UNIVERSITY OF EDUCATION, WINNEBA

COLLEGE OF TECHNOLOGY EDUCATION, KUMASI

PHYSICAL AND MECHANICAL PROPERTIES OF FIFTEEN (15) AND THIRTY (30) YEARS *GMELINA ARBOREA*

DANIEL AGBEDANU

JUNE, 2017

UNIVERSITY OF EDUCATION, WINNEBA

COLLEGE OF TECHNOLOGY EDUCATION, KUMASI

PHYSICAL AND MECHANICAL PROPERTIES OF FIFTEEN (15) AND THIRTY (30) YEARS *GMELINA ARBOREA*

DANIEL AGBEDANU

(8121780009)

A Dissertation in the Department of WOOD SCIENCE AND TECHNOLOGY EDUCATION, Faculty of TECHNICAL EDUCATION, submitted to the School of Graduate Studies, University of Education, Winneba in partial fulfillment of the requirements for the award of Master of Philosophy in (Wood Science and Technology) degree.

JUNE, 2017

DECLARATION

STUDENT'S DECLARATION

I, **Daniel Agbedanu**, declare that this Dissertation, with the exception of quotations and references contained in the published works which have all been identified and duly acknowledged, is entirely my own original work and it has not been submitted, either in part or whole, for another degree elsewhere.

SIGNATURE……………………………..……..

DATE…………………………………..……..

SUPERVISOR'S DECLARATION

I hereby declare that the preparation and presentation of this work was supervised in accordance with the guidelines for supervision of Dissertation as laid down by the University of Education, Winneba.

NAME: **PROF. NANA K. FRIMPONG-MENSAH**

SIGNATURE……………………………..……..

DATE…………………………………..……..

ACKNOWLEDGMENT

I am most grateful to Almighty God who in diverse ways helped me to overcome all the hurdles in writing this thesis and taking me through this program successfully.

My profound gratitude goes to my project supervisors Prof. Nana K. Frimpong Mensah of the Department of Wood Science and Technology FRNR-KNUST. Your thought provoking and leading questions which went a long way in the realization of this thesis are very much appreciated. Alhaji Haruna Seidu of CSIR- FORIG, Fumesua. You are a brother and I will be forever indebted to you and your wife Zenab. Mama Linda Nsiah Ababio for freely allowing me into your plantation and at no cost, and your sons led by Thomas Sarfo who harvested the trees and cut them into logs. Daddy Kwasi Owusu Boadu, I will never forget the interest you showed in this work in that you constantly checked on me as to where I have reached at any time you called me. Mr. Andy Bayuko of the Department of Wood Science and Technology workshop for the immerse work you did in helping to prepare the material for the laboratory works. Mr. Douglas Amoah of the Department of Wood Science and Technology Chemistry laboratory thanks very much. Mrs. Vida Agbedanu thanks so much for your support, may God bless you richly.

DEDICATION

This work is dedicated to the following people; Mrs. Vida Agbedanu, Michael Yaw Agbedanu (deceased), Margaret Ami Aglozah, Vida Dzekpe, Mr. and Mrs. Cephas Kekeli Kelly, Mr. and Mrs. Ebenezer Ghosh Agbedanu and Mama Selina Agbedanu.

TABLE OF CONTENTS

CHAPTER TWO

LITERATURE REVIEW

CHAPTER THREE

MATERIALS AND METHODS

CHAPTER FOUR

RESULTS PRESENTATION

CHAPTER FIVE

DISCUSSION

CHAPTER SIX

SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Approximately 680 tree species have been identified in Ghana's forest, but only a few of these have been put to commercial use. Of the 1999 timber production, some 60 percent was derived from a small number of species. Actually, 66 species dominated felling in 1999. Since there is an increasing demand for tropical timbers, there is therefore the need to consider less well known but commonly found species such as *Gmelina arborea* which could be developed for commercial use. The lesser used species (LUS), offer a number of potential advantages to both Ghana and the international market. It was against this background that the physical and mechanical properties of fifteen (15) and thirty (30) years *Gmelina arborea* were determined to recommend the suitability of the species for furniture production and wood products. One (1) fifteen (15) and one(1) thirty30 years trees from a plantation in the Odomi Forest Reserve in the Ashanti Region were extracted. Logs from the trees were quarter sawn and further prepared according to the British Standard BS 373-1957. Test was conducted using Instron Universal testing machine and the results analyzed with origin 9.0. There were significant difference among the MOE (15years: 8665 N/mm^2, 30years: 10875 N/mm^2), MOR (15years:64.30N/mm^2, 30years:69.16N/mm^2). The mechanical strength properties increased from the top, middle to the butt same as the densities. To achieve maximum results in terms of the mechanical and physical strength it is recommended that species of 30 years and above should be considered, since the mechanical and physical strength properties improve as the tree ages.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Upton and Attah (2003), stated that Ghana has one of the most carefully planned and monitored forest economies in Africa, hence, the country has made strong commitment to the sustainable management of the countries forests by becoming signatories to the International Tropical Timber Organization (ITTO) and the African Timber Organization (ATO). Ghana's natural forest resources are limited and the introduction of necessary constraints under sustainable forest management practices further reduces the availability of wood for harvesting. These constraints which restrict the amount of timber available for external commercial use include increasing domestic demand and growing population are putting great pressure on the country's timber supply (Upton and Attah, 2003).

According to Forestry Commission of Ghana (FC) (1999), approximately 680 tree species have been identified in Ghana's forest, but only a few of these have been put to commercial use. Of the 1999 timber production, some 60 percent was derived from a small number of species. Actually, 66 species dominated felling in 1999.

Twenty five percent of Ghana's productive forests are legally designated as Forest Reserves; therefore, government is responsible for all timber cutting activities both within and beyond these reserves (FC, 2003).

Many of the traditional species such as odum (*Milicia excelsa*), sapele (*Etandrophragma cylindricum*) and others are in great demand and very familiar to importers. However, this group of traditional species has been over exploited in the past and they are in need of protection. Since there is an increasing demand for tropical timbers, there is therefore the need to consider less known but commonly found species such as *Gmelina arborea* for commercial use. This group of timbers known as lesser used species (LUS), offer a number of potential advantages to both Ghana and the international buyer.

Many of the LUS timber are available in abundant supply in the forests of Ghana and are readily sustainable within Ghana's forest management systems and many of them are highly suitable for industrial purposes. Additionally, due to their underutilization, they are likely to be at lower prices (Upton and Attah, 2003). A wider promotion and usage of LUS will not only benefit all those dependent on the nation's forests but in addition Ghana can also enhance its forest economy by protecting its precious primary timbers.

1.2 Statement of the Problem

Ghana has long history of providing timbers for furniture manufacture. Some traditional timbers such as afromosia (*Afromosia elata*) with its teak-like appearance have long been regarded as suitable for manufacture of high quality furniture. However, this particular species of timber is now very scarce with supply strictly controlled to support regeneration, (Upton and Attah, 2003). The decreased in stock levels of traditional species calls for a shift towards the increased utilization of the LUS.

The timber industry has recently been one of the fastest growing sectors of the economy of Ghana. A recent study by the Forestry Commission (2000) into the performance of the wood industry estimated the total harvest for 1999 at about 3.7million m^3, which is almost four times the annual allowable cuts, (Agyeman, V. K. et al, 2003)

One of the biggest problems arising out of the uncontrolled expansion of the timber industry is the heavy reliance on the primary species resulting in the fast dwindling supply of the primary timber species, (Agyeman, V. K. et al, 2003). The wood industry is currently faced with technical problems in the areas of field identification, end-use categorization and processing efficiency of LUS. In spite of the problems associated with processing of LUS, the timber industry has increasingly been dependent on logs from LUS in recent years due to the increasing demand for wood resources. Another reason for the dependence on the timber industry on LUS is that of selective logging system being used concentrates on the extraction of primary species leaving behind the large proportion of LUS, (Agyeman, V. K. et al, 2003).

According to Agyeman, V. K. et al, (2003), recognizing the importance of increased utilization of LUS and value addition on the growth of the timber industry and its effects on the prevention of habitat loss and reduced genetic and species diversity, the Government of Ghana in collaboration with the International Tropical Timber Organization (ITTO) designed a programme entitled " industrial utilization and improved marketing of some Ghanaian less used timber species from sustainably managed forest – ITTO PD 179/91".

The supply situation for all species is increasingly governed by what can be harvested each year under sustainable forest management practices, (Upton and Attah, 2003). Some of the species that Ghana has been exporting for many years now face stricter limits on annual harvest volumes to ensure sustainability. As a result, more emphasis is being given to lesser used and lesser known species. Hence, a research on the potential of *Gmelina arborea*, a lesser used and known species. And by extension investigate into two different year group of the same species.

1.3 Objectives of the Study

The objective of study is to determine and promote *Gmelina arborea* as a source of timber material. The aim of the study will include;

- To determine properties Modulus of Elasticity (MOE), Modulus of Rupture (MOR), Compression parallel to the Grain and Shear of the two different year (15 and 30) group of *Gmelina arborea.*
- To determine the density and moisture content (MC) of two different year (15 and 30) group of *Gmelina arborea.*
- To compare the determined properties with an existing grades. And properties of three traditional wood species to its suitability furniture and other wood products.

1.4 Justification of the Study

Timber is one of Ghana most really available natural resource. The natural forest resources occupy an area of 81,306 square kilometers approximately one third of the entire country and hold more than 400 indigenous hardwood spices (Anon, 1996, Usher and Ocloo 1979).

According to Brazier (1978) and stated by Appiah-Kubi (2009), commercial hardwood harvested for industrial use often represent only three (3) to ten (10) percent of timber volume in any given area. This assertion is also supported by Young (1997) that 90% of log trade in Nigeria has been in only six (6) primary species. Likewise, Ofori (1985) reported that only about 80% tree species out of approximately 600 species in West Africa, which reach sizes suitable for timber and plywood production are exploited in an FAO (1988) inventory project classification of Ghana's high forest tree species, only 60 species were registered as having between exported from the country between 1973 and 1988. Large numbers of wood species growing in the natural tropical forest are excluded from the international timber market because they have been deemed 'undesirable' for a number of reasons including the chemical contents of their extractives and lack of adequate data on their mechanical properties (Appiah-Kubi, 2009).

According to Allotey (1992) lack of adequate data (mechanical properties) on lesser known and used species in Ghana has led to the over-exploitation of the few noble commercial species such as Odum, Mahogany, Iroko etc. whose properties are known and established.

According to Upton and Attah (2003) and cited by Appiah-Kubi, (2009) some species of timber have been protected from exploitation by the Forestry Commission of Ghana to prevent their depletion in the forest, and has banned the exploitation of such species due to the fact that they (species) possess poisonous and strange chemicals in their extractives, which have not yet been researched. This has lead to the over-exploitation of limited species.

There is therefore the need to explore and conduct test on the mechanical properties of a lesser known and used species such as *Gmelina arborea* so that its properties can be established for usage. This is because this material is a local resource and is in abundant supply and it is also unexploited compared to the over-exploited few hardwood species.
According to Appiah-Kubi (2009), before 1970, the characteristics of timber were assessed on the basis of the characteristics of small cleared piece of wood, however, following the work of Madsen (Madsen, 1992) it was realized that this could be quit misleading. This is because the strength of structural size timber is heavily dependent on the presence of natural features such as knots, pith, etc. Alik and Nakai (1997) noted that results from full size structural timber were considered to be more reliable to allocate design stresses so as to eliminate the risk of stress assumptions. In addition the values will reflect more on the actual strength of timber in use (Appiah-Kubi, 2009).

According to Appiah-Kubi (2009), wood may be described as an orthotropic material that is it has unique and independent mechanical properties in the directions of three mutually perpendicular axes; longitudinal, radial and tangential. Mechanical properties most commonly measured and represented as strength properties for design include, bending stress parallel to the grain, molecules of elasticity in bending, compressive stress perpendicular to the grain and shear strength parallel to the grain. Other measurements are often used to evaluate work to maximum load in bending, impact bending strength, tensile strength perpendicular to the grain and hardness.

1.5 Research Questions

- Are there significant differences between the means of the fifteen (15) and the thirty (30) years *Gmelina arborea,* in terms of their Modulus of Elasticity, Modulus of Rupture, Compression parallel to the Grain and shear?
- Are there significant differences between the means of the fifteen (15) and the thirty (30) years *Gmelina arborea* in terms of their moisture content and the density?

1.6 Limitation

The research should have used about three (3) trees of the fifteen (15) and three (3) trees of the thirty (30) years *Gmelina arborea*, however, due to financial constrains the research was limited to one (1) each of the two different year groups.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

The progress of mankind from the primitive state to the present day technologically highly advanced society has always been closely associated with man's dependence on wood. In prehistoric times man has relied on wood for survival, shelter, weapon and for fire to cook his food and warm himself, (Pushin and de Zeeuw, 1970).

The uses of wood dates back in antiquity, however, not much knowledge have been accumulated on its uses. Even though, heavy reliance on timber is placed on tradition. Though some of the information may be factual, much of it is coloured with prejudice or distorted. As a result, its exception qualities have only been taken for granted or have remained unappreciated while its faults have been grossly exaggerated. (Pushin and de Zeeuw, 1970).

According to Pushin and de Zeeuw (1970), a comprehensive knowledge of the characteristics of any material for that matter wood is essential, to its correct utilization, hence, the fundamental studies of wood must therefore, take into account;

1. Properties that are common to all woods regardless of their botanical origin.
2. Properties that are distinctive of certain species only and which frequently dictate the specific uses of those woods and

3. The degree of variability that may be present within a species because of environmental growth conditions and perhaps because of the influence of genetic factors.

Hence, in this research, an investigation into the strength properties of two different years group to establish that their mechanical and physical properties are of no significant variance of gmelina arborea as a timber resource. There is an extensive literature on research trends in the field of timber and the engineering basis of analysis is paramount. The physical structures of wood, the benefits of timber, stress grading and various grading systems been used. In addition research trends on Ghanaian timber species and the strength properties of timber have been reviewed.

2.1 Physical Structure of Wood

Wood, in the strict sense, is yielded by trees, which increase in diameter by the formation between the existing wood and the inner bark, of new woody layers which envelop the entire stem, living branches, and roots. This process is known as secondary growth; it is the result of cell division in the vascular cambium, a lateral meristem, and subsequent expansion of the new cells. Where there are clear seasons, growth can occur in a discrete annual or seasonal pattern, leading to growth rings; these can usually be most clearly seen on the end of a log, but are also visible on the other surfaces. If these seasons are annual these growth rings are referred to as annual rings. Where there is no seasonal difference growth rings are likely to be indistinct or absent.

2.1.1 Hard and Soft Woods

There is a strong relationship between the properties of wood and the properties of the particular tree that yielded it. The density of wood varies with species. The density of a wood correlates with its strength (mechanical properties). For example, mahogany is a medium-dense hardwood that is excellent for fine furniture crafting, whereas balsa is light, making it useful for model building. One of the densest woods is black ironwood.

It is common to classify wood as either softwood or hardwood. The wood from conifers (e.g. pine) is called softwood, and the wood from dicotyledons (usually broad-leaved trees, e.g. oak) is called hardwood. These names are a bit misleading, as hardwoods are not necessarily hard, and softwoods are not necessarily soft. The well-known balsa (a hardwood) is actually softer than any commercial softwood. Conversely, some softwood (e.g. yew) is harder than many hardwoods.

The weight of timber which in most cases is used to classify species into hard and softwoods varies with the amount of water it contains. Hence, it is necessary to state the moisture content at which the weight of the timber is determined. However, the weight of a timber at any other moisture content apart from moisture content of 12 per cent, within the range of 5 per cent to 25 per cent can be estimated by adding or subtracting 0.5 per cent of the given weight for each 1 per cent moisture content above or below 12 per cent (Handbook of Hardwood, 1972).

Gmelina arborea according to Upton and Attah (2003), is classified as a medium (450-575kg/m^3) weight timber, therefore, it could exhibit properties as compared to such timbers which fall into similar category;

Table 2.1: Data from Canadian Department of Forestry as cited in Handbook of Hardwood

Common Name	Moisture content	Bending strength		Modulus of elasticity		Compression parallel to grain	
		N/mm^2	lbf/in^2	N/mm^2	1000lbf/in^2	N/mm^2	lbf/in^2
Afara	Green						
	12%	83	1200	10600	1530	37.9	5490
African walnut	Green	57	8200	7300	1060	29.8	4320
	12%	82	11900	9200	1340	48.2	6990
Canarium African	Green	41	5900	6200	900	21.6	3130
	12%	70	10100	8100	1180	42.5	6160
Elm white	Green	52	7600	7200	1040	20.8	3020
	12%	85	12400	8600	1250	39.5	5730
Maple soft	Green	50	7200	8500	1240	21.0	3040
	12%	86	12500	10500	1530	43.1	6250
Crack willow	Green	35	5100	5600	810	14.8	2150
	12%	66	9500	7000	1010	28.1	4080

2.1.2 Heartwood and Sapwood

Figure 2.1: Heartwood and Sapwood

Heartwood is wood that as a result of a naturally occurring chemical transformation has become more resistant to decay. Heartwood formation occurs spontaneously (it is a genetically programmed process). Once heartwood formation is complete, the heartwood is dead. Some uncertainty still exists as to whether heartwood is truly dead, as it can still chemically react to decay organisms, but only once.

Sapwood is the younger, outermost wood; in the growing tree it is living wood and its principal functions are to conduct water from the roots to the leaves and to store up and give back according to the season the reserves prepared in the leaves. However, by the time they become competent to conduct water, all xylem tracheids and vessels have lost their cytoplasm and the cells are therefore functionally dead. All wood in a tree is first formed as sapwood.

2.1.3 Moisture Content

Perhaps the most important aspect of woodworking deals with the relationship between wood and moisture. A fundamental fact is that wood is hygroscopic. This means that wood, almost like a sponge, will gain or lose moisture from the air based upon the conditions of the surrounding environment. When a tree is first felled, it is considered to be in the green state, and contains a very large amount of moisture. This moisture exists in two different forms: as free water that is contained as liquid in the pores or vessels of the wood itself, and as bound water that is trapped within the cell walls. The amount of water in a given piece of wood is expressed as a percentage of the weight of the water as compared to its oven dry weight. Some species of trees, when they are initially felled, may contain more water by weight than actual wood fiber, resulting in moisture content (MC) over 100%.

Moisture Content % = (weight of water / oven dry weight of wood) x 100

2.1.4 Characteristics in wood which Influence Timber Strength and Stiffness

Various abnormal conditions and features of wood which permanently reduce the economic value of wood are termed as defects. According to Dowse (2010), for structural grading systems it is necessary that the parameters used to grade the timber must have adequate relationship with the timber strength and stiffness as follows;

2.1.4.1 Knots

The average knot volume in a stem is generally between 0.5 to 2%. The affected surface area of the timber, however, is up to 3 times greater than that of the knot itself, as the alignment of the axial tracheids around the knot is disturbed according to Walker,(1993), (as cited in Dowse, 2010, p.5). Walker also notes that knot volume is proportionally greater in young stands, especially with wide initial spacing and thinning, where the trees have larger branches. Large knots drastically reduce strength and are a major cause of downgrade in timber. Edge knots are knots that borders on the side or edge of the board, and are normally under tension or compression. They behave as if they are internal knots of approximately twice their actual size Walker, (1993), (as cited in Dowse 2010, p. 5). Both Johansson and Giudiccandrea and Verfurth (2006) as cited in Dowse, (2010) compared different studies and found degrees of determination (R^2) of 0.20 to 0.42 between various knot parameters and timber MOR and tension (see Tables 2 and 3). When knot parameters were measured using a modern X-ray scanner an R^2 of 0.5 with MOR of some of the European pines were found (Bacher, 2010). In a study done by Johansson et al. (1998) it was found that in destructive bending or tension tests the failure is caused almost exclusively by knots, while Johansson et al. (in Thelandersson and Larsen, 2003), (in Dowse, 2010,p. 5) found that knots account for up to 66% of downgrades during visual grading. Knuffel (1984), (as cited in Dowse, 2010, p.6) found from laboratory data that visual grading could be improved by placing more emphasis on knot data than on density.

Degrees of determination (R^2) from various investigations of the relationship between strength and other properties of Norway spruce timber (*Picea abies*) – the sources of the investigation are numbered from 1 to 6 (Hoffmeyer in Thelanderson and Larsen, 2003) (as cited in Dowse, 2010).

Table 2.2: Relationship between Strength and other Properties

Characteristics that can be Measured destructively	Degree of determination R^2						
	Modulus of rupture				Tension		
Source	[1]	[2]	[3]	[4]	[1]	[5]	[6]
Knots	0.27	0.20	0.16	0.25	0.36	0.42	0.30
Annual ring width	0.21	0.27	0.20	0.44	0.36	0.33	0.28
Density	0.16	0.30	0.16	0.40	0.38	0.29	0.38
MOE, bending and tension	0.72	0.53	0.55	0.56	0.70	0.69	
Knots + annual ring width	0.37	0.42	0.39		0.49		
Knots + density	0.38		0.38		0.55	0.61	
Knots + MOE	0.73	0.58	0.64		0.70	0.76	

[1]. Johansson et al. (1992), [2].Hoffmeyer (1984), [3].Hoffmeyer (1990),

[4]. Lackner et al. (1988), [5]. Glos et al. (1982), [6] Johanssen (1976)

Degrees of determination (R^2) for MOR predictions by different indicator properties (from Glos, 2004 as recreated by Giudiccandrea and Verfurth, 2006). (as cited in Dowse, 2010).

2.1.4.2 Density

Density affects the amount of moisture that wood can hold, its shrinkage and swelling, and its mechanical and other properties. Density, therefore, is a measure of the quality of clear wood— that is, wood without defects (n.d.). According to Zobel and Van Buijtenen, (1989) density has traditionally been considered as the most important "quality property" in wood and its correlations with the strength of timber are generally regarded as poor, with Table 1 showing R^2 values of 0.16 to 0.40 between density and bending or tensile strength. According to Wimmer, (1991) density in wood increases considerably from earlywood to latewood. A study done on ten 80-100 year-old Scots pine trees from Australia showed the latewood percentage to be an important criterion in assessing wood properties. Density is also affected by the silvicultural interventions typical of plantation forestry. Moschler et al. (1988) showed a decrease in earlywood density after thinning (425 kg/m^3 to 408 kg/m^3) and an increase in density for latewood (576 kg/m^3 to 643 kg/m^3) for 16 year-old *Pinus taeda* trees.

Dinwoodie and Desch, (1996) have stressed that some strength properties show a very marked correlation with density, and compression strength parallel to grain, bending strength and hardness fall into this category.

2.2 Orthotropic Nature of Wood

Mechanical properties are obtained from tests of small pieces of "clear" and "straight grained" wood because they did not contain characteristics such as knots, cross grain, checks, and splits. Wood may be described as an orthotropic material; that is, it has unique and independent mechanical properties in the directions of three mutually perpendicular axes: longitudinal, radial and tangential. The longitudinal axis *L* is parallel to the fiber (grain); the radial axis *R* is normal to the growth rings (perpendicular to the grain in the radial direction); and the tangential axis *T* is perpendicular to the grain but tangent to the growth rings.

2.3 Elastic Properties of Wood

According to Kretschman, D. E. & Green, D.W. (1999), twelve constants (nine are independent) are needed to describe the elastic behavior of wood: three moduli of elasticity *E*, three moduli of rigidity *G*, and six Poisson's ratios m.

2.3.1 Modulus of Elasticity

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. The three moduli of elasticity, which are denoted by E_L, E_R, and E_T, respectively, are the elastic moduli along the longitudinal, radial, and tangential axes of wood. These moduli are usually obtained from compression tests. The modulus of elasticity determined from bending, E_L, rather than from an axial test, may be the only modulus of elasticity available for a species (Green et al., 1999).

2.3.2 Modulus of Rigidity

The modulus of rigidity, also called shear modulus, indicates the resistance to deflection of a member caused by shear stresses. The three moduli of rigidity denoted by G_{LR}, G_{LT}, and G_{RT} are the elastic constants in the *LR*, *LT*, and *RT* planes, respectively. For example, G_{LR} is the modulus of rigidity based on shear strain in the *LR* plane and shear stresses in the *LT* and *RT* planes.

2.4 Stress Grading

According to American Institute of Timber Construction (1994), mechanical properties of timber even among its individual pieces may differ in strength by as much as 100%. For simplicity and economy in use, pieces of timber of similar mechanical properties such as bending strength, density and modulus of elasticity can be placed in single class known as grade (Appiah-Kubi, 2009).

Before the introduction of BS 5268 in 1984, (British Standard for Structural Use of Timber), timber strength was calculated by carrying out short – term loading tests on small clear specimen free from all defects. The data were used to estimate the minimum strength which was taken as the value below which not more than 1% of the test results fail. These strengths were multiplied by a reduction factor to give basic stress. According to Appiah-Kubi (2009), the reduction factor made an allowance for the reduction in strength due to duration of load, size of specimen and other effects normally associated with accidental overloads. Appiah-Kubi (2009), agreed with Arya (2003), that basic stress could safely be permanently sustained by timber free from any strength reducing characteristics. With the introduction of BS 5268, the concept of basic stress was largely abandoned and a revised procedure adopted (Appiah-Kubi, 2009).

2.4.1 Visual Grading

It is assumed that mechanical properties of timber differ from mechanical properties of clear wood because of naturally occurring characteristics that can be seen and judged by the eye (Kretschmann and Green, 1999). These visual characteristics are used to sort the timber into grades but are not limited to density, slope of grain, size and location of knots, checks and splits. When BS 5268 was published in 1984, the numbered grades i.e. 75, 65, 50 and 40 were withdrawn and replaced by two visual grades: General Structural (GS) and Special Structural (SS) (Appiah-Kubi, 2009). The SS grade was used as the basis for strength and modulus of elasticity determination by subjecting a large number of structural sized specimens to short-term load test.

2.4.2 Mechanical Stress Grading (MSG)

The MSG is based on the fact that there is direct relation between the modulus of elasticity measured over a relatively short span. The elasticity value of a timber is however, significant sorting parameters for this way of grading. The stiffness is assessed non-destructively by feeding individual pieces of timber through series of rollers on a machine which automatically applies small transverse loads over short successive lengths and measures the deflections (Appiah-Kubi, 2009).

2.4.3 Strength Classes

The current version of BS 5268 (2002), machine graded timber is now graded directly to one of the sixteen (16) strength classes define in BS EN 519, principally on the basis of bending stress, mean modulus of elasticity and characteristic density and marked accordingly. The sixteen (16) strength classes include C14, C16, C18, C22, C24, TR26, C27, C30, C35, C40, D30, D35, D40, D60 and D70. Meaning that C14 has the lowest strength characteristics and D70 has the highest strength characteristics. The strength classes C14 to C40 and TR26 are for softwoods (coniferous) and D30 to D70 are for hardwoods (deciduous) respectively and the values 14, 16 up to 70 denote the bending strength in N/mm^2. TR is softwood and is intended for use in the design of trussed rafters (TR denotes 'Trussed Rafter').

2.5 Some Standards (grades) for Physical and Mechanical Test

2.5.1 Ratio of dry to green grades, Ghana and USA.

Table 2.3: Ratio of dry to green grades, Ghana and USA

Ghanaian hardwood (mean)	1.20 – 1.61	1.13 – 1.39	1.4 – 1.75	1.39 – 1.71
USA hardwood (mean)	1.20 – 2.10	1.11- 1.52	1.61 – 260	1.13 – 1.82

Dry means 12% moisture content source: American Society for Testing and Materials (ASTM, 2008).

2.5.2 TEDB (1994) has classified strength of species based on the MOE at 12% moisture Content as follows: Medium to very high classification indicate that the tree can be used for construction, flooring, stairs, furniture and cabinet works, boats, canoes, panelling and mouldings.

‘Very High’ [19,000 N/mm^2 and more]

‘High’ [14,000 N/mm^2 – 19,000 N/mm^2]

‘Medium’ [11,000 N/mm^2 –14,000 N/mm^2]

‘Low’ [below 9,000 N/mm^2]

2.5.3 Classification according to Based on Bolza and Keating (1972)

Wood species that falls within the MOR ranges S2-S4 predicts the wood uses as carvings, artifacts, construction, bridges, sleepers, furniture, mouldings, and musical instruments.

S2 [MOR of 134 N/mm^2 and more]

S3 [MOR of 114 N/mm^2 - 134 N/mm^2]

S4 [MOR of 93.7 N/mm^2 -114 N/mm^2]

2.5.4 TEDB (1994) Weight classification. The weight of a species is a broad guide to its performance. Lighter weight species are softer, less durable and less strong. Heavy species can exhibit high level of strength, and toughness.

To assist in gaining a general idea of the nature of a species, the descriptions provide the average weight of that species when dried to 12-15% moisture content. In practice there is always variation. Wood species with very high to light-medium classification predicts the tree uses as construction, furniture, panelling, moulding, frames, trims, sleepers, floorings, vehicle and truck bodies.

Weight (kg per m^3) at 12-15% moisture content.

Light	350 or less
Light-Medium	350 – 450
Medium	450 – 575
Medium-Heavy	575 – 725
Heavy	725 – 900
Very Heavy	900 or higher

2.6 Natural Durability of Wood

According to Toole (1970), Eslyn and Highley (1976), wood is a natural polymer consisting primarily of cellulose, hemicellulose, and lignin in a matrix that provides structural support to the living tree and some resistance against microbial attack. Cellulose, because of its partial crystallinity, is somewhat resistant to microbial attack. Lignin is a heterogenous polymer of phenyl propane units and is extremely resistant to some decay fungi. Nevertheless, other organisms have developed the ability to attack one or more of the polymers in the wood cell wall. Some wood species have evolved to produce extractive compounds that can protect the wood; these are the principal source of decay resistance in all species. These compounds are produced as the living ray cells in the inner sapwood zone die, forming the non-living heartwood. As the sapwood dies in wood species with durable heartwood, a series of reactions in the storage or parenchyma cells of the wood rays converts the stored sugars and starch into a wide array of fungi toxic compounds that become a constituent of the new heartwood. Sapwood of nearly all species has no natural durability. Heartwood of some species has a distinctive darker color, while in others it differs little in color from the sapwood. Scheffer and Cowling (1966) indicated that the decay resistance among woods may vary among tree species, among individual trees, and within individual trees. Variation in the inhibitory components of the heartwood is considered.

2.7 Literature about the Species for the Research

Gmelina arborea, according to Akachukwu (1990), is an exotic species from the Indo – Burma region of South – East Asia, is a potential source of several types of industrial raw materials, with density and strength properties. *Gmelina arborea* is an unarmed, moderately sized to large deciduous tree with a straight trunk. It is wide spreading with numerous branches forming a large shady crown, attains a height of 30 m or more and a diameter of up to 4.5 m. Bark smooth, pale ashy-grey or grey to yellow with black patches and conspicuous corky circular lenticels. When first cut, the wood is yellowish- to reddish-white, turning light russet or yellowish-brown with a density of 450-575 kg/m^3. The wood seasons well without degrading, but it is slow to dry both in the open and in a kiln. Where it is indigenous, it is regarded as a valuable general-purpose wood because of its dimensional stability. Uses include the manufacture of furniture, plywood core stock, mine props, matches and timber for light construction. It is a highly light-demanding species and regenerates naturally only in the open and on the edge of forests. It is an ideal choice for large-scale afforestation programmes.

2.8 Conclusion

The review of the research works on strength properties of timber and previous works conducted in similar topics aided in finding the types of tests that were conducted on the two different years group of the species. Test procedures, methods and analysis of results to be employed in Chapter 3 of this thesis were based on approved test standards as used in research reviewed above. It was observed that the use of small clear size specimen e.g. 20mmx20mmx300mm gave higher mechanical properties than structural size specimen e.g. 50mmx100mmx3000mm. This is as a result of the presence of defects that weaken and subsequently cause variability in the strength properties of the timber.

CHAPTER THREE

MATERIALS AND METHODS

3.0 Introduction

One (1) fifteen (15) and one (1)thirty (30) years *Gmelina arborea* were harvested from a plantation in the Odomi Forest Reserve in the Juaso District in the Ashanti Region. The compartment where the materials were procured lies between latitude 6^0 $35^{''}$ N and longitude 1^0 $12^{''}$ W. This plantation is located in the Semi-Deciduous Rainforest ecological zone of Ghana which has a bimodal rainfall with an annual rainfall of 1400mm, Brammer, (1962) as cited by Adjei-Agyapong and Asiamah, (2000). According to Brammer (1962), the soil in this ecological zone is deep and highly weathered and has moderate to strong acid in the surface soil. The soil has high organic matter in the top horizon which contributes to Nitrogen levels in the soil.

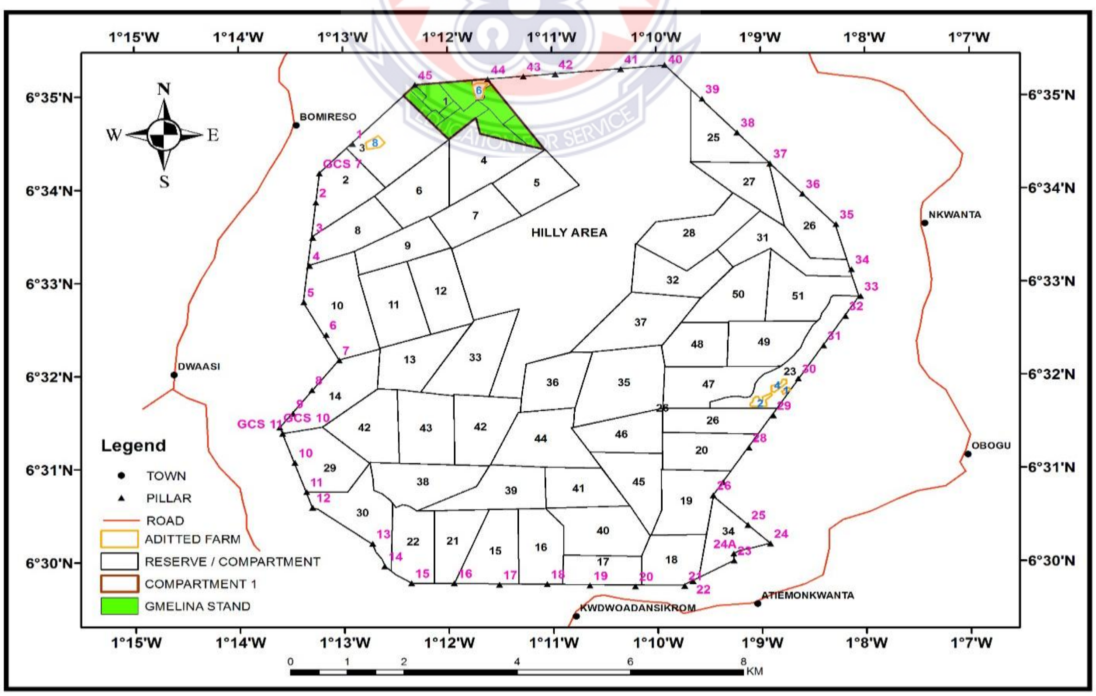


Figure 3.1: Map of the Study Area

3.1 Collection of *Gmelina arborea* Samples

One (1) fifteen (15) and one (1) thirty (30) years *Gmelina arborea* trees were purposefully selected because of native knowledge of the ages of the trees from the plantation. The thirty (30) years tree measuring 20m in length and 0.30-0.45m in diameter was randomly selected from the plantation forest. The bole of the 30 year old was divided into three sections (base, middle and top) each measuring 0.4m. And the 15 years was cut into three sections (base, middle and top) measuring 0.4m.They were labeled and transported from the plantation in Konongo in the Ashanti region to the workshop of the Department of Wood Science and Technology, Kwame Nkrumah University of Science And Technology (KNUST) for air drying.

3.2 Preparation of Test Samples for Experimentation

The samples were prepared based on British Standards BS 373 (1957) for modulus of rupture, modulus of elasticity, compression parallel to grain, moisture content, oven-dry density and shear parallel to grain were prepared based on American Society for Testing and Materials (ASTM 1666) methods of testing small clear specimen of timber. It utilizes small, clear, straight-grained pieces of wood, which represent maximum quality that can be obtained. Samples were carefully selected from the prepared stakes of each board (sawn planks) free from defects such as knots, sloping grain and other deterioration caused by insects and fire as from literature these factors reduce some strength properties of wood.

The sections of *Gmelina arborea* were sawn into billets using the quarter sawing method. Desired samples sizes (Table 3.1, *a* and *b*) for the various tests (i.e. oven dry mass, density and moisture content, compression parallel to the grain, and static bending) were then obtained from defect free billets without differentiating between the heartwood and the sapwood. Thirty(30) samples each from the base, the middle and the crown of the thirty (30) years old and same quantities of samples obtained from the fifteen (15) years *Gmelina arborea* were used for the mechanical tests. After sawing, the boards were further planned and carefully examined for any visible defect. Two hundred and seventy (270) samples (made up of heart, sapwood portions and billet divisions) of each tree were prepared for dry compression parallel to the grain, shear strength, modulus of elasticity (MOE) and modulus of rupture (MOR) tests. Thirty(30) samples each from the base, the middle and the crown of the thirty (30) years old and same quantities of samples obtained from the fifteen (15) years *Gmelina arborea* were used for the oven-dry density and moisture content tests.

Table 3.1*a*: Sample sizes and the number of replicates used for Physical and Mechanical Properties Tests for the 30 years *Gmelina arborea*.

Type of Test	Sample Size	Part of Stem Used			Total
		Base	Middle	Top	
Density	20×20×20	30	30	30	90
Moisture Content	20×20×20	30	30	30	90
Compression Parallel to Grain	20×20×60	30	30	30	90
MOE and MOR	20×20×300	30	30	30	90
Shear Strength	50×50×50	30	30	30	90

Units (mm)

Table 3.1*b*: Sample sizes and the number of replicates used for Physical and Mechanical Properties Tests for 15 years *Gmelina arborea*.

Type of Test	Sample Size	Part of Stem Used			Total
		Base	Middle	Top	
Density	20×20×20	30	30	30	90
Moisture Content	20×20×20	30	30	30	90
Compression Parallel to Grain	20×20×60	30	30	30	90
MOE and MOR	20×20×300	30	30	30	90
Shear Strength	50×50×50	30	30	30	90

Units (mm)

3.3 Physical Test

Physical properties investigated were moisture content (mc) and density.

3.3.1 Moisture content of *Gmelina arborea*

MC was determined using the oven-dry method. The samples were weighed and oven-dried at 103±2°C until constant mass was attained at the Faculty of Renewable and Natural Resource (FRNR). The moisture content (MC) was calculated using the formula:

$$\%MC = \frac{Initial\ mass - oven\ dry\ mass}{oven\ dry\ mass}\ x\ 100\ (Hartley\ and\ Merchant, 1995)$$

3.3.2 Density of *Gmelina arborea*

The test samples were cut into the dimensions of 20 × 20 × 20 mm according to (KIAEI *et al*., 2011). In all, 30 samples were prepared along the stem. Wood samples were soaked in water for 72 hours to ensure that their moisture content was above the fiber saturated point. Their dimensions were measured in all three principal directions (length, breadth and height) with a digital caliper to the nearest 0.001mm. The samples were finally oven-dried at 103 ± 2° C to 0 % constant moisture content after which the oven-dried weights and volumes of the specimens were measured using the balance and the digital caliper respectively.

3.4 Mechanical Properties of *Gmelina arborea*

The determinations of mechanical properties of *Gmelina arborea* were carried out at the laboratory of the Forestry Research Institute of Ghana (FORIG) of the Council for Scientific and Industrial Research (CSIR) at Fumesua in Kumasi. All tests were carried out using BS 373 (1957).

3.4.1 MOR and MOE of *Gmelina arborea*

The test procedure for MOR and MOE involves the determination of the maximum load required to cause rupture using small clear wood specimens (BS 373, 1957). A laboratory table with two metal supports solidly mounted by means of screws was used for the experiment. A rectangular- shaped metal was hanged at the midpoint of the specimen and a hook with a circular base was hanged on the metal. The test specimen was placed on the supports, maintaining a length of 10mm at both ends of the support. Weights were placed on the specimen until failure and the maximum load that caused failure of the test samples were recorded. The MOR in three-point bending was calculated from the Equation: **MOR** = $\frac{3PL}{2bd^2}$ (Haygreen and Bowyer, 1981).

Where: MOR = Modulus of Rupture (N/mm^2), P = maximum load (N), L = span in mm, b = the width of sample (mm), and d = depth of sample (mm). The ultimate strength [ρW (12%)] will be computed at an adjustment of strength at 12% moisture content, using the equation $\rho W\ (12\%) = \rho W\{1 + \alpha(W - 12)\}$ (Haygreen and Bowyer, 1981), where: W is the mc of the test specimen and α is a constant, 0.04.

The modulus of elasticity (MOE) in three point bending was calculated using the formula

MOE = $\frac{l^3}{4bd^3}\ x\ \frac{\Delta W}{\Delta X}$: (Pashin, 1974; Bektas et al., 2002) where: MOE is Modulus of Elasticity (N/mm^2), W = load (N), L = the length of span (mm), b = width of specimen (mm), d-depth or thickness of specimen (mm) and Δx deflection at mid-span. The term $\frac{\Delta W}{\Delta X}$ is the gradient of the elastic region of the load-deflection graph.

3.4.2 Shear Strength Parallel to the Grain

Wood samples were placed in a shear machine and a loads applied parallel to its grains until its failure. The maximum load that caused the failure was recorded (BS 373, 1957). Shear strength (ρW) was computed using the equation: $\rho W = \frac{\rho max}{b.l}$ (Haygreen and Bowyer, 1981). Where: ρmax = the maximum load (N) and b = the thickness of the piece (mm) and l = the length.

3.4.2 Compressive Strength Parallel to the Grain

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 (ρmax) recorded during test by the cross- sectional area (A) of the specimen.

CHAPTER FOUR

RESULTS PRESENTATION

4.0 Introduction

According to Akachukwu (1990) *Gmelina arborea* is an unarmed, moderately sized to large deciduous tree with a straight trunk. It is wide spreading with numerous branches forming a large shady crown, attains a height of 30 m or more and a diameter of up to 4.5 m. Bark smooth, pale ashy-grey or grey to yellow with black patches and conspicuous corky circular lenticels. When first cut, the wood is yellowish- to reddish-white, turning light russet or yellowish-brown with a density of 450-575 kg/m^3. *Gmelina arborea* is widely distributed in the major rain forests in Ghana and it is a highly light-demanding species and regenerates naturally only in the open and on the edge of forests. Furthermore, it is an ideal choice for large-scale afforestation programmes.

The density, the MOE, MOR, compression parallel to the grain and shear were tested for normality and homogeneity in mechanical strength using the Tukey mean comparison at a confidence level of 0.05 using the Origin Analysis Software version 9.0. The data obtained was processed and changed into Microsoft Excel formats before subjecting them to the ANOVA one way using the Origin.

For null hypothesis the means of all levels are equal, alternative hypothesis the means of one or more levels are different and at 0.05 levels the population means are significantly different. Also Sig equals 1 indicates that the difference of the means is significant at the 0.05 level and Sig equals 0 indicates that the difference of the means is not significant at the 0.05 level. (Appendix).

Results were obtained for the two year groups, that is, the 15 years and the 30 years and in each case for each test they were further grouped into top, middle and the base. The tables below shows the results obtained from the physical and mechanical properties.

Table 4.1: 15 Years *Gmelina arborea*: Density, Moisture Content and Mechanical Properties

Property	Means		Sig	Means		Sig	Means		Sig
	Mid	Top		Base	Top		Base	Mid	
MC %	14.55	13.32	1	13.58	13.32	0	13.58	14.55	0
Density(kgm^{-3})	403.31	426.12	0	433.56	426.12	0	433.56	403.31	1
MOE (Nmm^{-2})	8703	8003	1	9287	8003	1	9287	8703	0
MOR (Nmm^{-2})	64.61	59.97	0	68.88	59.97	1	68.88	64.61	0
Comp.*ll*g(Nmm^{-2})	31.57	29.65	0	37.09	29.65	1	37.09	31.57	1
Shear (Nmm^{-2})	10.53	8.88	1	11.13	8.88	1	11.13	10.53	0

N = 30 in each section for each property

Table 4.1 considered the physical and mechanical properties of the various sections along the tree height of the 15 years, i e, the top, the mid and the base. From the table, the results show that there were significant differences of the means (1) between the mid and the top, no significant differences of the means (0) between the base and the top and no significant difference (0) between the base and the mid for the moisture content.

Observing from table, the mid and the top there were no significant difference of the means (0) as well as the base and the top in terms of the density, however there was a significant difference between the base and the top means (1).

The results from the Table 4.1, show that there was a significant difference between the mid and the top means (1) as well as the base and the top means (1) but there was no significant difference between the means (0) of the base and the mid for the MOE. The MOR results showed that there were no significant differences between the means (0) of the mid and the top, and the base and the mid. But it showed a significant difference between the base and the top means (1).

From the Table 4.1, the results showed that there was no significant difference between the mid and the top means (0). While there were significant differences between the base and the top means and that of the base and the mid means (1) for the compression parallel to the grain. The differences between the mid and the top and that of the base and the top means (1) were significant for shear strength. Yet there was no significant difference between the means (0) of the base and the mid in terms of the shear strength.

Table 4.2: 30 Years *Gmelina arborea*: Density, Moisture Content and Mechanical Properties.

Property	Means		Sig	Means		Sig	Means		Sig
	Mid	Top		Base	Top		Base	Mid	
MC %	13.60	13.00	0	12.10	13.00	1	12.10	13.60	1
Density(kgm^{-3})	459.17	453.06	0	463.09	453.06	0	463.09	459.17	0
MOE (Nmm^{-2})	10443	10222	0	11721	10222	1	11721	10443	1
MOR (Nmm^{-2})	66.52	65.51	0	75.07	65.51	1	75.07	66.52	1
Comp.*ll*g (Nmm^{2})	32.35	29.84	0	38.58	29.84	1	38.58	32.35	1
Shear (Nmm^{-2})	11.04	10.23	0	11.58	10.23	1	11.58	11.04	0

N = 30 in each section for each property

Table 4.2 results show the physical and mechanical properties of the various sections along the tree height of the 30 years, i e, the top, the mid and the base. The results showed that there was no significant difference between the means (0) of the mid and the top. However, there were significant differences between the means (1) of the base and the top and that of the base and the mid for the moisture content. It was observed that for the density of this tree there were no significant differences in the means (1) throughout the tree.

There was no significant difference between the means (0) of the mid and the top with regards to the MOE. But there were significant differences between the means (1) of the base and the top and the base and the mid of the tree. The results from the table show that there was no significant difference between the means (0) of the mid and the top for the MOR. However there were significant differences between the means of the base and the top and the base and the mid.

Of the compression parallel to the grain of the wood, it was observed that between the mid and the top there was no significant difference in the means (0). With the base and the top and the base and the mid there were significant differences between the means (1).
Results from the table show that there were no significant differences between the means (0) of the mid and the top and the base and the mid. But there was significant difference between the means (1) of the base and the mid concerning the shear.

Table 4.3: 15 and 30 Years *Gmelina arborea*: Density, Moisture Content and Mechanical Properties

Property	15 years			30 years			Sig
	N	Mean	SD	N	Mean	SD	
MC %	90	13.32	0.54	90	13.00	0.24	0
Density(kgm^{-3})	90	403.31	19.56	90	473.06	19.57	1
MOE (Nmm^{-2})	90	8665	1179.26	90	10875	1473.17	1
MOR (Nmm^{-2})	90	64.30	10.56	90	69.16	10.04	1
Comp.*ll*g (Nmm^{-2})	90	33.03	4.97	90	33.33	5.88	0
Shear (Nmm^{-2})	90	10.18	1.75	90	10.95	1.65	1

Table 4.3 finds the physical and mechanical properties of the 15years to that of the 30 years. Results from the table show that there are significant differences between the means (1) of moisture content, MOE, MOR and the shear strength of the two (2) different year groups. Notwithstanding there was no significant difference between the means of the compression parallel to the grain.

Table 4.4: 15 and 30 Years Top *Gmelina arborea*: Density, Moisture Content and Mechanical Properties

Property	15 years Top			30 years Top			Sig
	N	Mean	SD	N	Mean	SD	
MC %	30	12.56	0.49	30	13.58	0.32	0
Density(kgm^{-3})	30	433.56	32.01	30	463.09	24.56	1
MOE (Nmm^{-2})	30	8003	759.88	30	10043	927.51	1
MOR (Nmm^{-2})	30	59.97	9.40	30	65.51	7.68	1
Comp.*ll*g (Nmm^{-2})	30	29.65	4.04	30	29.84	5.95	0
Shear (Nmm^{-2})	30	8.87	1.50	30	10.23	1.36	1

Table 4.4 shows the tops of the two (2) different year groups in terms of their moisture content, density, MOE, MOR, compression parallel to the grain and shear strength. It was observed that comparing the two tops there were no significant differences between the means (0) of the moisture content and the compression parallel to the grain. Yet the results show significant differences in the means (1) of the following properties density. MOE, MOR and the shear strength.

Table 4.5: 15 and 30 Years Mid *Gmelina arborea*: Density, Moisture Content and Mechanical Properties

Property	15 years Mid			30 years Mid			Sig
	N	Mean	SD	N	Mean	SD	
MC %	30	13.60	0.28	30	14.55	0.40	0
Density(kgm^{-3})	30	409.31	34.53	30	458.17	32.63	1
MOE (Nmm^{-2})	30	8703.96	1283.19	30	10443.93	1218.49	1
MOR (Nmm^{-2})	30	64.61	9.98	30	66.52	9.85	0
Comp.*ll*g (Nmm^{-2})	30	31.57	3.96	30	32.35	3.72	0
Shear (Nmm^{-2})	30	10.53	1.22	30	11.04	1.56	0

Table 4.5 results show the mid of the two (2) different year groups in terms of their moisture content, density, MOE, MOR, compression parallel to the grain and shear strength. Comparing the mid of the two trees, the result showed that there were significant differences between the means (1) of the properties density and MOE. However, there were no significant differences between the means (0) of the properties moisture content, MOR, compression parallel to the grain and shear strength.

Table 4.6: 15 and 30 Years Base *Gmelina arborea*: Density, Moisture Content and Mechanical Properties

Property	15 years Base			30 years Base			Sig
	N	**Mean**	**SD**	**N**	**Mean**	**SD**	
MC %	30	13.43	0.53	30	13.33	0.26	0
Density(kgm^{-3})	30	416.13	34.67	30	463.05	19.23	1
MOE (Nmm^{-2})	30	9287	1090.26	30	11721	1119.12	1
MOR (Nmm^{-2})	30	68.88	10.94	30	75.07	9.87	1
Comp.*ll*g (Nmm^{-2})	30	37.09	4.04	30	38.57	3.24	0
Shear (Nmm^{-2})	30	11.13	1.67	30	11.58	1.77	0

Table 4.6 the base of the two (2) different year groups in terms of their moisture content, density, MOE, MOR, compression parallel to the grain and shear strength. From the results the properties moisture content, compression parallel to the grain and shear strength had no significant differences between the means (0). But the properties density, MOE and MOR had significant differences between the means (1) of the base of the two trees.

CHAPTER FIVE

DISCUSSION

5.0 Introduction

This chapter presents the discussion on the results, the summary of the findings from the data gathered. It also looks at the suggestions for further research. The focus of the discussion will be on the mechanical strength properties of the *Gmelina arborea* for ages fifteen (15) and thirty (30) with respect to the density and moisture content. Also the intra-comparison (longitudinal comparison) within the year groups shall be considered, that is, the top, middle and the base. Data of the mechanical properties has been collected and analyzed, including the Modulus of Elasticity, Modulus of Rupture, Compression parallel to the grain and Shear parallel to the grain.

5.1 Research Findings

5.1.1 Mechanical and Physical Properties of 15 years old *Gmelina arborea*

According to the results obtained, the Modulus of Elasticity (MOE) and the Modulus of Rupture (MOR) for the Fifteen (15) years *Gmelina arborea*, were higher as the moisture content reduces and the density increases. This phenomena is in line with the general principles of mechanical strength properties of wood according to Panshin & de Zeeuw (1980),which states that wood increases in strength when the moisture content of the wood reduces and for density the higher the density the stronger the wood. From the results realized the MC for base and mid was not significantly different as there was no significant difference among the means of their MOEs.

In the case of the compression parallel (Comp.*llg*) to the grain there were significantly difference between the means of the base and top and that of the base and mid. And shear there were also significant difference in the means of the mid and top and the base and top. Regarding density, the base has the highest top and mid respectively with moisture content being the opposite. This explains why the base with the highest density and low moisture content had the highest compressive and shear strength followed by the base and the top.

The strength of the fifteen (15) year *Gmelina arborea* at 12% moisture content is slightly higher than *Rhodognaphalon brevicuspe* (Agyeman, V. K. et al, 2003). The strength properties of the fifteen (15) years *Gmelina arborea* are: compressive strength parallel to the grain, 33.03Nmm^{-2}, Modulus of Elasticity, 8,665Nmm^{-2} and modulus of Rupture, 64.30Nmm^{-2}.

5.1.2 Mechanical and Physical Properties of 30 years old *Gmelina arborea*

The Modulus of Elasticity and Modulus of Rupture, MOE and MOR respectively, increased in strength from the top to the base of the 30 years *Gmelina arborea*. Considering the mean moisture content of the samples, it reduced in percentages from the base to the top, and knowing that the strength of wood increase with decreases in MC, the base which recorded greater density although densities for top, mid and base were not significantly different, eventually became stronger on MOE and MOR. The compressive and shear strength recorded the highest strength from the top to the base with alternative moisture content. However, considering Table 4.2, the means for all the properties for the mid and the top were not significantly different, meaning there is a possibility of *Gmelina arborea* growing to uniform properties along the tree as it ages beyond thirty years. Density at the age thirty (30) years was not significantly different as the case of the 15 years old. This means as *Gmelina arborea* ages, its densities become uniform along the tree under normal circumstances.

The strength of the thirty (30) year *Gmelina arborea* at 12% of moisture content are: Modulus of elasticity, 10,875Nmm^{-2}, Modulus of rupture, 69.16Nmm^{-2} and Compression parallel to the grain, 33.33Nmm^{-2} and according to Addae-Mensah et al, (1989) and cited by Agyeman, V. K. et al, (2003), these strength properties compare favourably with *Canarium schweinfurthii*.

5.1.3 General Comparison between 15 and 30 years for Mechanical and Physical Properties

Strength properties of wood samples are related to the moisture content of the wood, (Kollmann and Cote, 1968). From Table 4.3, the mean moisture content for the 15 years shows a higher value of 13.32% and 13.00% for the 30 years although they were not significantly different. However, there were also significant difference between the two year group as shown in Table 4.3, that is, 403.31kgm^3 and 473.06 kgm^3 for 15 and 30 years respectively. (Kollmann & Cote, 1968). The result indicates that, increase in the age of *Gmelina arborea* increases the density, which is why mechanical properties of 30 years old *Gmelina arborea* were significantly higher than that of the 15 years. With the exception of the compression parallel to the grain, which was not significantly different among the two year groups, the MOE (15years: 8665 N/mm^2, 30years: 10875 N/mm^2), MOR (15years:64.30N/mm^2, 30years:69.16N/mm^2) and Shear were significantly different. This means age does not necessarily have influence on the compressive strength of *Gmelina arborea*. This conclusion was drawn from the variance (ANOVA) analysis of the two year groups where N=90 in each case.

5.1.4 Longitudinal Comparison between fifteen (15) and thirty (30) years, Mechanical and Physical Properties

Regarding the mechanical properties and the structural use of wood, moisture content is known to be one of the major influencing factors (Arnold, 2010). According to the results obtained in Tables 4.4, 4.5 and 4.6 there were no significant difference in the mean value of the moisture content of the tops, the middles and the bases of the two different year groups. However, the density showed significant difference among the tops, mid and the butt (base). The Modulus of elasticity for the top, middle and butt were significantly different for the two ages which can be attributed to the significant difference in their densities.

The Modulus of elasticity is a measure of resistance to bending. The Modulus of elasticity of the two tops from Tables 4.4, 4.5 and 4.6 when they are at a moisture content of 12% were as follows: MOE (15) and (30) top 8,003 Nmm^{-2} – 10,043 Nmm^{-2}, MOE (15) and (30) mid 8,703.96 Nmm^{-2} – 10,443.93 Nmm^{-2} and MOE (15) and (30) base 9,287 Nmm^{-2} – 11,721 Nmm^{-2}. It was observed among the Tables 4.4, 4.5 and 4.6 that, there was consistent variation among the MOEs of the various portions of the two trees. When compared to the three known species ,*Aningeria altissima* 11,100.00 Nmm^{-2} , *Terminaria ivorensis* 9300.00 Nmm^{-2} , *Antiaris toxicaria* 7200.00 Nmm^{-2}, the various MOEs of the parts are closely related and predict that these parts of *Gmelina arborea* wood performance when used for furniture production. Among the parts (MOE) varies but the variations are not significant as the variation within the tree.

Compressive strength properties of the two year groups remains insignificantly different among the top, middle and the butt, the results compared to three known species, *Gmelina arborea* gave lower values. *Aningeria altissima* had 52.00 - 57.00 Nmm^{-2}, *Terminaria ivorensis* had 35.00 Nmm^{-2} and *Antiaris toxicaria* had 54.00 Nmm^{-2}, there were no significant variations in the compressive strength along the longitudinal parts of the two trees, Tables 4.4, 4.5 and 4.6, however, they do not compare favorably in value with the three trees. Another observation was that with *Gmelina arborea*, the compressive strength is independent of the age of the tree.

Considering the shear strength from Tables 4.4, 4.5 and 4.6 when they are at a moisture content of 12% were as follows: shear (15) and (30) tops 8.87 Nmm^{-2} and 10.23 Nmm^{-2}, for mids 10.53 Nmm^{-2} and 11.04 Nmm^{-2} and bases 11.13 Nmm^{-2} and 11.58 Nmm^{-2} respectively, it was observed that there were no significant differences among the means, however, shear strength in the top regions of the two trees showed a significant difference. Comparing the results to three known species, *Aningeria altissima* 9.50 Nmm^{-2} *Terminaria ivorensis* 12.10 Nmm^{-2} and *Antiaris toxicaria* 7.90 Nmm^{-2}, the results showed higher values for shear strength, however, there were no significant variations along the two *Gmelina arborea* trees.

CHAPTER SIX

SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

6.0 Conclusions

The purpose of this research was to find the variation between the 15 and 30 years old *Gmelina arborea* in terms of their physical and mechanical strength properties which were extracted from a plantation in the Odomi Forest Reserve near Konongo in the Ashanti Region which happens to be a tropical forest zone of Ghana. After analyzing the results from the test conducted, the following conclusions were drawn.

There were no significant difference in the moisture content between the 15 and 30 years *Gmelina arborea* with the means of 13.32% and 13.00% respectively. However, the use of wood for furniture, structural beams, mouldings and other artifacts depends on other factors either than moisture content.

There were significant difference in the densities between the 15 and the 30 years years old *Gmelina aborea*. This adversely accounted for the significant difference in mechanical properties. Hence using the 30 year old *Gmelina arborea* for furniture and structural works will not compromise its integrity as that of the 15 year old.

It was also established that the densities of the *Gmelina arborea* increased as the tree ages, therefore, *Gmelina arborea* will be structurally sound if it is allowed to grow beyond 30years.

There were significant difference among the MOE (15years: 8665 N/mm^2, 30years: 10875 N/mm^2), MOR (15years:64.30N/mm^2, 30years:69.16N/mm^2) and Shear (15years: 10.18N/mm^2, 30 years 10.95N/mm^2) properties, however, the compressive strength (15 years: 33.03N/mm^2), 30 years: 33.33 N/mm^2) of *Gmelina arborea* in this experiment did not matter, the age had no significant difference. However, according to TEDD (1994) classifications, the strength of the 15 years in service will be compromised in the shortest possible time, since the MOE falls below 9,000 N/mm^2

The mechanical strength properties increased from the top, middle to the butt same as the densities, indicating that the butt and the mid of trees will be able to withstand loads better than the top.

6.1 Recommendations

The following recommendations have been made based on the findings and conclusions.

1. For use of *Gmelina arborea* in constructions with much compressive loads, the 15 years old can be considered since there was no significant difference with that of the 30 years.
2. The use of the specie in constructions to act as beams, the 30 years old is recommended since it is significantly better in terms of their MOE, MOR and even the shear.
3. Considering *Gmelina arborea* for construction for their density, the 30 year old is recommended since it showed much significance to that of the 15 years.

4. To achieve maximum results from *Gmelina arborea*, it is recommended that species of 30 years and above should be considered. This is because, the mechanical strength properties improves as the tree ages.

6.2 Suggestions for Future Research

The following are being suggested for future research into *Gmelina arborea*

1. Consider trees from different ecological zones of Ghana as climatic conditions of a particular location could adversely affect the current research findings.
2. As this research focuses on top, mid and butt, considerations could be given to the hearts and the sap of the species.
3. The anatomical aspect of the species should be considered as well as the fire safety test.

REFERENCES

Addae-Mensah, A. et al, (1989). Users guide of some secondary and primary species based on the strength and related properties. Information Bulletin No. 9. Forest Products Research Institute, Kumasi, Ghana.

Agyeman, V. K. et al, (2003). Technological and Investment Profiles of some lesser used timber species in Ghana.

Alik, D. & Nakai, T. (1997a). Preliminary study for structural grading based on full size bending test of Resak durian and Keruing utap Sarawak. Proceedings of the International Tropical Wood Conference, Kuala Lumpur. June 17 – 20, pp 252-260.

Allotey, I. (1992). "Design and construction of a new bridge in Ghana: Problems and solutions." Presented at the 1992 International Winter Meeting. The American Society of Agricultural Engineers, Nashvile.

American Institute of Timber Construction (AITC), (1994). Timber Construction Manual. Fourth Edition. John Wiley & Sons Inc. New York. ISBN 0-471-30970-2.

Anon (1996), Ghana Forest Development Master Plan 1996 – 2020. Ministry of Lands and Forestry, Accra, Ghana.

Appiah-Kubi, E. (2009). Investigation into lesser known timber species for light bridge construction. An M. Phil thesis presented to the Department of Wood Science and Technology, Kumasi.

Arya, C. (2003). Design of Structural Elements. Second Edition. Spon Press – Taylor & Francis Group. London, UK. Pp271.

ASTM D 143-52, Standard test methods for small clear specimens of timber. ASTM International. West Conshohocken, PA.

ASTM D4761 (1991). Standard methods for determining mechanical properties of lumber and wood based structural materials. ASTM International. West Conshohocken, PA.

Bacher, M. (2010). Grading of structural timber, unpublished presentation at Sawmilling SA meeting on 14 July 2010, Johannesburg, South Africa.

Brammer, (1962). World Reference Base (WRB).

Bolza, E. & Keating, W. G. (1972). African Timbers – the properties, uses and characteristics of 700 species. CSIRO, Division of Building Research, Melbournre, Australia.

Brazier, J.B. (1978). Harvesting mixed tropical timber for paper. Unasylva, Food and Agricultural organization (FAO), Volume 30 No. 122, p 14.

BS 5268 (2002). Code of practice for structural use of timber. British Standard Institution (BSI).

BS 5268 (1985). Code of practice for structural use of timber. BSI.

BS 373 (1957). Methods of testing small clear specimens of timber. BSI.

BS 5820 (1979). Methods of test for determination of certain physical and mechanical properties of timber in structural sizes. BSI.

Dowse, G. P. (2010). Selected mechanical properties and the structural grading og young *Pinus patula* sawn timber.

EN 384 (2004). Structural timber determination of characteristic values of mechanical properties and density. European Committee for standardization, Brussels, Belgium.

FAO (1988). Food and Agriculture Organization Year Book of Forest Products. Forestry Series No. 23, Rome, Italy. pp 50 – 58.

FC (1999). Report on export of wood products. Timber Industry Development Division, Takoradi, Ghana.

Giudiccandrea, F. & Verfurth, P. (2006). Combined strength and appearance lumber grading by multisensor technology. Wood SA and Timber Times 31(9): 50-53.

Green, D. W. & Kretschmann, D. E. (1997). Properties and grading of Southern pine timbers. For Prod J 7(9): 78-85.

Handbook of hardwood (1972).

Johansson, C. J., Bostrom, L., Brauner, L., Hoffmeyer, P., Holmquist, C. & Solli, K. H. (1998). Laminations for glued laminated timber. Swedish national testing and research institute, SP REPORT 1998:38.

Knuffel, W. E. (1984). An improved visual and mechanical stress grading system for SA pine timber. Hout 318, CSIR.

Kretschman, D. E. & Green, D. W. (1999). Wood Handbook – Wood as an Engineering Material. Forest Products Laboratory. General Technical Report FPL – GTR – 113. Madison, WI. 463p

Madsen, B. (1992). Structural behaviour of timber. Timber Engineering Ltd, North Vancouver, B.C. Canada. ISBN O – 9696162 – 0 – 1.

Moschler, W. W., Dougal, E. F. & McRae, D. D. (1989). Density and growth ring characteristics of *Pinus taeda* following thinning. Wood and Fiber Science 21 (3): 313- 319.

Ocloo, J. H. & Laing, E. (1991). Anatomical properties of the wood of some Celtis species indigenous to Ghana. Disc and Innov 3:89 – 98.

Ofori, J. (1985). A comparative study in minimizing the splitting of plantation grown Emire, *Terminalia ivorensis* A. Chev. Fencing posts during drying. Tech. Bull. For. Prod. Res. Inst., Ghana 5:1-8.

Pushin, A. J. & de Zeeuw, C. N. (1970). Textbook of wood technology, volume 1, 3rd edition. Mcgraw – Hill Book Company. NY.

Thelandersson, S. & Larsen, H. J. (eds) (2003). Timber Engineering. John Wiley & Sons Ltd. 445pp.

Upton, D. A. J. & Attah, A. (2003). Commercial timbers of Ghana. The potential for lesser used species. Forestry Commission of Ghana.

Usher, M. B. & Ocloo, K. K. (1976). The natural resistance of eighty-five West African timbers to attack by termites and microorganisms. The Tropical Pest Bulletin No. 5. Natural Resource Intitute. ISBN 10 : 0851351034. December 1979.

Walker, J. C. (1993). Primary wood processing. London: Chapman & Hall. 595pp.

Wimmer, R. (1991). Relations between growth ring parameters and density of Scots pine wood (in German). Holzforschung und Holzverwertung 43 (4): 79-82.

Wood Handbook (1974). Wood as an Engineering Material. Forest Products Laboratory, Forest Service and US Department of Agriculture.

Youngs, R. L. (1977). Research in tropical wood utilization. Unasylva 29(117), pp 9 – 11.

Zobel, B. J. & Van Buijtenen, J. P. (1989). Wood variation. Its causes and control. Springer, Heidelberg, 363pp.

APPENDICES

	N Analysis	N Missing	Mean	Standard Deviation	SE of Mean
15 Y Top	30	0	29.649	4.03554	0.73679
15 Y Mid	30	0	31.57	3.96234	0.72342
15 Y Base	30	0	37.09067	4.03872	0.73737

	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	2	895.46404	447.73202	27.81118	4.59119E-10
Error	87	1400.61226	16.09899		
Total	89	2296.0763			

Null Hypothesis: The means of all levels are equal.
Alternative Hypothesis: The means of one or more levels are different.
At the 0.05 level, the population means are significantly different.

Fit Statistics

	R-Square	Coeff Var	Root MSE	Data Mean
	0.39	0.12244	4.01235	32.76989

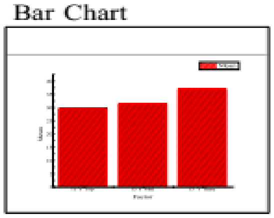
Means Comparisons

Tukey Test

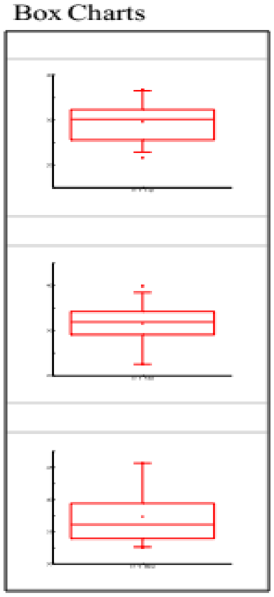
	MeanDiff	SEM	q Value	Prob	Alpha	Sig	LCL	UCL
15 Y Mid 15 Y Top	1.921	1.03599	2.62234	0.15832	0.05	0	-0.54929	4.39129
15 Y Base 15 Y Top	7.44167	1.03599	10.15854	0	0.05	1	4.97138	9.91195
15 Y Base 15 Y Mid	5.52067	1.03599	7.53621	2.25626E-6	0.05	1	3.05038	7.99095

Sig equals 1 indicates that the difference of the means is significant at the 0.05 level.
Sig equals 0 indicates that the difference of the means is not significant at the 0.05 level.

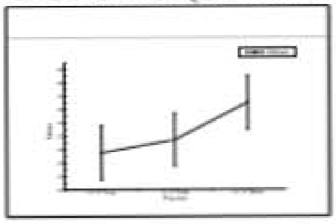
Bar Chart



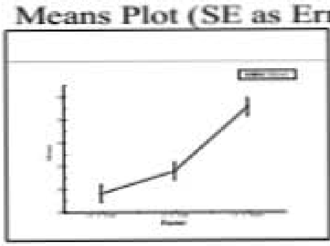
Box Charts



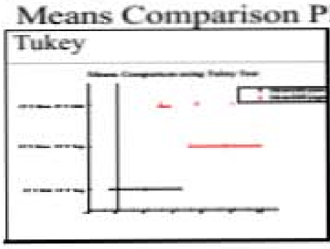
Means Plot (SD as Error)



Means Plot (SE as Error)



Means Comparison Plot



ANOVAOneWay (3/1/2017 21:19:05)

Descriptive Statistics

	N Analysis	N Missing	Mean	Standard Deviation	SE of Mean
15 Y	90	0	33.02878	4.96983	0.52387
30 Y	90	0	33.32889	5.87507	0.61929

One Way ANOVA

Overall ANOVA

	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	4.053	4.053	0.13689	0.71183
Error	178	5270.19125	29.60782		
Total	179	5274.24425			

Null Hypothesis: The means of all levels are equal.
Alternative Hypothesis: The means of one or more levels are different.
At the 0.05 level, the population means are not significantly different.

Fit Statistics

	R-Square	Coeff Var	Root MSE	Data Mean
	7.68451E-4	0.164	5.44131	33.17883

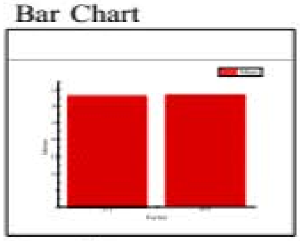
Means Comparisons

Tukey Test

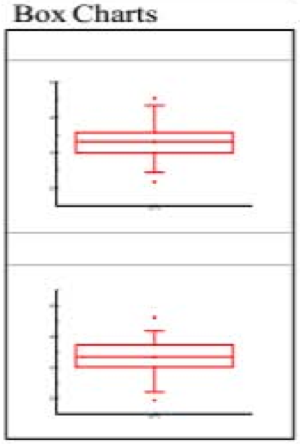
	MeanDiff	SEM	q Value	Prob	Alpha	Sig	LCL	UCL
30 Y 15 Y	0.30011	0.81114	0.52324	0.71183	0.05	0	-1.30058	1.9008

Sig equals 1 indicates that the difference of the means is significant at the 0.05 level.
Sig equals 0 indicates that the difference of the means is not significant at the 0.05 level.

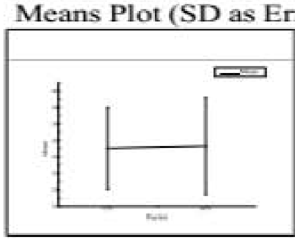
Bar Chart



Box Charts



Means Plot (SD as Error)



ANOVAOneWay (3/2/2017 05:52:46)

Descriptive Statistics

	N Analysis	N Missing	Mean	Standard Deviation	SE of Mean
30 Y Top	30	0	29.84067	5.95304	1.08687
30 Y Mid	30	0	32.34667	3.71997	0.67917
30 Y Base	30	0	38.576	3.24371	0.59222

One Way ANOVA

Overall ANOVA

	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	2	1213.90678	606.95339	30.44989	9.45148E-11
Error	87	1734.15877	19.93286		
Total	89	2948.06556			

Null Hypothesis: The means of all levels are equal.
Alternative Hypothesis: The means of one or more levels are different.
At the 0.05 level, the population means are significantly different.

Fit Statistics

	R-Square	Coeff Var	Root MSE	Data Mean
	0.41176	0.13292	4.46462	33.58778

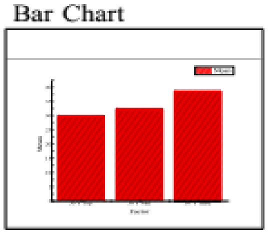
Means Comparisons

Tukey Test

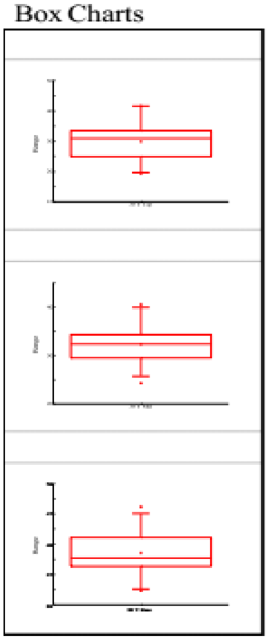
	MeanDiff	SEM	q Value	Prob	Alpha	Sig	LCL	UCL
30 Y Mid 30 Y Top	2.506	1.15276	3.07438	0.08142	0.05	0	-0.24273	5.25473
30 Y Base 30 Y Top	8.73533	1.15276	10.71656	0	0.05	1	5.9866	11.48407
30 Y Base 30 Y Mid	6.22933	1.15276	7.64218	1.64456E-6	0.05	1	3.4806	8.97807

Sig equals 1 indicates that the difference of the means is significant at the 0.05 level.
Sig equals 0 indicates that the difference of the means is not significant at the 0.05 level.

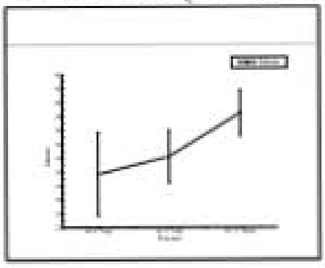
Bar Chart



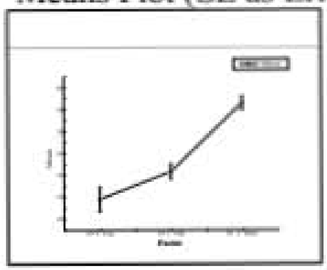
Box Charts



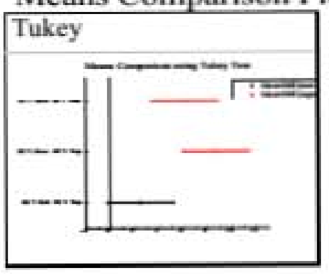
Means Plot (SD as Error)



Means Plot (SE as Error)



Means Comparison Plot



ANOVAOneWay (2/28/2017 09:03:18)

Descriptive Statistics

	N Analysis	N Missing	Mean	Standard Deviation	SE of Mean
15 Y Top	30	0	8003.36667	759.8874	138.73582
15 Y Mid	30	0	8703.96667	1283.19309	234.27793
15 Y Base	30	0	9287.4	1090.26244	199.05378

One Way ANOVA

Overall ANOVA

	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	2	2.47998E7	1.23999E7	10.9004	5.96473E-5
Error	87	9.89679E7	1.13756E6		
Total	89	1.23768E8			

Null Hypothesis: The means of all levels are equal.
Alternative Hypothesis: The means of one or more levels are different.
At the 0.05 level, the population means are significantly different.

Fit Statistics

	R-Square	Coeff Var	Root MSE	Data Mean
	0.20037	0.12309	1066.56545	8664.91111

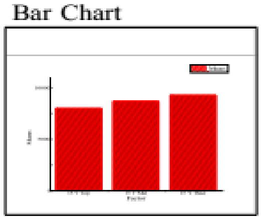
Means Comparisons

Tukey Test

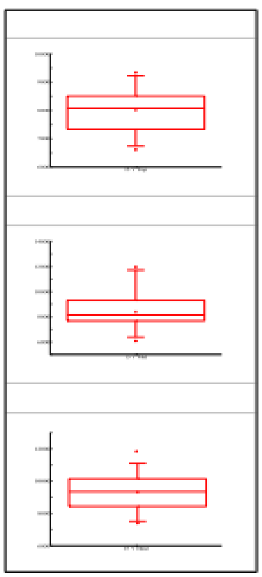
	MeanDiff	SEM	q Value	Prob	Alpha	Sig	LCL	UCL
15 Y Mid 15 Y Top	700.6	275.38601	3.59785	0.0337	0.05	1	43.94771	1357.25229
15 Y Base 15 Y Top	1284.03333	275.38601	6.59401	3.3076E-5	0.05	1	627.38104	1940.68563
15 Y Base 15 Y Mid	583.43333	275.38601	2.99616	0.09195	0.05	0	-73.21896	1240.08563

Sig equals 1 indicates that the difference of the means is significant at the 0.05 level.
Sig equals 0 indicates that the difference of the means is not significant at the 0.05 level.

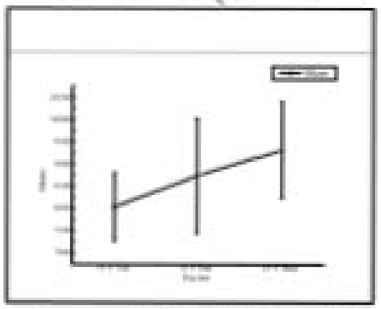
Bar Chart



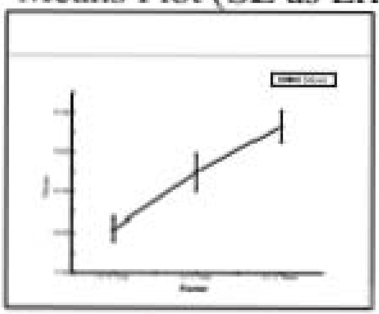
Box Charts



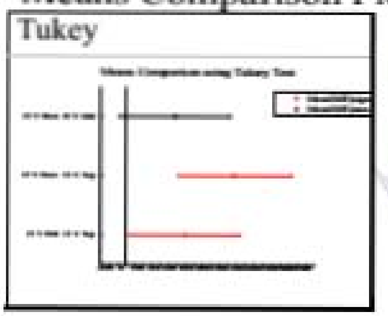
Means Plot (SD as Error)



Means Plot (SE as Error)



Means Comparison Plot



ANOVAOneWay (2/28/2017 09:23:46)

Descriptive Statistics

	N Analysis	N Missing	Mean	Standard Deviation	SE of Mean
15 Y	90	0	8664.91111	1179.25727	124.30463
30 Y	90	0	10875.74444	1473.16546	155.28527

One Way ANOVA

Overall ANOVA

	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	2.1995E8	2.1995E8	123.53759	0
Error	178	3.16917E8	1.78043E6		
Total	179	5.36867E8			

Null Hypothesis: The means of all levels are equal.
Alternative Hypothesis: The means of one or more levels are different.
At the 0.05 level, the population means are significantly different.

Fit Statistics

	R-Square	Coeff Var	Root MSE	Data Mean
	0.40969	0.13657	1334.32833	9770.32778

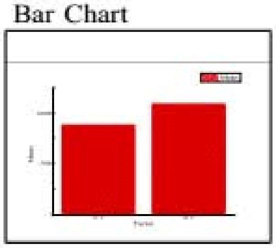
Means Comparisons

Tukey Test

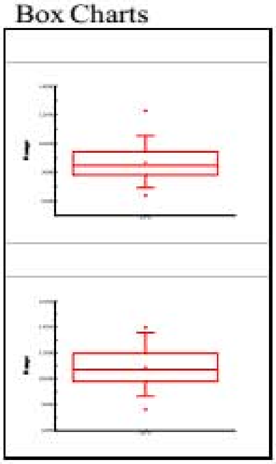
	MeanDiff	SEM	q Value	Prob	Alpha	Sig	LCL	UCL
30 Y 15 Y	2210.83333	198.90992	15.71862	2.41738E-8	0.05	1	1818.30819	2603.35848

Sig equals 1 indicates that the difference of the means is significant at the 0.05 level.
Sig equals 0 indicates that the difference of the means is not significant at the 0.05 level.

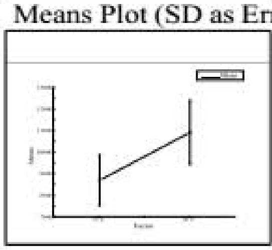
Bar Chart



Box Charts



Means Plot (SD as Error)



ANOVAOneWay (2/28/2017 09:17:21)

Descriptive Statistics

	N Analysis	N Missing	Mean	Standard Deviation	SE of Mean
30 Y Top	30	0	10222.36667	1048.80199	191.48417
30 Y Mid	30	0	10443.93333	1218.49327	222.46542
30 Y Base	30	0	11721.8	1119.11879	204.3222

One Way ANOVA

Overall ANOVA

	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	2	3.93034E7	1.96517E7	15.36432	1.9307E-6
Error	87	1.11277E8	1.27905E6		
Total	89	1.5058E8			

Null Hypothesis: The means of all levels are equal.
Alternative Hypothesis: The means of one or more levels are different.
At the 0.05 level, the population means are significantly different.

Fit Statistics

	R-Square	Coeff Var	Root MSE	Data Mean
	0.26101	0.10476	1130.94921	10796.03333

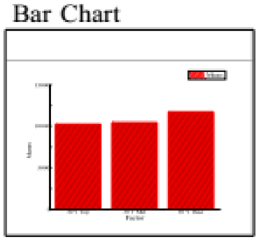
Means Comparisons

Tukey Test

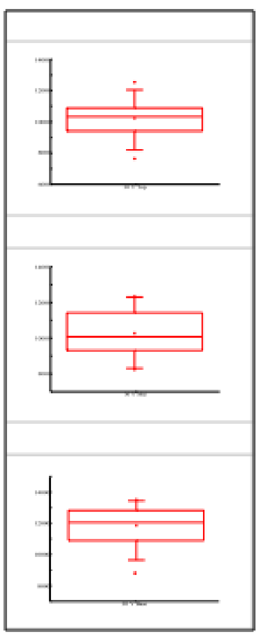
	MeanDiff	SEM	q Value	Prob	Alpha	Sig	LCL	UCL
30 Y Mid 30 Y Top	221.56667	292.00983	1.07305	0.72915	0.05	0	-474.72477	917.85811
30 Y Base 30 Y Top	1499.43333	292.00983	7.26181	5.04129E-6	0.05	1	803.14189	2195.72477
30 Y Base 30 Y Mid	1277.86667	292.00983	6.18875	9.84535E-5	0.05	1	581.57523	1974.15811

Sig equals 1 indicates that the difference of the means is significant at the 0.05 level.
Sig equals 0 indicates that the difference of the means is not significant at the 0.05 level.

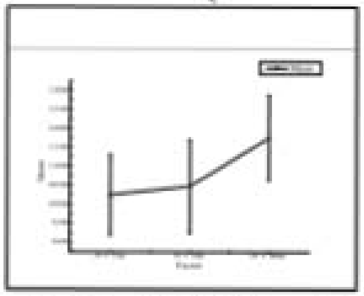
Bar Chart



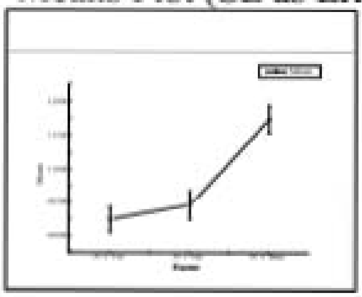
Box Charts



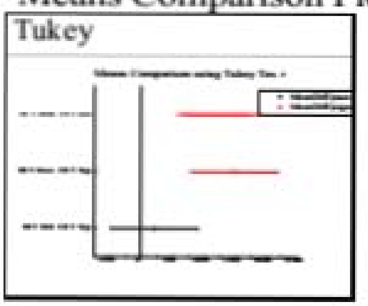
Means Plot (SD as Error)



Means Plot (SE as Error)



Means Comparison Plot



ANOVAOneWay (2/28/2017 22:45:11)

Descriptive Statistics

	N Analysis	N Missing	Mean	Standard Deviation	SE of Mean
15 Yr	89	0	64.29506	10.55968	1.11932
30 Yr	89	0	69.15652	10.04722	1.065

One Way ANOVA

Overall ANOVA

	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	1051.70409	1051.70409	9.90057	0.00194
Error	176	18695.89284	106.22666		
Total	177	19747.59694			

Null Hypothesis: The means of all levels are equal.
Alternative Hypothesis: The means of one or more levels are different.
At the 0.05 level, the population means are significantly different.

Fit Statistics

	R-Square	Coeff Var	Root MSE	Data Mean
	0.05326	0.15446	10.30663	66.72579

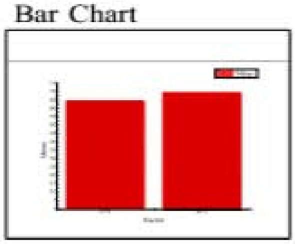
Means Comparisons

Tukey Test

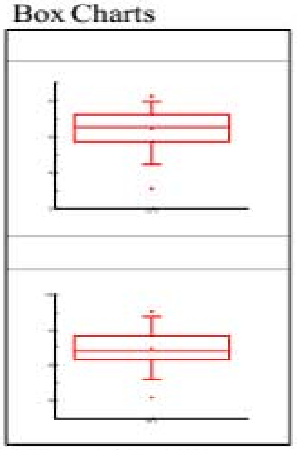
	MeanDiff	SEM	q Value	Prob	Alpha	Sig	LCL	UCL
30 Y 15 Y	4.86146	1.54503	4.44985	0.00194	0.05	1	1.81229	7.91063

Sig equals 1 indicates that the difference of the means is significant at the 0.05 level.
Sig equals 0 indicates that the difference of the means is not significant at the 0.05 level.

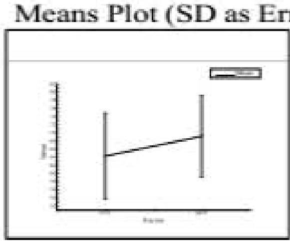
Bar Chart



Box Charts



Means Plot (SD as Error)



ANOVAOneWay (2/28/2017 22:39:58)

Descriptive Statistics

	N Analysis	N Missing	Mean	Standard Deviation	SE of Mean
30 Y Top	30	0	65.509	7.68028	1.40222
30 Y Mid	30	0	66.52067	9.84684	1.79778
30 Y Base	30	0	75.07333	9.86798	1.80164

One Way ANOVA

Overall ANOVA

	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	2	1656.48049	828.24024	9.80847	1.44094E-4
Error	87	7346.39572	84.44133		
Total	89	9002.87621			

Null Hypothesis: The means of all levels are equal.
Alternative Hypothesis: The means of one or more levels are different.
At the 0.05 level, the population means are significantly different.

Fit Statistics

	R-Square	Coeff Var	Root MSE	Data Mean
	0.18399	0.13311	9.1892	69.03433

Means Comparisons

Tukey Test

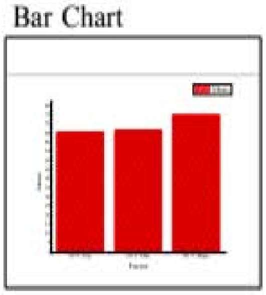
	MeanDiff	SEM	q Value	Prob	Alpha	Sig	LCL	UCL
30 Y Mid 30 Y Top	1.01167	2.37264	0.603	0.90476	0.05	0	-4.64585	6.66918
30 Y Base 30 Y Top	9.56433	2.37264	5.70083	3.46445E-4	0.05	1	3.90682	15.22185
30 Y Base 30 Y Mid	8.55267	2.37264	5.09782	0.0015	0.05	1	2.89515	14.21018

Fisher Test

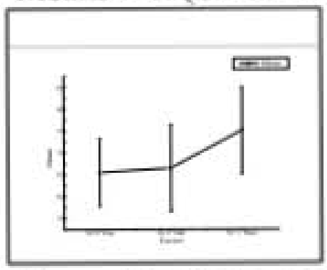
	MeanDiff	SEM	t Value	Prob	Alpha	Sig	LCL	UCL
30 Y Mid 30 Y Top	1.01167	2.37264	0.42639	0.67088	0.05	0	-3.70421	5.72755
30 Y Base 30 Y Top	9.56433	2.37264	4.03109	1.18656E-4	0.05	1	4.84845	14.28021
30 Y Base 30 Y Mid	8.55267	2.37264	3.6047	5.20181E-4	0.05	1	3.83679	13.26855

Sig equals 1 indicates that the difference of the means is significant at the 0.05 level.
Sig equals 0 indicates that the difference of the means is not significant at the 0.05 level.

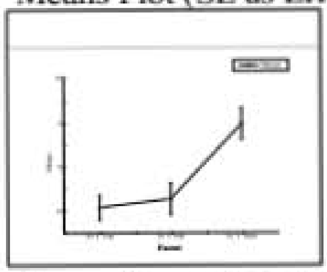
Bar Chart



Means Plot (SD as Error)

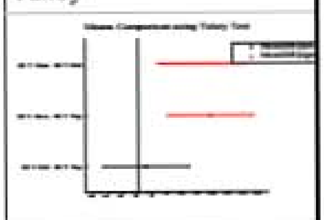


Means Plot (SE as Error)

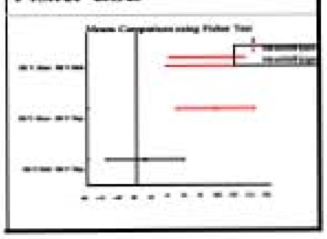


Means Comparison Plot

Tukey



Fisher LSD



ANOVAOneWay (2/28/2017 22:33:43)

Descriptive Statistics

	N Analysis	N Missing	Mean	Standard Deviation	SE of Mean
15 Y Top	30	0	59.97267	9.40191	1.71655
15 Y Mid	30	0	64.614	9.98406	1.82283
15 Y Base	30	0	68.88467	10.94201	1.99773

One Way ANOVA

Overall ANOVA

	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	2	1192.04313	596.02156	5.80908	0.00429
Error	87	8926.34765	102.6017		
Total	89	10118.39078			

Null Hypothesis: The means of all levels are equal.
Alternative Hypothesis: The means of one or more levels are different.
At the 0.05 level, the population means are significantly different.

Fit Statistics

	R-Square	Coeff Var	Root MSE	Data Mean
	0.11781	0.15707	10.12925	64.49044

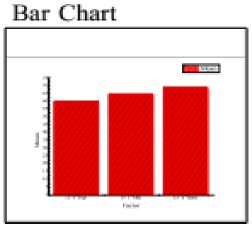
Means Comparisons

Tukey Test

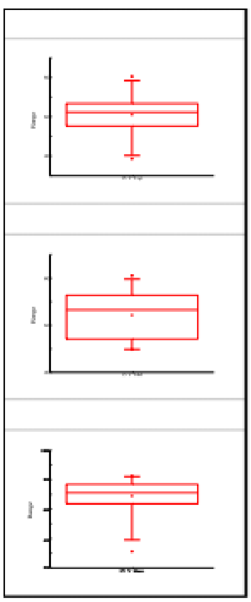
	MeanDiff	SEM	q Value	Prob	Alpha	Sig	LCL	UCL
15 Y Mid 15 Y Top	4.64133	2.61536	2.50972	0.18414	0.05	0	-1.59494	10.87761
15 Y Base 15 Y Top	8.912	2.61536	4.81902	0.00283	0.05	1	2.67573	15.14827
15 Y Base 15 Y Mid	4.27067	2.61536	2.30929	0.23737	0.05	0	-1.96561	10.50694

Sig equals 1 indicates that the difference of the means is significant at the 0.05 level.
Sig equals 0 indicates that the difference of the means is not significant at the 0.05 level.

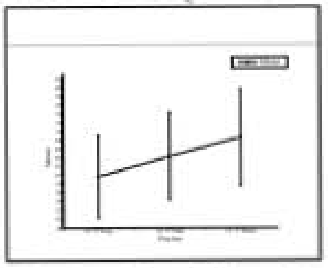
Bar Chart



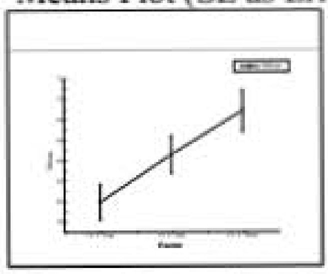
Box Charts



Means Plot (SD as Error)

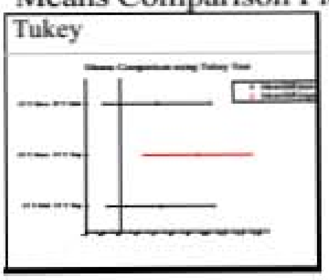


Means Plot (SE as Error)



Means Comparison Plot

Tukey



ANOVAOneWay (3/2/2017 13:57:21)

Descriptive Statistics

	N Analysis	N Missing	Mean	Standard Deviation	SE of Mean
15 Y Top	30	0	8.8754	1.50417	0.27462
15 Y Mid	30	0	10.5308	1.22357	0.22339
15 Y Base	30	0	11.13127	1.66943	0.30479

One Way ANOVA

Overall ANOVA

	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	2	81.89844	40.94922	18.76498	1.67755E-7
Error	87	189.85267	2.18221		
Total	89	271.75111			

Null Hypothesis: The means of all levels are equal.
Alternative Hypothesis: The means of one or more levels are different.
At the 0.05 level, the population means are significantly different.

Fit Statistics

	R-Square	Coeff Var	Root MSE	Data Mean
	0.30137	0.14512	1.47723	10.17916

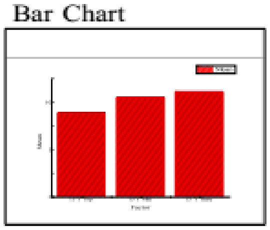
Means Comparisons

Tukey Test

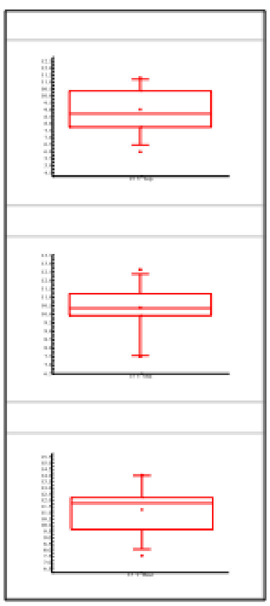
	MeanDiff	SEM	q Value	Prob	Alpha	Sig	LCL	UCL
15 Y Mid 15 Y Top	1.6554	0.38142	6.13783	1.12594E-4	0.05	1	0.74591	2.56489
15 Y Base 15 Y Top	2.25587	0.38142	8.36422	1.60793E-7	0.05	1	1.34638	3.16535
15 Y Base 15 Y Mid	0.60047	0.38142	2.22639	0.26218	0.05	0	-0.30902	1.50995

Sig equals 1 indicates that the difference of the means is significant at the 0.05 level.
Sig equals 0 indicates that the difference of the means is not significant at the 0.05 level.

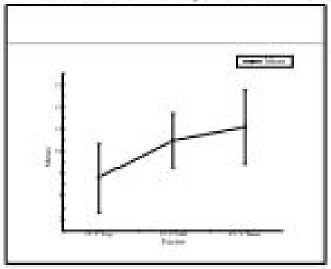
Bar Chart



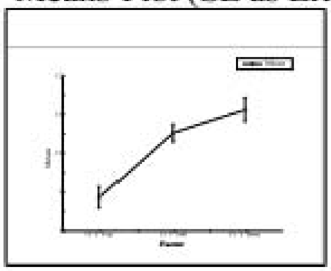
Box Charts



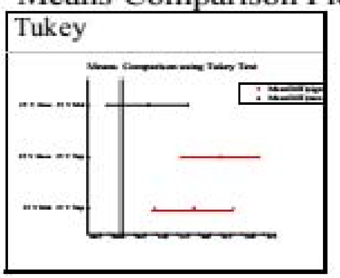
Means Plot (SD as Error)



Means Plot (SE as Error)



Means Comparison Plot



ANOVAOneWay (3/8/2017 12:34:52)

Descriptive Statistics

	N Analysis	N Missing	Mean	Standard Deviation	SE of Mean
15 Y Top	30	0	8.8754	1.50417	0.27462
30 Y Top	30	0	10.22933	1.35859	0.24804

One Way ANOVA

Overall ANOVA

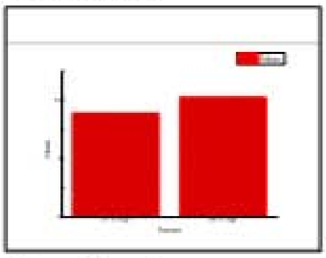
	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	27.49703	27.49703	13.38608	5.48621E-4
Error	58	119.14074	2.05415		
Total	59	146.63777			

Null Hypothesis: The means of all levels are equal.
Alternative Hypothesis: The means of one or more levels are different.
At the 0.05 level, the population means are significantly different.

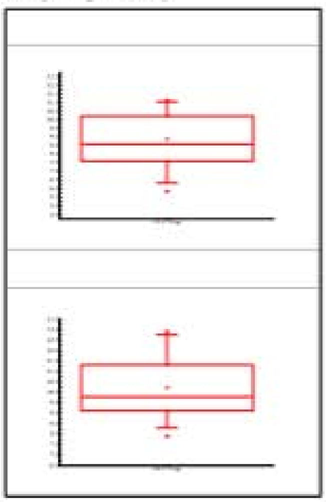
Fit Statistics

	R-Square	Coeff Var	Root MSE	Data Mean
	0.18752	0.15004	1.43323	9.55237

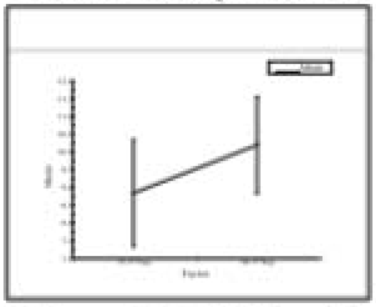
Bar Chart



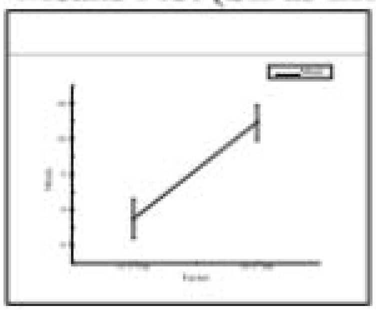
Box Charts



Means Plot (SD as Error)



Means Plot (SE as Error)



Means Comparison Plot