s}	0.8^{s}	0.3^{s}	0.1^{ns}		
10	1.6^{s}	0.9^{s}	0.4^{s}	0.2^{s}	0.1^{ns}	

Appendix 13H: Tukey's Multiple Comparison Test for the Hardness of TREE 5 at 12% MC

Height (m)	1.5	3.2	4.9	6.6	8.3	10
Dermal						
1.5						
3.2	1.3^{s}					
4.9	3.7^{s}	2.4^{s}				
6.6	4.5^{s}	3.3^{s}	0.8^{ns}			
8.3	6.7^{s}	5.5^{s}	3.0^{s}	2.2^{s}		
10	7.8^{s}	6.5^{s}	4.1^{s}	3.3^{s}	1.1^{s}	
Sub-dermal						
1.5						
3.2	0.4^{ns}					
4.9	1.0^{s}	0.6^{ns}				
6.6	1.5^{s}	1.1^{s}	0.5^{ns}			
8.3	3.1^{s}	2.7^{s}	2.1^{s}	1.6^{s}		
10	5.6^{s}	5.2^{s}	4.6^{s}	4.1^{s}	2.5^{s}	
Central						
1.5						
3.2	0.4^{s}					
4.9	1.2^{s}	0.8^{s}				
6.6	1.5^{s}	1.1^{s}	0.3^{ns}			
8.3	1.8^{s}	1.4^{s}	0.5^{s}	0.3^{s}		
10	2.1^{s}	1.7^{s}	0.9^{s}	0.6^{s}	0.3^{s}	

Appendix 13I: Tukey's Multiple Comparison Test for the Hardness of All 5 TREES at 12% MC

	Tree 1 Dermal	Tree 2 Dermal	Tree 3 Dermal	Tree 4 Dermal	Tree 5 Dermal
Tree 1 Dermal					
Tree 2 Dermal	-0.2^{ns}				
Tree 3 Dermal	1.7^{ns}	1.9^{ns}			
Tree 4 Dermal	1.4^{ns}	1.6^{ns}	-0.2^{ns}		
Tree 5 Dermal	0.4^{ns}	0.6^{ns}	-1.3^{ns}	-1^{ns}	
	Tree 1 Sub-dermal	Tree 2Sub-dermal	Tree 3 Sub-dermal	Tree 4 Sub-dermal	Tree 5 Sub-dermal
Tree 1 Sub-dermal					
Tree 2 Sub-dermal	-1.8^{ns}				
Tree 3 Sub-dermal	-0.7^{ns}	1.0^{ns}			
Tree 4 Sub-dermal	-1^{ns}	0.8^{ns}	-0.2^{ns}		
Tree 5 Sub-dermal	0.2^{ns}	1.9^{ns}	0.9^{ns}	1.1^{ns}	
	Tree 1 Central	Tree 2 Central	Tree 3 Central	Tree 4 Central	Tree 5 Central
Tree 1 Central					
Tree 2 Central	-0.2^{ns}				
Tree 3 Central	0.3^{ns}	0.5^{ns}			
Tree 4 Central	-0.1^{ns}	0.1^{ns}	-0.4^{ns}		
Tree 5 Central	-0.1^{ns}	0.1^{ns}	-0.3^{ns}	0.1^{ns}	
	Tree 1	Tree 2	Tree 3	Tree 4	Tree 5
Tree 1					
Tree 2	-0.7^{ns}				
Tree 3	0.4^{ns}	1.1^{ns}			
Tree 4	0.1^{ns}	0.8^{ns}	-0.3^{ns}		
Tree 5	0.2^{ns}	0.9^{ns}	-0.2^{ns}	0.05^{ns}	

Appendix 14A: Summary of the basic statistics of the Physical Properties of the Bulge areas for the 5 *Borassus aethiopum* Species.

Tree No		Mean	S.Dev.	Minimum	Maximum	Count	CL(95.0%)
Tree 1	MC	253.3	19.3	228.6	285.7	10.0	13.8
	BASIC DENSITY	134.1	12.0	117.6	152.2	10.0	8.6
Tree 2	MC	255	31.4	216.7	298.0	10	14.09
	BASIC DENSITY	127.1	19.7	78.4	147.1	10	19.30
Tree 3	MC	228.1	26.6	200	266.7	10	22.24
	BASIC DENSITY	129.4	18.2	106.4	159.1	10	13.04
Tree 4	MC	246.1	31.1	212.5	283.3	10	22.24
	BASIC DENSITY	136.2	15.0	113.2	160.0	10	10.73
Tree 5	MC	248.5	24.8	200.0	271.4	10	17.74
	BASIC DENSITY	146.8	13.1	122.4	163.3	10	9.40
ALL 5 Trees MC		246.2	27.6	200	298	50	7.9
ALL 5 Trees Basic Density		134.7	16.7	78.43	163.3	50	4.75

Appendix 14B: Analysis of Variance (ANOVA) of the Physical Properties for all the 5 *Borassus aethiopum* Tree species for the Bulge Area

Physical Properties	Degrees of freedom	F-ratio	F-Critical
Green MC	F(4,45)	1.57	2.58
Basic Density	F(4,45)	1.59	2.58
Density at 12% MC	F(4,45)	2.33	2.58

Appendix 14 C: Tukey's Multiple Comparison Test for the Physical Properties of All 5 Trees Bulge areas at 12% MC

Basic Density	Tree 1	Tree 2	Tree 3	Tree 4	Tree 5
Tree 1					
Tree 2	7.1^{ns}				
Tree 3	4.7^{ns}	-2.4^{ns}			
Tree 4	-2^{ns}	-9.1^{ns}	-6.7^{ns}		
Tree 5	-12.7^{ns}	-19.7^{ns}	-17.4^{ns}	-10.7^{ns}	
Moisture Content	**Tree 1**	**Tree 2**	**Tree 3**	**Tree 4**	**Tree 5**
Tree 1					
Tree 2	15.7^{ns}				
Tree 3	25.2^{ns}	9.5^{ns}			
Tree 4	7.3^{ns}	-8.4^{ns}	-17.9^{ns}		
Tree 5	4.8^{ns}	-10.9^{ns}	-20.4^{ns}	-2.4^{ns}	

Appendix 15A: Summary of the basic statistics of the Mechanical Properties of the Bulge areas for the 5 *Borassus aethiopum* Species at 12% MC.

Tree No		Mean	S.Dev.	Minimm	Maximm	Count	CL(95.0)
Tree 1	MOR	1.79	0.25	1.37	1.98	5	0.315
	MOE	100.79	24.99	79.35	142.13	5	31.029
	Compression	0.637	0.129	0.49	0.78	5	0.160
	Hardness	0.124	0.005	0.107	0.132	5	0.013
	Shear	0.356	0.045	0.296	0.401	5	0.056
Tree 2	MOR	2.196	0.843	1.153	3.296	5	1.046
	MOE	99.516	14.552	79.736	117.433	5	18.069
	Compression	0.752	0.268	0.473	1.081	5	0.333
	Hardness	0.292	0.007	0.273	0.316	5	0.019
	Shear	0.383	0.047	0.337	0.457	5	0.058
Tree 3	MOR	2.658	0.279	2.172	2.835	5	0.346
	MOE	107.61	5.646	101.461	114.325	5	7.010
	Compression	1.210	0.677	0.487	1.943	5	0.841
	Hardness	0.106	0.010	0.090	0.144	5	0.027
	Shear	0.133	0.014	0.118	0.146	5	0.017
Tree 4	MOR	2.917	0.214	2.701	3.202	5	0.266
	MOE	157.133	29.710	122.621	188.464	5	36.890
	Compression	1.971	0.305	1.649	2.341	5	0.378
	Hardness	0.371	0.026	0.302	0.444	5	0.073
	Shear	0.323	0.031	0.278	0.364	5	0.038
Tree 5	MOR	1.630	0.423	1.156	2.317	5	0.525
	MOE	83.348	7.807	70.265	90.238	5	9.693
	Compression	0.929	0.105	0.802	1.063	5	0.131
	Hardness	0.354	0.011	0.330	0.381	5	0.031
	Shear	0.622	0.041	0.566	0.665	5	0.051
ALL 5 TREES	MOR	2.238	0.657	1.153	3.296	25	0.271
	MOE	109.679	30.894	70.265	188.464	25	12.752
	Compression	1.100	0.587	0.473	2.341	25	0.242
	Hardness	0.249	0.119	0.090	0.444	25	0.049
	Shear	0.363	0.163	0.118	0.665	25	0.067

Appendix 15B: Analysis of Variance (ANOVA) of the Mechanical Properties for all the 5 *Borassus aethiopum* Tree species for the Bulge Area at 12% MC

Mechanical Properties	Degrees of freedom	F-ratio	F-Critical
MOE	F(4,20)	135.35	2.87
MOR	F(4,20)	79.74	2.87
Comp llg	F(4,20)	160.85	2.87
Shear llg	F(4,20)	72.01	2.87
Hardness	F(4,20)	120.79	2.87

Appendix 15C: Tukey's Multiple Comparison Test for the Mechanical Properties of All 5 Tree Bulge areas at 12% MC

MOR	Tree 1	Tree 2	Tree 3	Tree 4	Tree 5
Tree 1					
Tree 2	-0.4^{ns}				
Tree 3	-0.9^{ns}	-0.5^{ns}			
Tree 4	-1.1^{s}	-0.7^{ns}	-0.3^{ns}		
Tree 5	0.2^{ns}	0.6^{ns}	1.0^{s}	1.3^{s}	
MOE	**Tree 1**	**Tree 2**	**Tree 3**	**Tree 4**	**Tree 5**
Tree 1					
Tree 2	1.3^{ns}				
Tree 3	-6.8^{ns}	-8.1^{ns}			
Tree 4	-56.3^{s}	-57.6^{s}	-49.5^{s}		
Tree 5	17.4^{ns}	16.1^{ns}	24.3^{ns}	73.8^{s}	
HARDNESS	**Tree 1**	**Tree 2**	**Tree 3**	**Tree 4**	**Tree 5**
Tree 1					
Tree 2	-0.2^{s}				
Tree 3	0.02^{ns}	0.2^{s}			
Tree 4	-0.2^{s}	-0.1^{s}	-0.3^{s}		
Tree 5	-0.2^{s}	-0.1^{s}	-0.3^{s}	0.01^{ns}	
Compression	**Tree 1**	**Tree 2**	**Tree 3**	**Tree 4**	**Tree 5**
Tree 1					
Tree 2	-0.1^{ns}				
Tree 3	-0.6^{ns}	-0.5^{ns}			
Tree 4	-1.3^{s}	-1.2^{s}	-0.8^{s}		
Tree 5	-0.3^{ns}	-0.2^{ns}	0.3^{ns}	1.0^{s}	
Shear	**Tree 1**	**Tree 2**	**Tree 3**	**Tree 4**	**Tree 5**
Tree 1					
Tree 2	-0.03^{ns}				
Tree 3	0.2^{s}	0.3^{s}			
Tree 4	0.04^{ns}	0.1^{ns}	-0.2^{s}		
Tree 5	-0.3^{s}	-0.2^{s}	-0.5^{s}	-0.3^{s}	

Appendix 16: Ratio of Dry to green mechanical strength values of *Borassus aethiopum* and that of Ghanaian and USA hard woods

DERMAL	MOR	MOE	C llg	Shear llg	Hardness
TREE 1	1.24	1.16	1.26	1.66	1.41
TREE 2	1.35	1.30	1.27	1.33	1.42
TREE 3	1.57	1.48	1.36	1.32	1.45
TREE 4	1.30	1.25	1.38	1.29	1.61
TREE 5	1.27	1.25	1.25	1.27	1.39
MEAN	1.35	1.29	1.30	1.37	1.46
	1.24-1.57	1.16-1.48	1.25-1.38	1.27-1.66	1.39-1.61
Sub-dermal	MOR	MOE	C llg	Shear llg	Hardness
TREE 1	1.53	1.54	1.41	1.88	1.83
TREE 2	1.39	1.43	1.44	1.40	1.56
TREE 3	1.48	1.56	1.52	1.32	1.28
TREE 4	1.18	1.26	1.40	1.32	1.65
TREE 5	1.61	1.77	1.29	1.47	1.41
MEAN	1.44	1.51	1.41	1.48	1.55
	1.18-1.53	1.26-1.77	1.29-1.41	1.32-1.88	1.41-1.83
Central	MOR	MOE	C llg	Shear llg	Hardness
TREE 1	1.42	1.48	1.78	1.48	3.44
TREE 2	1.75	1.72	1.42	1.83	2.16
TREE 3	1.71	1.68	1.71	1.67	2.36
TREE 4	1.70	1.87	1.53	1.34	1.89
TREE 5	1.29	1.31	1.58	1.68	1.97
MEAN	1.57	1.61	1.60	1.60	2.36
	1.29-1.75	1.31-1.87	1.42-1.78	1.34-1.83	1.89-3.44
*Ghanaian hardwoods	1.20-1.61	1.13-1.39	1.41-1.75	1.39-1.71	1.19-1.52
**USA hardwoods	1.32-2.10	1.11-1.53	1.61-2.60	1.13.1.82	

Source: (J. Ofori *et al,* 2009) and **(ASTM,1978)

Appendix 17A: Correlation between the basic density and the green mechanical strength values for the five *Borassus aethiopum* species - Dermal.

	Basic Density	*Green MOR*	*Green MOE*	*Green Comp.llg*	*Green shear.llg*	*Green Hardness*
Basic Density	1					
Green MOR	0.985	1				
Green MOE	0.978	0.991	1			
Green Comp.llg	0.992	0.995	0.982	1		
Green shear.llg	0.992	0.998	0.985	0.999	1	
Green Hardness	0.990	0.992	0.997	0.990	0.991	1

Appendix 17B: Correlation between the density and the mechanical strength values at 12% MC for the five *Borassus aethiopum* species - Dermal.

	Density at 12% MC	*MOR at 12% MC*	*MOE x 100 at 12% MC*	*Comp.llg at 12% MC*	*shear.llg at 12% MC*	*Hardness at 12% MC*
Density at 12% MC	1					
MOR at 12% MC	0.993	1				
MOE x 100 at 12% MC	0.991	0.997	1			
Comp.llg at 12% MC	0.990	0.999	0.995	1		
Shear.llg at 12% MC	0.989	0.995	0.988	0.991	1	
Hardness at 12% MC	0.980	0.986	0.996	0.984	0.971	1

Appendix 17C: Correlation between the basic density and the mechanical strength values for the five *Borassus aethiopum* species – Sub-dermal.

	Basic Density	*Green MOR*	*Green MOE x100*	*Green Comp.llg*	*Green shear.llg*	*Green Hardness*
Basic Density	1					
Green MOR	0.993	1				
Green MOE x100	0.990	0.999	1			
Green Comp.llg	0.990	0.997	0.998	1		
Green shear.llg	0.997	0.9923	0.991	0.992	1	
Green Hardness	0.988	0.9875	0.987	0.988	0.996	1

Appendix 17D: Correlation between the density and the mechanical strength values for the five *Borassus aethiopum* species – Sub-dermal zone.

	Density at 12% MC	*MOR at 12% MC*	*MOE x 100 at 12%*	*Comp.llg at 12%*	*shear.llg at 12%*	*Hardness at 12%*
Density	1					
Dry MOR	0.993	1				
Dry MOE x 100	0.994	0.992	1			
Dry Comp.llg	0.996	0.989	0.991	1		
Dry shear.llg	0.997	0.986	0.996	0.997	1	
Dry Hardness	0.975	0.952	0.978	0.975	0.986	1

Appendix 17E: Correlation between the basic density and the mechanical strength values for the five *Borassus aethiopum* species – Central

	Basic Density	*Green MOR*	*Green MOE*	*Green Comp.llg*	*Green Shear.llg*	*Green Hardness*
Basic Density	1					
Green MOR	0.940	1				
Green MOE	0.924	0.998	1			
Green Comp.llg	0.993	0.961	0.946	1		
Green Shear.llg	0.959	0.990	0.983	0.976	1	
Green Hardness	0.977	0.944	0.927	0.980	0.978	1

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Appendix 17F: Correlation between the density and the mechanical strength values for the five *Borassus aethiopum* species – Central.

	Density at 12% MC	*MOR at 12% MC*	*MOE at 12% MC*	*Comp.llg at 12% MC*	*Shear.llg at 12% MC*	*Hardness at 12% MC*
Density at 12% MC	1					
MOR at 12% MC	0.9657	1				
MOE at 12% MC	0.9712	0.9994	1			
Comp.llg at 12%MC	0.9945	0.9483	0.9532	1		
Shear.llg at 12% MC	0.9646	0.9981	0.9963	0.9521	1	
Hardness at 12% MC	0.9864	0.9548	0.9560	0.9923	0.9628	1

Appendix 17G: Correlation between the density and the mechanical strength values for the five *Borassus aethiopum* trees – Bulge Area

	Density (kg/m³)	*Dry MOE x 10* (N/mm²)	*Dry MOR* (N/mm²)	*Dry Comp.llg* (N/mm²)	*Dry shear.llg* (N/mm²)	*Dry Hardness* kN
Density	1					
Dry MOE x 10	-0.183	1				
Dry MOR	-0.475	0.841	1			
Dry Comp.llg	0.094	0.893	0.822	1		
Dry Shear.llg	0.775	-0.429	-0.725	-0.290	1	
Dry Hardness	0.504	0.283	0.049	0.430	0.645	1