UNIVERSITY OF EDUCATION, WINNEBA

COLLEGE OF TECHNOLOGY EDUCATION, KUMASI

THE POTENTIALS OF *BAMBUSA V. VULGARIS* (BAMBOO) BIOMASS AS FEEDSTOCK TO PRODUCE BIOFUELS

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DOCTOR OF PHILOSOPHY (WOOD SCIENCE AND TECHNOLOGY)

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A THESIS IN THE DEPARTMENT OF CONSTRUCTION AND WOOD TECHNOLOGY EDUCATION, FACULTY OF TECHNICAL EDUCATION, SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES, UNIVERSITY OF EDUCATION, WINNEBA IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR AWARD OF THE DOCTOR OF PHILOSOPHY (WOOD SCIENCE AND TECHNOLOGY) DEGREE.

OCTOBER, 2018

DECLARATION

I, **Joseph Appiah-Yeboah** declare that this thesis, 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 thesis as laid down by the University of Education, Winneba.

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SUPERVISOR: ………………………………………………..

DATE: ……………………………………………………….

DEDICATION

This work is dedicated to the Almighty God for strengthening and guiding me throughout this work. The work is also dedicated to my late mother Leticia Baduassor for taking care of my secondary school education.

ACKNOWLEDGEMENT

I gratefully acknowledge the extraordinary effort of my principal supervisor Prof. Martin Amoah and Dr. S.L. Tekpetey for their guidance and directions for this project work. Their effort has substantially enhanced the lucidity, consistency and coverage of the entire work. The author is indebted to Mr. Joe Acquah of the Department of Agriculture, Chemistry and Soil Laboratory at Kwame Nkrumah University of Science and Technology. I wish to thank my family; Mercy Appiah-Yeboah (my wife), Josephina, Stephen, Gideon and Esther for helping to prepare the samples.

ABSTRACT

Many technologies are now being prepared worldwide to convert stored energies in lignocellulosic materials such as bamboos to provide bioenergy in the form of heat, electricity, gas and transport fuel. This study investigated the fuel properties of bamboo (*Bambusa vulgaris* Schrad. ex J. C. Wendl. var. *vulgaris)* feedstock to produce biofuels – heat, transport fuels, gas and electricity. In all, 1 200 samples were tested for morphological properties, physical properties, proximate analysis, ultimate analysis and ash elementals (minerals) analysis. The results showed that there is an interaction between ecological zones and the growth stages. The clump sizes ranged from 512cm to 622.33cm. However, there was no significant difference at 5% significance level among the three zones. Culm heights ranged from 9-14m, internode distance from 35-38mm, culm diameter from 8-10cm and culm wall thickness and 9-13mm were observed across the ecological zones. The culm wall thickness decreases from the base (9.10 cm) to the top (8.43 cm). The calorific value increases with increase wall thickness of the culm. The mean values for density ranged from 395 to 745 kg/m^3, bulk density ranged from 0.12 to 0.52 g/m^3, calorific values ranged from 12 to 18 MJKg^{-1}. Increase in the bamboo culm wall thickness has correspondent increase in density. The ash content ranged from 0.48 to 3.40%. The mean values for VM (76 – 84%), FC (14-16), C (46-52%), H (6.4-6.6%), N (0.12-1.3%) and O (40-44%). The mean values for heavy metals (*ppm*) were *Cu* (1.3-7.6), *Zn* (2.95-4.87), *Pb* (0.04-0.10), *As* (0.07-0.11), *Ni* (0.64-1.33) and *Cd* (0.79-4.21). The mean values for the minor metals (*ppm*) were *Ca* (26-29), *K* (0.6-2.4), *Mg* (0.13-0.18), *P* (0.06-0.18), *Na* (0.6-1.1), *Al* (0.14-0.21) and *Fe* (0.20-0.17). Mature and dead bamboo culms in any zone can be used for the production of charcoal and biofuels. The leaves of the studied bamboo specie had higher ash, nitrogen and cadmium contents than the culms. Removal of the leaves therefore is necessary when using bamboo for biofuels.

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CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Energy is needed for heating, lighting and cooking in households and for almost every industrial, commercial and transport activity. The world's energy for transport, electricity, heat and chemicals depends greatly on fossil fuel-coal, petroleum oil and gas (Klass, 2004). Globally, primary energy consumption increased by 2.3% in 2013 (European Commission, 2005; BP, 2014) which is 1.8% higher in the 2015 consumption levels (BP, 2014). Global demand for energy is expected to increase with increase in population growth (Kaygusuz, 2012) by 40% between 2007 and 2030 (IEA, 2009). Fossil fuels are non-renewable, which take millions of years to form its chemicals. It is estimated that fossil fuels will be largely exhausted in the next 60 to 100 years, depending on the type (Saxena *et al*., 2007: Klass, 2004).

Increasing crude oil prices results in increases cost of transportation fuels, diesel import for electricity generation and liquefied petroleum gas (LPG) for both industrial and domestic use (Lambrides *et al*., 2006; Zverlov, *et al*., 2006). The burning of fossil fuels can also result in emission of greenhouse gases, such as carbon dioxide into the atmosphere (Davis & Caldeira, 2010; Street & Yu 2011; Le Quere *et al*., 2009). The emission of greenhouse gases has brought about climate change such as global warming, flooding (World Bank, 2009), droughts and famines and water shortages, extreme heat (Riché *et al*, 2009: Koutsoyiannis *et al*., 2009; NAPA, 2007), desertification (World Bank, 2009), Greenhouse refugees (about 200,000 people became refugees in the Maldives islands in the Pacific Ocean), heavy rains, strong winds, frost, high temperatures (Goldemberg *et al*, 2000; NAPA, 2007) and resource depletion (Goldemberg *et al*, 2000; Williams *et al*, 1995). The pollution of the atmosphere by the GHG brings flooding and acid rains (Goldemberg *et al*, 2000; Williams *et al*, 1995). Oxfam estimates that drought costs

Ethiopia roughly $1.1billon a year – almost eclipsing the total annual overseas assistance to the country (Oxfam International, 2009).

In order to address the climate change, Kyoto protocol was formed. The Kyoto Protocol is an agreement made under the United Nations Framework Convention on Climate Change (UNFCCC) to address climate change by reducing GHG emissions, caused primarily by burning oil, gas and coal and by deforestation (UNFCCC, 2008; Berman *et al*., 2003; Kyoto Protocol, 1997). This was adopted in Kyoto, Japan, in December 1997 and entered into force on 16 February 2005 (UNFCCC, 2008). More than 160 countries globally ratified this protocol were committed to reducing the emissions of carbon dioxide (CO_2) and five other greenhouse gases - methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6) which are primarily caused by the burning fossil fuels (Koutsoyiannis *et al*., 2009; UNFCCC, 2008). The earth is warming due to the accumulation of GHGs from the intensive use of fossil fuels and other natural resources (Koutsoyiannis *et al*., 2009). These GHGs are trapping heat over the earth's surface, resulting in changes in temperature and other climatic processes. The Intergovernmental Panel on Climate Change (IPCC) estimates that 1.6 billion tons of carbon is released annually due to land-use change, of which the major part is traced to tropical deforestation (Denman *et al.* 2007). This represents about one fifth of current global carbon emissions, which is more than what emanates from the fossil fuel-intensive global transport sector. The Protocol encourages countries around the world to move to more environmentally responsible ways of producing and using energy, in order to meet their targets for emission reductions. Deforestation and increased CO_2 emissions threaten the earth's biodiversity and the very air we breathe (Koutsoyiannis *et al*., 2009; Pandey and Shyamasundar, 2008). The protocol also support for renewable energy, improving energy efficiency and reducing deforestation (UNFCCC, 2008). In the United States, the Energy Independence and Security Act (EISA) of 2007 has increased the volume of renewable fuel required to be blended into transportation fuel from 9 billion gallons in 2008 to 36 billion gallons by 2022 (Tilman *et al*, 2009). Today biomass is seen as the most promising energy source to mitigate greenhouse gas emissions (Khan *et al.* 2009).

The high demand for energy and the depletion of fossil fuels suggests that source of energy supply in the future has to come from renewable sources (Prins, 2005; Demirbas and Arin, 2002). Additionally, concerns about environmental degradation and the need for sustainability have led to the utilisation of various forms of biomass as a renewable source of energy. A transition from energy based largely on fossil fuels to a greater reliance on renewable energy has been a central focus of many of the current discussions on climate policy (White, 2010). These renewable sources of energy offer the possibility of generating fuels that can partially substitute for fossil fuels and chemical feedstock for industries (Encinar *et al*., 2000). Unlike conventional fossil and nuclear fuels which have a high level of geographic concentration, renewable energy resources are widely available (The NEED Project, 2011). The potential renewable biomass includes wood, energy crops (Demirbas and Arin, 2002; Bridgwater, 2004; Filho and Badr, 2004), agricultural and forestry residues, animal waste, (Demirbas and Arin, 2002; Bridgwater, 2004) municipal solid waste and manufacturing waste and vegetable oils (Filho and Badr, 2004). Trees and crops can always be grown and waste will always exist (The NEED Project, 2011).

The demand for biofuel was insatiable; as a result many researchers around the world are delving into using lignocellulosic materials such as woody materials, crops and agricultural wastes to produce biofuels (IEA, 2010; Sun and Cheng 2002). Between 2000 and 2010, global biofuel production grew from 16 billion litres to 100 billion litres (IEA, 2011). White (2010) also anticipated a problem that increased use of woody biomass for bioenergy (electricity or heat) is expected to have some ripple effects in the forest and agriculture sectors. Increased use of mill residues for bioenergy will likely decrease their availability for their current use (e.g., oriented strand board, bark mulch, and pellet fuel). Forest residues are currently left in the woods both because they have little product value and, in some management systems, they recycle soil nutrients and improve micro-climate site conditions.

A debate existed between the production of food and biofuel. Countries like Brazil and US produce bioethanol for transport, power and heat by using sugar cane, corn, soya or wheat (BRDB, 2008). The EU also uses straight vegetable oil (SVO) as biofuel and biogas in the transport sector, especially in Germany. In 2006, the consumption of these two types of biofuels represented 12.1 percent of the total consumption of biofuels in Europe (Kutas *et al,* 2007). However, using crops to produce biofuel have adverse effects on; food supply for the increasing population, poultry and farm animal feeds. As the grains to feed poultry and livestock become more costly, so do meat, eggs, and dairy (White, 2010). A number of studies examined the factors responsible for the global food price inflation in 2008 (Abbott *et al*. 2009; IFPRI, 2008; IRRI, 2008; Mitchell, 2008). These include negative economic growth, rising energy prices, adverse weather, devaluation of the U.S. dollar and biofuel policies contributed to the 2008 food crisis, the magnitude of these effects is a source of debate. In 2008, the cereal price (such as rice, corn (maize), wheat and soybeans) index reached a peak 2.8 times higher than in 2000; as of July 2010, it remained 1.9 times higher than in 2000 (FAO, 2010).

1.2 Statement of the Problem

The burning of fossil fuels has brought climate change such as global warming, flooding, droughts, famines, water shortages, desertification and extreme heat (World Bank, 2009; Le Quere *et al*., 2009; Davis & Caldeira, 2010; Street & Yu 2011). The continued use of fuelwood and charcoal has been reported to be partly responsible for deforestation and desertification in some part of Africa (World Bank, 2009). The use of bamboo as a substitute for woody biomass has been explored by researchers in recent times. Bamboo is sustainable, fast growing plant which takes 3 to 4 years to mature (INBAR and BARADEP, 2003). On account of its low moisture content, the use of bamboo as a substitute for sugar cane for power generation has been explored in Puerto Rico (Molini and Irizarry, 1983). Ram and Seenayya used de-lignified mature bamboo culm pulp as a substrate for ethanolic fermentation (Ram and Seenayya, 1991).

Bamboo is used for fuel and chemicals production. It is therefore not surprising that researchers in recent years have devoted their energy exploring the possibility of using bamboo in the area of bioenergy production. Scurlock *et al*., (2000) studied nine bamboo samples for fuel analyses based on proximate (moisture, ash, volatiles and fixed carbon) higher heating value; Alkali Index (kg) alkali oxide/GJ); ultimate (*C, H, N, S* and *Cl*) and ash (oxides). Whereas the authors studied the variation of heating properties with bamboo age, the possibility of using bamboo branches and leaves as fuel source was not explored. They dealt with the bamboo ages from 1 to 5 years, thus, juvenile and mature culms. However, they did not consider ecological zones, shoots, dead culms, branches and leaves fuel properties. Ganesh (2003) studied bamboo characterisation for thermochemical conversion and feasibility study of bamboo based gasification and charcoal making. The study covered proximate, ultimate, ash elemental analyses, heating value and bulk density based on the top, middle and bottom of *Bambusa vulgaris'* culm. The researcher did not consider other age groups and parts of the bamboo such as the shoot, juvenile or young, dead or over-grown culms, branches and leaves of the bamboo. Caminiti *et al*., (2007) carried on a project to assess the viability of creating biofuels industry in Ghana. The first phase consisted of desk research on the global market of biofuels. The second phase was carried out through an on-the ground assessment in Ghana, to understand the national enabling environment and the industry's supply chain. The third phase consisted on building models to estimate the costs of local biofuel production. The feedstocks considered for the biodiesel included *jatropha curcas*, oil palm and coconuts whilst that of ethanol were sweet potatoes, cassava, and sugar cane. They did not consider bamboo as a feedstock. Sarfo (2008) worked on chemical properties on three species of bamboo (*Bambusa v. vulgaris, Bambusa v. vittata and Bambusa heterostachya*) of matured bamboo culms from the one ecological zone of Ghana. The researcher concentrated on gross calorific value, proximate (moisture content, ash,), ultimate (proportion of Carbon, Nitrogen, Sulphur and Chlorine), ash elementals (Potassium – *K,* Lead – *Pb,* Iron – *Fe* and phosphorus – *P*) and chemical (proportion of cellulose, lignin, hemicellulose and extractives) analyses in the three bamboos. However, the author did not cover age groups and other parts of the bamboo such as the shoot, juvenile, dead or over-matured, branches and leaves of the bamboos. In addition, the researcher covered only four of the Ash elementals of the bamboos and one ecological zone. Wang *et al*., (2011) evaluated Ma bamboo (*Dendrocalamus latiflorus Munro*) as a feedstock for bioethanol in Taiwan. They determined the ash content, lignin, holocellulose and α-cellulose. They also estimated of ethanol yields from bamboo by different pretreatments (pretreatment yield, ethanol yield, raw material to ethanol and estimate yield). They did not look at the proximate, ultimate, ash elemental analyses and concentration of heavy metals which can affect the production of the bioethanol. Choy *et al*., (2005) analysed the elemental and ultimate compositions of mature bamboo culms – the major elements were carbon and oxygen. Other elements include hydrogen, nitrogen, sulfur and ash. Information on different age groups, properties such as morphology, physical and ash elemental analysis were rather limited. Tekpetey *et al*. (2007) studied the ultra-microstructural, physical, thermogravimetric behaviour, chemical and phytochemical properties of bamboo species. Information on the properties such as proximate, ultimate, calorific value, minor and heavy metals were not tackled. Li (2004) evaluated the physical, chemical, and mechanical properties of the bamboo species *Phyllostachys pubescens*. The effects of bamboo age, horizontal layer, and vertical height location on physical, chemical, and mechanical properties of bamboo were investigated. The chemical properties of the bamboo including holocellulose content, alpha-cellulose content, Klason lignin content, hot water extractives content, alcohol-toluene extractives content, and ash content. However, the investigations did not cover proximate, ultimate, ash elemental analyses, minor and heavy metals.

Chemical compositions varied with tree part (root, stem and branch), type of wood, geographical zone, climate and soil conditions (Pettersen. 1984). Bamboo is an anisotropic and heterogeneous material (Ray *et al*., 2005; Ghavami, 2005). Ebanyenle and Oteng-Amoako (2008) reported that there is significant variation in the morphological and physical properties of wood from different ecological zones. As a result, full knowledge of the fuel properties of bamboo should cover various parts to identify its potential utilisations.

A number of studies have examined the fuel and chemical compositions of bamboo. However, systematic and thorough research on a commercially important bamboo species is needed to determine utilisation potential for biofuels production. Most of the previous studies provided either only general information of several bamboo species or focuses on only on the culm or stem of the bamboo. In addition, most of the studies did not investigate the various parts such as the top, middle and base, different age groups or different ecological zones. This project assesses the potential chemical elements in bamboo (*Bambusa v. vulgaris*) parts - shoots, juvenile, mature, dead or senescent (from the top, middle and bottom), branches and leaves/foliage. The practicality of this project is to investigate the energy potentials in *Bambusa vulgaris* for the production of heat, power and transportation fuels to boost the energy industries for economic and social development.

1.3 Significance of Study

This study deals with a worldwide concern that point toward severe social, economic and environmental problems created through using fossil fuel, charcoal and fuelwood. The outcome of the project will serve as bases to produce biofuel such as transport fuel, heat and electricity. From the theoretical framework the expected results will be to identify the fuel properties such as calorific values, proximate and ultimate values like metallic elements and non-metallic elements built-in the parts of bamboo (*Bambusa vulgaris*) plants (leaves, branches and stems) from the early growth, youthful, matured and dead stages to produce biofuel and biopower. Other outcome of the project will serve the following;

Firstly, this project may help to identify properties of bamboo for transport fuel: thus bioethanol and biobutanol can be produced by fermenting the sugars accumulated in the bamboo shoots and stem to be used in internal – combustion engines either in pure form or more often as a gasoline additive (AHSD, 2005). Secondly, bamboo as a woody material can be co-fired with coal to make electricity (Ontario Power Generation, 2008; UNEP, 2009). Thirdly, biomethane can be produced by bamboo plants and residues (Metan, 2003; Reith *et al.,* 2001). Hydrogen can be extracted from biomass to run electricity (Zhou *et al*., 2013). Fourthly, charcoal in the form of solid or briquettes can be used for both domestic and industrial heating. Lastly, using bamboo for biofuel is a renewable and biodegradable energy source of which can be used as a substitute for the fossil fuels. Biomass can be found everywhere in the world. This will encourage many farmers to plant more bamboos to solve more environmental problems, for example, deforestation and desertification.

The expected results of the research work may also be important in the international discussions on the reduction of greenhouse gas emissions; which Ghana is a signatory to the Kyoto Protocol. The work would also be meaningful to Governments, investors, entrepreneurs, the energy sector, foresters and farmers. Governments, entrepreneurs, investors and the ministry of energy may be coaxed to build bamboo-based ethanol plants in Ghana to boost biofuel production for the transport, rural electrification and the cottage industrial sectors.

The expected results will also enable the entrepreneurs or the industries to produce more bamboo charcoal or charcoal briquettes for the home or the industries. Bamboo charcoal is highly adsorptive and is often used in purification systems, particularly the sugar industry, and in household odour treatments. It can also provide heat for homes, kiln seasoning of timber in some of the timber industries (for example – Samartex in Western Region of Ghana), the cottage industries – soap making, tie and dye, gari processing, bricks and tile (Ando *et al*., 2000). Furthermore, biomass is one of the most important raw materials in bioethanol production (Balat, 2008) for the transport sector.

Lastly, the implementation of the various technologies in Ghana to produce bioenergy will boost the morale of farmers to plant more bamboos to improve their livelihood. Bamboo is easy to grow and maintain, and can provide additional food, energy and income security to the rural poor, as well as a range of environmental services and uses in its growing and harvested forms (Kigomo, 2007). However, some policymakers overlook the importance and role of bamboo in society. As a general rule, undervalued resources tend to be over-exploited or abused by users because of the impression that they are neither scarce nor important. As a consequence, producers are less likely to invest in production technologies for less valuable resources. Thus, policymakers and forest managers tend to favour the development of resources considered to be more valuable (Pabuayon *et al*. 2001).

The expected outcomes of the study will be implemented in the following ways; it will be published in international journal to pave way as a basis to enable informed and critical discussion among researchers for further research. Seminars will also be organised for the Forest Division, Ministry of Energy, Environmental Protection Agency (EPA), farmers at bamboo communities and Policymakers the need to plant and use bamboos as a substitute for timber. Nevertheless, Policymakers should provide access to raw material on state lands, plantations and community projects to the rural people. Make available technologies to produce bioenergy raw materials. Articles will be written to the National dailies Newspapers to educate individuals especially engineers and members of parliament to plead them to enact laws to enable Ghanaians to patronize made in Ghana goods. These measures are aim at alleviating the prevalent shortages of timber products and to safeguard their potential for sustainable production. The establish guidelines for sustained management of existing timber resources in the forests, in particular for bamboo.

1.4 Research Questions

This study tries to find answer to the following questions;

1. What are the morphological differences among *Bambusa v. vulgaris'* age groups (shoot, juvenile, mature and dead culms), branches or foliage and their affects on biofuel production?

2. What are the physical and fuel properties such as density, bulk density and calorific value of *Bambusa v. vulgaris* age groups culms?

3. Are there any variations among the proximate and ultimate elements stored in *Bambusa v. vulgaris* growth ages, branches and foliage across the three ecological zones in Ghana for the production of biofuels?

4. What effects do the ash elementals - heavy and minor metals concentrations in the *Bambusa v. vulgaris* age groups have on human health and fuel conversion technology plants?

1.5 GENERAL OBJECTIVES

The main objective of the project is to investigate the fuel properties of *Bambusa v. vulgaris* and its utilisation potential to the production of biofuels.

Specific Objectives

To achieve this goal the following specific objectives need to be met:

1. Compare the morphological properties of *Bambusa v. vulgaris* (bamboo) culms and their affects on biofuel production across 3 ecological zones (DSD, MSD and MED) in Ghana;

2. Determine the physical properties such as density, bulk density and calorific value of *Bambusa v. vulgaris* (bamboo) age groups' culms;
3. Assess the ultimate and proximate values of *Bambusa v. vulgaris* age groups across the three ecological zones in Ghana for the production of biofuels and
4. Evaluate the concentrations of minor and heavy metals found in the *Bambusa v. vulgaris* age groups and how they affect human health and fuel conversion technology plants.

CHAPTER TWO

LITERATURE REVIEW

2.1. OVERVIEW

This chapter provides a review of literature related to the trends of global energy consumption, production of biofuel from biomass resources, production of biofuel from bamboo as a promising feedstock and the utilisation of bamboo as biofuels.

2.2. THE TREND OF GLOBAL ENERGY CONSUMPTION

2.2.1. Fossil Fuel

Resources like gasoline, coal, natural gas, diesel, and other products derived from fossil fuels are nonrenewable (Brown, 2003) because once used it does not regenerate. It takes millions of years for fossil fuel chemicals to form and it is estimated that they will be largely exhausted within 60-100 years, depending on the type of fossil fuel (Klass, 2004; Saxena *et al*., 2007; Erbach and Wilhelm, 2009). The world demand of petroleum-based fuels has increased as a result of increasing industrialisation and motorisation (Agrawal, 2007). This implies that the world's population currently meets its energy needs is therefore not sustainable (Erbach and Wilhelm, 2009). Escobar *et al*., (2009) reported that today fossil fuels take up 80% of the primary energy consumed in the world, transport sector alone consumes58%. Many researchers have predicted that the world's sources of these fossil fuels will start to depreciate in the next 20 to 30 years (Biobased Industrial Products, 1998; Adegoke and Mohammed, 2002; Prasad, *et al*., 2007; IEA, 2009; Zhao, 2009).

Increasing prices of fossil fuel (coal, oil and gas) increases cost of transportation fuels, diesel import for electricity generation and liquefied petroleum gas for both industrial and domestic use (Lambrides *et al*., 2006; Zverlov, *et al*., 2006). Price increases of crude oil have affected many countries. Some experts predict that the recent increases in oil prices are just the beginning to a steady decrease in supply and increase in prices (Launder, 2002). Unless energy saving and use of renewable resources and sustainable energy management, the core problem of the next decades will span all aspects of life, economy, society, demography and science (Koutsoyiannis *et al*., 2009).

The burning of fossil fuels and the use of other natural resources accumulate greenhouse gases (GHG), namely; carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs) and Sulphur hexafluoride (SF_6), which are the sources of heat over the earth's surface, resulting in changes in temperature and other climatic processes (UNFCCC, 2008; Koutsoyiannis *et al*., 2009; Le Quere *et al*., 2009; Davis & Caldeira, 2010; Street & Yu 2011). These emissions have brought about climate change such as global warming, flooding (World Bank, 2009), droughts, famines and water shortages, extreme heat (Riché *et al*, 2009: Koutsoyiannis *et al*., 2009; NAPA, 2007), desertification (World Bank, 2009), receding of glaciers, rise in sea level, loss of biodiversity, (Gullison *et al.,* 2007), greenhouse refugees (about 200,000 people became refugees in the Maldives islands in the Pacific Ocean), heavy rains, strong winds, frost, high temperatures (Goldemberg *et al*, 2000; NAPA, 2007) and resource depletion (Goldemberg *et al*, 2000; Williams *et al*, 1995). The pollution of the atmosphere by the greenhouse gases bring flooding and acid rains (Goldemberg *et al*, 2000; Williams *et al*, 1995). Oxfam estimated that drought costs Ethiopia roughly $1.1billion a year – almost make disappearance the total annual overseas assistance to the country (Oxfam International, 2009). The Intergovernmental Panel on Climate Change (IPCC) estimated that 1.6 billion tons of carbon is released annually due to land-use change, of which the major part is traced to tropical deforestation (Denman *et al.* 2007). This is about one fifth of current global carbon emissions, which is more than what comes from the fossil fuel-intensive global transport sector.

Kyoto Protocol was set up to address climate change by reducing greenhouse gas emissions under the United Nations Framework Convention on Climate Change (UNFCCC). More than 160 countries globally which signed the agreement were committed to reduce their emissions of greenhouse gases (UNFCCC, 2008; Berman *et al*., 2003; Kyoto Protocol, 1997). It was adopted in Kyoto, Japan, in December 1997 and entered into force on 16th February 2005 (UNFCCC, 2008). The protocol pleaded with countries around the world to move to more environmentally responsible ways of producing and using energy, in order to meet their targets for emission reductions (Koutsoyiannis *et al*., 2009; Pandey & Shyamasundar, 2008). This was also supported the use of renewable energy (UNFCCC, 2008). As a follow up of the protocol, the Energy Independence and Security Act (EISA) in the United States, of 2007 increased the volume of renewable fuel required to be blended into transportation fuel from 9 billion gallons in 2008 to 36 billion gallons by 2022 (Tilman *et al*, 2009). Today biomass is seen as the most promising energy source to mitigate greenhouse gas emissions (Khan et al. 2009). A shift from energy based largely on fossil fuels to a greater reliance on renewable energy has been a central focus of many of the current discussions on climate policy (Demirbas and Arin, 2002; Prins, 2005; White, 2010). Several scenarios for the future (example; Shell, 2001) foreseen a strong increase in the use of biofuels between 2025 and 2050. These renewable sources of energy offer the possibility of generating fuels that can in part substitute for fossil fuels and chemical feedstock for industries (Encinar *et al*., 2000). Unlike conventional fossil and nuclear fuels which have a high level of geographic concentration, renewable energy resources are widely available (The NEED Project, 2011). Renewable biomass potential includes wood, energy crops (Demirbas and Arin, 2002; Bridgwater, 2004; Filho and Badr, 2004), agricultural and forestry residues, animal waste, (Demirbas and Arin, 2002; Bridgwater, 2004) municipal solid waste and manufacturing waste and vegetable oils (Filho and Badr, 2004). Trees and crops can always be grown and waste will always exist (The NEED Project, 2011).

2.2.2. Biomass Energy Statistics

Biomass contributes about 12% of today's world primary energy supply, while in many developing countries, its contribution ranges from 40% to 50% (Scarlata 2007; IRENA, 2012). More than two billion people in the world rely on biomass in the form of fuelwood and charcoal for domestic use (World Energy Assessment, 2004; IEA, 2002). In 2001, the consumption of energy by type in Africa shows that biomass 59%; petroleum 25%; electricity 8%; coal and gas 4% each. Solid biomass fuels are used to generate energy for essential daily activities in the homes for cooking, heating and cottage industries for those who live in rural areas; low incomes and the lack of access to alternative, modern fuels (IEA, 2011; IEA, 2013).

2.2.3. Production of biofuel from biomass

Biomass is organic matter which is produced by plants, animals and microorganisms (IUPAC, 1997). The term biomass - abbreviation for biological mass (Greek *bio* meaning *life* + *maza* meaning *mass*) refers to non-fossilized and biodegradable organic material originating from plants, animals and microorganisms (Demirbas, 2010**;** Atakora, n.d). Energy from the sun is converted to organic matter by green plants, algae and photosynthetic bacteria (Glazer & Nikaido, 2007). As a result of photosynthesis, plants and micro-organisms convert carbon dioxide into carbohydrates e.g. sugars, starch and cellulose (Australian Institute of Energy, 2009). The oxygen in carbohydrates during burning forms carbon dioxide and water which plant fixed during its growth (Australian Institute of Energy, 2009). Biomass is also defined as any organic matter which is available on a renewable basis through natural processes or as a by-product of human activity such as wood, short-rotation woody crops, agricultural wastes, short-rotation herbaceous species, wood wastes, bagasse, industrial residues, waste paper, municipal solid waste, sawdust, biosolids, grass, waste from food processing, aquatic plants and algae animal wastes, and a host of other materials (Xu *et al*. 2008; Demirbas, 2008a; Jenkins *et al*., 1998). Biomass is a renewable energy source because its supplies are not limited. Trees, crops and waste will always available (AIE, 2010; The NEED project, 2010).

Biomass was one of the earliest sources of energy especially in rural areas where it is often the only accessible and affordable source of energy (Demirbas, 2004). Direct burning has been done for centuries even though; it is not the most efficient method of biomass utilisation because of its incomplete combustion, low efficiency and pollution. Therefore it would be more feasible to convert the biomass to other fuel forms which are better to handle and pollute less when used. Biomass can be converted to fuels in the form of liquids – methanol, butanol and ethanol, gasses – hydrogen, methane (Environmental Literacy Council, 2008a; Kopetz, 2007). It has great potential to provide renewable energy, automotive fuel, large-scale electrical power cogeneration (Manning, 2004), electricity, heat (Kopetz, 2007) and raw material for bulk chemicals (Manning, 2004) for the modern chemical industry (Hamelinck, 2004).

Biomass fuels are still considerably more expensive than fossil fuels but emerging technologies will decrease this cost in coming years (Ni *et al.*, 2006; Balat, 2010). A key question, however, is how large a role could biomass play in responding to the world's energy demands. When evaluating the future global biomass availability it can be concluded (Faaij 2005) that a major contribution to global energy supply is possible, although major transitions are required. There are several methods described to assess the major properties of biomass fuels (Biofuels for Transport, 2004; Scarlata, 2007; Zhou *et al.*, 2013). Some of these methods were developed for other fuels, such as coal, but are more generally applicable and have been found to be adequate for biomass as well.

2.3. CATEGORISATION OF BIOMASS FEEDSTOCKS

Biomass materials naturally vary depending on geographical location, variety, climate conditions and harvest methods (Clarke and Preto, 2011). Nigam and Singh (2011) classified biomass for generating biofuels as primary and secondary.

The primary fuels are natural, organic and unprocessed biomass. They are directly combusted as cooking fuel, heating or used to produce electricity in either small or large-scale industries applications. Substrates such as firewood, wood chips, pellets, animal wastes, landfill gas, residues from crops and forest are termed as the primary feedstock. Secondary Biomass Resources are modified or processed primary fuels to produce solid (for example charcoal) or liquid (bioethanol, biodiesel and bio-oil) or gases (biogas, syngas and hydrogen). Generally, first, second and third generation feedstocks are termed as secondary resource.

2.3.1. First Generation Feedstocks for Biofuels

The first generation crops, sometimes edible crops are termed as energy crops. They are feedstocks grown purposely to produce some form of bioenergy. Many researchers reported the use of sugar and starch-based crops to produce bioethanol as fuel for the transport sector (Giamipietro *et al*., 1997; Ulgiati 2001; Kim and Dale, 2004; Knauf and Moniruzzaman, 2004; Pimentel and Patzek, 2005; Farrell *et al*., 2006). Energy crops can be used to produce electricity and heat, or by converting them to liquid fuels such as ethanol for use in vehicles (Biobased Industrial Products, 1998; Scahill, 2004). Energy crops are divided into two types; herbaceous and woody plants (US Congress OTA 1995). They are sugars crops such as nypa palm, sugar beets, sugar cane, sugar palm and sweet sorghum; starches like cassava, corn, (Thurmond, 2008) sweet potato, sorghum and wheat (Giamipietro *et al*., 1997; Ulgiati 2001; Pimentel and Patzek, 2005; Farrell *et al*., 2006) and edible oil plants, animal oils and fats (Bain, 2004; Scahill, 2004). Through transesterification the edible sugar or starch crops are converted to biodiesel, which can run in any diesel engine without modification (Bain, 2004; Scahill, 2004).

New technologies have been developed to process sugar and starch crops commercially. Energy crops could be used for electricity generation, heating and the production of chemicals through gasification. They could also be used to generate electricity through combustion or cofired with coal. Energy crops could also be used to produce ethanol (Launder 2002).

2.3.2. Second generation feedstocks for biofuels

Second generation feedstocks biomass are refer to as lignocellulosic biomass (Sun and Cheng, 2002; Kagan, 2010). Second-generation biomass is the feedstocks ranging from municipal solid wastes to woody and non-woody plants (Lavole *et al*., 2011; Launder, 2002). The cellulose in the feedstocks is converted to biofuels. Perennial grasses (switchgrass, miscanthus, bluestem, elephant grass, and wheatgrass) and short rotation woody crops (SRWC) such as cottonwood, silver maple, black locust, and poplar (US Congress OTA, 1995; Launder, 2002) can be converted to cellulosic ethanol, biomass-to-liquids, biogas and chemicals. Switchgrass and miscanthus also called dedicated cellulosic crops are two perennial grasses considered to hold enormous potential for ethanol production. They give other advantages like lower rates of soil erosion and higher soil carbon sequestration (Wyman 1999; Lynd 1996). There are concerns about how much forest and other residue that can be extracted for fuel production without adverse impacts (SAFNW 2011).

It is more complex to convert the second-generation feedstocks to biofuels without new technologies. Lignocellulosic biomass can be converted to ethanol by hydrolysis and subsequent fermentation (Hamelick, 2005). Also, thermo chemical processes can be used to produce ethanol through gasification followed by either by fermentation or by a catalysed reaction (US DOE, 2003). Cellulosic biomass are categorised into three. They are homogeneous, quasi-homogeneous and non-homogeneous (Lavole *et al.,* 2011).

Homogeneous woody feedstocks: These feedstocks have the same or similar kind of materials. Woody materials such as wood chips and fuelwood is primarily used directly for cooking and heating at the household level and to lesser extent wood chips used for producing electricity at a small scale (Ravindranath and Hall 1995). Wood can be co-fired with coal to reduce power plant emissions which can yield two to ten times as much wood per acre as natural forests (Launder, 2002). Technologies being developed permit the conversion of wood to ethanol as a transportation fuel (Wyman 1999; Lynd 1996; Rajagopal and Zilberman, 2007). Cellulose conversion technologies allow the utilisation of non-grain parts of crops like corn stover, rice husk, sorghum stalk, bagasse from sugarcane, and the woody parts to bioethanol (Wyman 1999; Lynd 1996).

Quasi-homogeneous materials are agricultural and forest residues which are similar in appearance, similar external and superficial resemblance are used together. Fermented residues rich in lignin, which is the co-product of ethanol made from crop residues and sugarcane bagasse, can potentially generate both 458 TWh5 of electricity (about 3.6% of world electricity production) and 2.6 EJ6 of steam (Kim and Dale, 2004). Research was carried out by observation and monitoring show that biomass Wastes (Kryvoruchko *et al*., 2009), household wastes (Krzystek *et al*., 2001) and biogas digestate are used as solid fuel (Kratzeisen *et al*., n.d.) are sources of biogas. Scahill (2004) listed some forest wood residues as thinning residues, wood chips, urban wood waste (pallets, crate discards and wood yard trimmings). Others are whole trees, branchwood, coppice products, forest thinning, arboricultural trimming, energy cropping or sawdust and shavings. Agricultural wastes or residues such as corn stover, sugarcane bagasse, rice hulls, animal biosolids (Scahill, 2004) sugarcane leaves, fishery, and livestock are substrates for the production of heat, electricity, biogas and bioethanol. A study organised by Kim and Dale (2004) found that there are about 73.9 million tonnes of dry wasted crops and about 1.5 billion tonnes of dry lignocellulosic biomass from seven crops namely, maize, oats, barley, rice, sorghum, wheat, and sugarcane. These could potentially yield about 490 billion liters of ethanol or about 30% of global gasoline use today. Dairy wastes are biogas source (Göblös *et al*., 2008).

The non-homogeneous feedstocks include low value feedstocks such as municipal solid wastes and industrial wastes. Municipal solid waste (MSW) is defined as waste durable goods, nondurable goods, containers and packaging, food scraps, yard trimmings, and miscellaneous inorganic wastes from residential, commercial, and industrial sources (Demirbas 2004). Others are waste paper and yard clippings (UNEP, 2009). CIWMB (2005) compared producing electricity using thermochemical and biochemical conversion technologies on various options for disposal of municipal solid waste (MSW). The result showed that it would yield higher energy and lower emissions of carbon dioxide criteria air pollutants (oxides of nitrogen and sulphur) than land filling and incineration (direct burning) of MSW. Researchers have showed that Municipal solid wastes (Demirbas 2004; Pognani *et al*., 2009) and processing waste water (Stoica, *et al*., 2009) are potential resources for the production of biogas. Biodiesel can be produced from sewage sludge (Angerbauer *et al*., 2008).

Industrial wastes are possible key supplier of biogas, especially food industry or restaurant wastes (Rani and Nand, 2004), fruit industry wastes (Llaneza Coalla *et al*., 2009) and animal by-products (Hejnfelt and Angelidaki, 2009; Mueller, 2007). In the study by Strong *et al.,* (2004), Biodiesel is made up of fourteen different types of fatty acids, which are transformed into fatty acid methyl esters (FAME) by transesterification. Different fractions of each type of FAME present in various feedstocks influence some properties of fuels. Among these animal fats are lard, tallow, and poultry Fat.

2.3.3. Third Generation Feedstocks for Biofuels

Third generation biomass feedstocks for production of biofuels are algae (Bastianoni, *et al*., 2008; Brennan and Owende, 2010; Kagan, 2010) and hydrogen (Meyer 2004; Zhou, 2013). Demirbas (2010) enumerated a wide variety of aquatic biomass resources exist such as algae, giant kelp, water weed, water hyacinth, reed and rushes, and marine microflora. Algae are used for biodiesel production (Bastianoni, *et al*., 2008; Brennan and Owende, 2010). Thurmond (2008) reported that in 2008, demand for alternative feedstocks shifted to waste grease, jatropha and algae as price trends of higher feedstocks like soy, rapeseed, and palm oil increased. Algae-based biodiesel offers the promise of high-yield, commercial-grade, and Non-Food Based which grown in non-rainforest areas.

2.3.4. Fourth Generation Biofuels

Kagan (2010) reported that fourth generation biofuels are either created using petroleum – like hydro-processing, advanced biochemistry, or revolutionary processing like joules "Solar-to-fuel method that defies any other category of biofuels.

2.3.5. Typical Biomass Composition

Lignocellulosic biomass is the major element of most plant matter. The composition of specific lignocellulose feedstocks is available in several databases (U.S. Department of Energy, 2004; Scurlock, 2004; PHYLLIS, 2004). The components of biomass include cellulose, hemicelluloses, lignin, extractives, lipids, proteins, simple sugars, starches, water, hydrocarbons, ash, and other compounds (Launder, 2002, Scurlock, 2004, U.S. Department of Energy, 2004). Lignocellulose materials vary in their proportions of cellulose, hemicellulose, and lignin. Typical biomass contains 40% to 60% cellulose, 20% to 40% hemicellulose, and 10% to 25% lignin (U.S. Department of Energy, 2004). Extractives and minerals generally account for less than 10% of the dry biomass weight. The sugar and ash composition of various biomass feedstocks (weight percent) is as follows:

Table 2.1: Typical Composition of Biomass

Material	**Six-Carbon Sugars**	**Five-Carbon Sugars**	**Lignin**	**Ash**
Hardwoods	39-50	18-28	15-28	0.3-1.0
Softwoods	41-57	8-12	24-27	0.1-0.4
Ag Residues	30-42	12-39	11-29	2-18

Source: U.S. Department of Energy, 2004

In its natural form, cellulose is a linear polymer containing thousands of glucose units linked together by β-1.4-glucose bonds (McMurry & Simanek, 2007). Two glucose units form cellobiose which is the fundamental unit of the polymer. These fibers form a thin layer that form a variety of building blocks of plant cells. Structure of cellulose can have crystalline or amorphous region, depending on the source and combination (Glazer & Nikaido, 2007). Cellulose is very tolerant towards degradation due to secondary and tertiary structure of the cellulose chain and how it is integrated with other polymers (lignin, starch, pectin, hemicellulose and protein) in the cell wall plant (Kosaric *et al*., 2001).

Hemicellulose is a complex non-cellulose polysaccharide, inhomogeneous high polymeric glycan, which consists of 2 glycosyl or more in the cell wall and the intercellular layer (Hendriks & Zeeman, 2008). It connects lignin and cellulose together and gives the lignocellulosic structure greater strength (Hendriks & Zeeman, 2008). However mechanically, hemicellulose contributes little to the stiffness and strength of fibres or individual cells (Thompson, 1993). The polymer is usually shorter than cellulose (< 200 units) and is highly branched with many different kinds of sugars (Glazer & Nikaido, 2007). Hemicellulose is chemically heterogeneous and easily hydrolyzed into sugars than cellulose. The sugar content in the hemicellulose is fermented to enable industrialists produce fuels such as ethanol (Madsen, 2004; Reddy and Yang, 2005; Glazer & Nikaido, 2007). Fibres containing a higher proportion of hemicellulose are the cell wall polymer with the highest water sorption (Madsen, 2004). The high moisture absorption of natural fibre leading to swelling and presence of voids which results in poor mechanical properties and reduces dimensional stability of composites (Maya and Sabu, 2008). Depending on the plant source, these monosaccharides may include hexoses (glucose, galactose, mannose, rhamnose) (Ezeji *et al*., 2007; Glazer & Nikaido, 2007) and pentoses (xylose, arabinose) (Ezeji *et al*., 2007; Glazer & Nikaido, 2007).

Lignin is the most common aromatic polymer on earth present in all lignocellulosic biomass (Hendriks, & Zeeman, 2008). The structure is an amorphous heteropolymer consisting of three different phenyl propane units (p-coumaryl, coniferyl and sinapyl alcohols) which are bound together with different chemical bonds (Hendriks, & Zeeman, 2008). Lignin is formed from three alcohols (the lignols) with free radical copolymerisation (Perry, Stanley & Lory, 2002). It provides the plant compressive strength, stiffens the cell wall of the fibres, impermeability, protecting the carbohydrates from chemical and physical damage, and invasion of oxygen (Saheb & Jog, 1999; Hendriks & Zeeman, 2008). Because of its strength, trees are able to grow up to several hundred meters (Glazer & Nikaido, 2007). Using lignocellulosic materials is greatly dependent on the lignin content (Saheb and Jog, 1999).”Higher” plants and ferns contain lignin but “lower” plants, like mosses, do not (Perry, Stanley & Lory, 2002).

The physical appearance of various types of lignocellulosic biomass appears quite different; however, the composition is very similar with the major fraction of cellulose with lesser amount of hemicellulose and lignin (Wyman and Goodman, 1993). A research on the chemistry of the immature culm of a moso bamboo (*Phyllostachys pubescens Mazel*) was conducted by Fujji *et al*. (1993). The results specified that the contents of cellulose, hemicellulose and lignin in immature bamboo increased while proceeding downward of the culm. The increase of cellulose in the lower position was also accompanied by an increase in crystallinity.

2.4. FOOD VERSUS BIOFUEL DEBATE

Brazil produces bioethanol from sugar cane for transport, power and heat while US produce bioethanol by using sugar cane, corn, soyabean or wheat (BRDB, 2008; Koh and Wilcove, 2008). The EU also uses straight vegetable oil (SVO) such as rape oilseed to produce biodiesel and biogas in the transport sector, especially in Germany. Palm oil biodiesel produced in Malaysia and Indonesia is gaining more interest (Koh and Wilcove, 2008). Many researchers reported that these important food crops and their use for fuel can have adverse impacts on food supply by raising demand for farm inputs, including land, labour and chemicals (Galbe and Zachhi, 2002; Sun and Cheng, 2002; Zerbe, 2006). In 2007, approximately 24 percent of the corn acreage planted in the U.S. was used for corn ethanol production (BRDB 2008). Ethanol produced from corn or sugar cane (or other sugar/starch crops) is less technically challenging (and thus currently less costly) than producing ethanol from lignocellulose in woody materials (Galbe and Zachhi, 2002; Zerbe 2006). The production of biofuels by using energy crops can also create environmental problems such as intensive use of land, water, fertilizer and pesticides (Giamipietro *et al*., 1997; Ulgiati 2001; Pimentel and Patzek, 2005; Farrell *et al*., 2006) and accelerating deforestation (Galbe and Zachhi, 2002; Sun and Cheng, 2002; Zerbe, 2006; Kutas *et al.,* 2007; BRDB, 2008). Edible straight vegetable oil (SVO) and oilseed crops such as sunflower, cottonseed, rapeseed, canola (a modified version of rapeseed), soybean, safflower, (Sheehan *et al*., 2000; Demirbas, 2001; Strong *et al*., 2004; Shahid and Jamal, 2008), yellow mustard seed (Strong *et al*., 2004), palm oil and peanut oil are very useful for biodiesel production (Shahid and Jamal, 2008).

Between 2007 and 2008, World food prices brought untold hunger and poverty in countries such as Malawi, Senegal (FAO, 2011) and Ethiopia (Oxfam International, 2009). Many families were forced to borrow money under unfavourable conditions, making recovery much harder (FAO, 2011). The continued food unavailability made some people in Ghana sold their land and source of livelihood in 2011 (Khan, 2011). Other researchers are of the view that there is enough land to accommodate additional food crops and biomass production to be transformed into biofuels (Fresco, 2006; European Environmental Agency, 2007).

2.5. RESEARCHERS' PROPOSITION OF LIGNOCELLULOSIC MATERIALS FOR BIOFUELS

The demand for biofuel was insatiable; as a result many researchers around the world are delving into using lignocellulosic materials such woody materials, crops and agricultural wastes to produce biofuels (IEA, 2010; Sun and Cheng, 2002). Between 2000 and 2010, global biofuel production grew from 16 billion litres to 100 billion litres (IEA, 2011). However, White (2010) also anticipated a problem that increased use of woody biomass for bioenergy (electricity, gas or heat) is expected to have some ripple effects in the forest and agriculture sectors. Increase use of mill and forest residues for bioenergy will likely decrease the production of oriented strand board, bark mulch recycle soil nutrients and improve micro-climate site conditions. Many researchers suggest bamboo as feedstock instead of other wood biomass (Scurlock *et al* 2000; Xuhe, 2003; Shenxue, 2004; INBAR (2004).

2.6. BAMBOO AS A RESOURCE FOR BIOFUEL PRODUCTION

Bamboo is said to be one of the fastest growing plant on earth which take 3 to 5 years to mature (Ghavami and Rodrigues, 2000; Xuhe, 2003). It is renewable, widespread, low cost, environment enhancing resource with great potential to improve poverty alleviation and environment conservation (Xuhe, 2003). Bamboo is a perennial, giant, woody grass belonging to the group angiosperms (Chapman, 1996; Shenxue, 2004) and the order monocotyledon (Abd. Latif *et al.*, 1990). There are more than 70 genera and over 1250 species of bamboos that grow throughout the world (Scurlock *et al* 2000). Bamboo Structure (2013) reported that more than 100 of these species are used commercially. Bamboos grow naturally in tropical, subtropical, and temperate regions around the world (Gratani *et al*., 2008). Bowyer *et al* (2005) and Anon, (2000) described it as the “Poor Man’s Timber”, because bamboo can be used as timber. Balakrishnan Nair (1990) also described bamboo as a single-most important item of forest produce used by rural communities of the tropics, from the cradle to the coffin. INBAR (2004) was confident that Bamboo is very versatile and effective substitute for wood. There are more than 1500 different documented traditional uses of bamboo (INBAR 1997; Shrestha 1999). Presently, there are about 3000 companies around the world engaged in the production of various bamboo-based products such as panels, flooring, pulp, charcoal, edible shoots, and other daily-use articles (Xuhe, 2003).

Bamboo is perennial plant that can be used to achieve energy sufficiency and fuel diversification while meeting environmental challenges through the utilisation of biofuels.

Solid bamboo charcoal or briquette bamboo charcoal can traditionally be used as a substitute for wood charcoal or mineral coal in Africa. This will minimize depletion of the forests. Bamboo can be used as feedstock to supply constant electricity, heat, gas and transport fuel (Kigomo, 2007; Bain, 2010; Preto, 2010). Bamboo biomass can be converted to Bio oil & Biogas for Power Production through gasification (Preto, 2010). Bamboo biomass has the potential to accelerate the realisation of hydrogen as a major fuel of the future (Gupta, 2004).

2.6.1. The morphology of a bamboo plant

Morphology of the bamboo plant is described as the outer appearance of the plant which includes culm/stem, internode, node, sheath, sulcus, branches, leaves, shoots and roots (Bamboo Structure, 2013; Okwori *et al*., 2013). The morphological properties were describe as the macroscopic characteristics of bamboo such as culm height, internode length, internode distance, culm diameter and wall thickness (Malanit *et al*., 2008). Bamboo culm is composed of a number of bamboo tubes joined together with a node, each internode is of a different size (Zehui, 2002).

2.6.2. The bamboo stem or culm

Bamboo plant is made up of an underground axis and above ground axis. The underground axis comprises of rhizomes, roots, and buds (Kigomo, 2007; LeBeau Bamboo Nursery, 2012). A rhizome grows horizontally underground (LeBeau Bamboo Nursery 2012). Buds on the rhizomes may develop into shoots that come out from the ground (Kigomo, 2007; Jaimik *et al*., 2011). The rhizome system develops and matures new and larger shoots which come out annually until the maximum size of the species has been reached (Figure 2.1). There are two main systems of rhizome arrangement in bamboos, namely clump and running or creeping rhizomes. Clump forming bamboos have rhizomes that exhibit a *sympodial* branching pattern. Running bamboos, on the other hand, have rhizomes with a *monopodial* branching pattern (Kigomo, 2007; Okwori *et al*., 2013). Taxonomists reserve the terms *pachymorph* (sympodial branching) and *leptomorph* (monopodial branching) to describe the morphology of two basic types of rhizomes (Kigomo, 2007; Stapleton, 1997; Dransfield & Widjaja, 1995).

The aboveground axis is consists of culms, branches and foliage. The life of the bamboo plant is however sustained by the new shoots and culms (Kigomo, 2007). The shoot grows into young or juvenile culms covering with sheaths. As the culm thickens, the sheath begins to tear away from the culm at its base, leaving the distinctive ring at the node (Okwori *et al*., 2013). Bamboo culm is the woody section of the plant. It is commonly known as the "cane" (LeBeau Bamboo Nursery, 2012). Usually a culm is fully mature after 3 or 4 years. As mature culms grow older, they deteriorate and eventually die and rot. There is a vertical groove called the sulcus in the internode region. This groove is caused by the presence of a branch bud that is emerging from the node, in some species of bamboo (LeBeau Bamboo Nursery, 2012; Okwori *et al*. 2013). The stem is a conical format which has several nodes and internodes and hollow center (Kigomo, 2007; Rahmati, Ebrahimi and Sedghi, 2010). The diameter decreases from the base to the top with some differences among bamboo species (Tekpetey, 2011; Okwori *et al.* 2013). They grow to the height of 10-40 m (Scurlock *et al*., 2000) and 35cm in diameter (Kassahun, 2003). The increase in weight of the culm depends on age of the bamboo (Shanwughavel *et al*., 2013). Bamboo culm as a lignocellulosic feedstock can yield 10-40 Ton/Ha-year as compared to 7-10; 6-12 and 10-20 of cane bagasse, wheat straw and wood respectively (Montano, 2014). Bamboo culms are used for housing, flooring, furniture, charcoal and paper (Kigomo, 2007; Montaño 2014).

2.6.3. Branches and foliage of bamboo

Branches can be many depending on bamboo species. The bamboo buds may emerge from the node of the culm elongates later to form branches. An additional bud called the branch can grow creating a pair or "V" – like branches from the node (Kigomo, 2007; Okwori *et al*. 2013). The leave provides photosynthetic function of the plant by converting sunlight into energy. The appearance of the leaves vary among species. In some species, the leaves are very large and less numerous while other species have large amount of very small leaves. The appearance of leaves plays a vital role in its identification of the type of bamboo (Okwori *et al*., 2013). The leaves of bamboos are left in the field as fertilizer, and/or collected for animal feed (Montaño 2014). The branches have low value application such as making chopsticks (Montaño, 2014). Branches, shoots and roots of bamboo can be used to produce charcoal by pyrolysis (carbonizing) under high temperatures at about 1000 °C (Kittinaovarat and Suthamnoi, 2009).

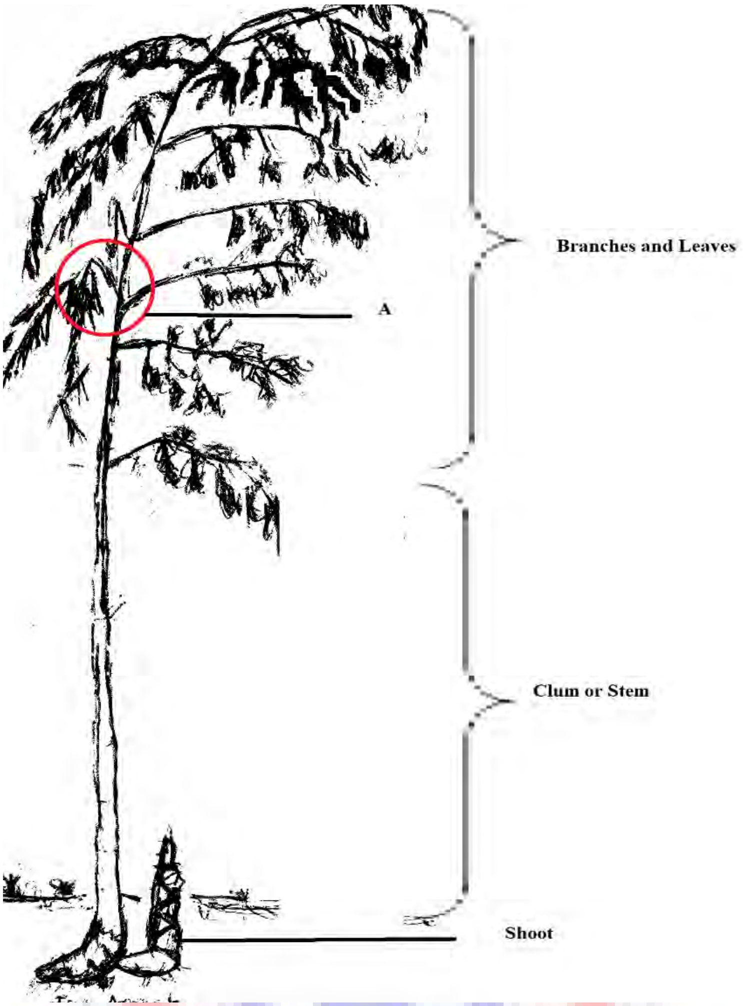


Figure 2.1a Parts of the Bamboo

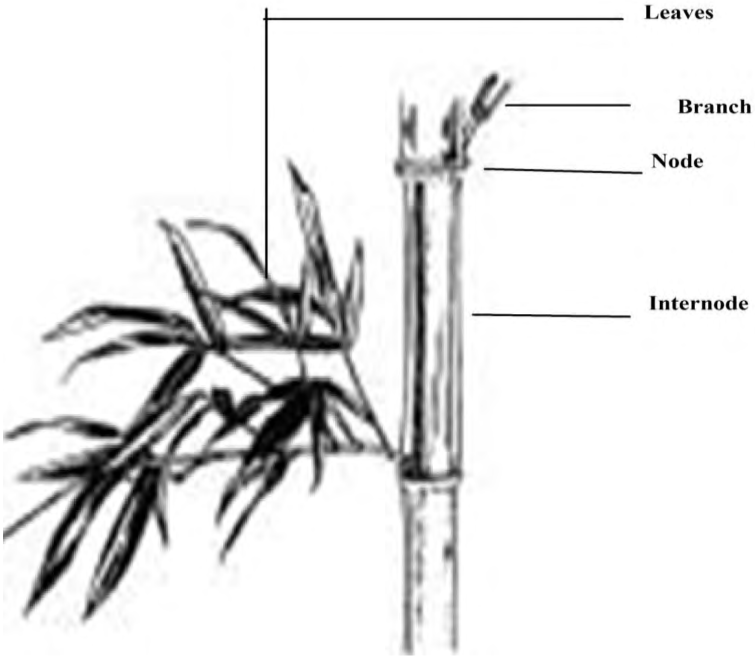


Figure 2.1b Parts ‘A’ of the Bamboo

2.6.4. Conclusion of bamboo morphology

The study of the morphological composition in bamboo gives knowledge about the quality in physical and mechanical proprieties of the plant for better utilisation. The stems of bamboo have nodes (diaphragms) between two internodes. The length of the internode is shorter towards the base of the culm as compared to the intermodal distance towards the tip of the stem. The culm or the stem is tapered from the base to the top.

2.6.5. Utilising bamboo as a feedstock for the production of biofuel

Research has shown that bamboo has a very wide variety of energy needs, including generating electricity (Launder, 2002; Ranjan, 2005; Kigomo 2007, Miertus & Zinaview, 2008; Demirbas, 2010; Preto, 2010), heating homes (Preto, 2010), fueling vehicles (Kigomo 2007, Miertus & Zinaview, 2008; Bain, 2010) and providing process heat for industrial facilities (Preto, 2010). Molini and Irizarry (1983) predicted the use of bamboo as a fuel for power generation in Puerto Rico in as a substitute to sugar cane, since its lower moisture content at harvest obviates the need for drying, however they gave few data in support of their case. Some degree of experience has been gained by fermenting de-lignified bamboo pulp as a feedstock to produce ethanol (Ram and Seenayya, 1991).

2.6.6. Global bamboo for energy production

Bamboo was proposed to be used as fuel for power generation in Puerto Rico in place of sugar cane, because of its lower moisture content in other to do away with drying (Molini and Irizarry 1983). However, they provided few data in support of their case. Little experience has been gained using de-lignified bamboo pulp as a substrate for ethanolic fermentation (Ram and Seenayya, 1991). In 1947, work was done by preparing a diesel-like fuel from bamboo culms which appears like “black liquor” from bamboo pulping, although it does not seem to have progressed beyond the laboratory scale (Tewari 1992). Bamboo has desirable fuel characteristics with certain other bioenergy feedstocks, such as low ash content and alkali index. Even though, it's heating value is lower than many woody biomass feedstocks but higher than most agricultural residues, grasses and straws (Scurlock, 2000).

In most African countries, the commercial uses of bamboo are lacking. This may be due to the lack of awareness of scientific research into the physical properties (Sharma, 1980; IFAR/INBAR, 1991). In Africa, bamboo is used mainly for scaffolding, fencing, farm hut, handicraft, basic living room furniture, some musical instrument and fishing system as fish traps like acadja" in Benin (Kwaku, 2006). Bamboo wine is produced from young shoots of *Oxytenantherea abyssinica* in Tanzania (Kigomo, 1998; Chihongo *et, al.,* 2000). In Madagascar, the culms of *Valiha diffusa* are used for the construction of wall and roof (Ferraro 2001).

2.6.7. Bamboos as an energy resource in Ghana

A research conducted by the Forestry Research Institute of Ghana (FORIG) identified seven species of bamboo from four genera in Ghana and also made sample bamboo resources of about 300,000 hectares available in Ghana. The species are; *Bambusa Vulgaris (green variety); Bambusa Vulgaris (yellow-green variety); Bambusa arundinacea; Dendrocalamus strictus; Oxytenanthera abyssinica; Bambusa multiplex and Bambusa pervariabilis* (INBAR 2006). Bamboos were identified in eight out of the ten regions in Ghana (Tekpetey, 2011).

The most common and abundant bamboo in the wild is *Bambusa vulgaris* Schrad. ex J. C. Wendl. var. *vulgaris* Hort followed by the *Bambusa vulgaris* Schrad. ex J. C. Wendl. *var. vittata Rivière* (Ebanyenle *et al*., 2005; Ebanyenle and Oteng-Amoako 2008, Tekpetey *et al*. 2008; Competitions, 2011). Similarly, Oteng-Amoako *et al*, (2005) reported that *Bambusa vulgaris* is the predominant bamboo species in southern Ghana, constituting 95% of the stocks in that area. The green and yellow types are available, however, the green type is naturally widely distributed in the wild, and hence the one predominantly collected for both domestic and commercial uses (Obiri and Oteng-Amoako, 2007).

Several studies have been conducted to investigate the physical, mechanical and chemical properties in Ghana (Ebanyenle *et al*., 2005; Oteng-Amoako *et al*, 2005; Ebanyenle and Oteng-Amoako, 2008, Tekpetey *et al*. 2008; Obiri and Oteng-Amoako, 2007; Hammond, 2006; Competitions, 2011; Tekpetey, 2011). Tekpetey (2011) stated that majority of bamboo species and their biology in Africa are not much known. Bamboo has been used for a variety of purposes including environmental restoration and in the production of handicrafts, artefacts and furniture. Bamboo-ply, laminated boards, flooring, roofing sheets, props and many others, have been key wood substitutes of bamboo in the construction industry world-wide (Obiri and Oteng-Amoako, 2007). Other vital products such as medicines, food, charcoal, vinegar, beverages, natural pesticides, and toiletries, among many others have been produced from bamboo (Hammond, 2006).

In the case of using bamboo as a biofuel, Sarfo (2008) worked on chemical properties on three species of bamboo (*Bambusa v. vulgaris, Bambusa v. vittata and Bambusa heterostachya*) of matured bamboo culms from the one ecological zone in Ghana. The researcher concentrated on gross calorific value, proximate analysis (moisture content, ash,), ultimate analysis (proportion of Carbon, Nitrogen, Sulphur and Chlorine), ash elementals (Potassium – *K,* Lead – *Pb,* Iron – *Fe* and phosphorus – *P*) and chemical (proportion of cellulose, lignin, hemicellulose and extractives) analyses in the three bamboos. However, the author did not cover age groups and other parts of the bamboo such as the shoot, juvenile, dead or over-matured, branches and leaves. In addition, the researcher covered only four of the Ash elementals of the bamboos and one ecological zone. Tekpetey *et al*. (2007) studied the ultra-microstructural, physical, thermogravimetric behaviour, chemical and phytochemical properties of bamboo species. Information on the properties such as proximate, ultimate, calorific value, minor and heavy metals were not tackled. Antwi-Boasiako *et al* (2011) determined proximate composition of dry powdered leaf samples for four tropical bamboo varieties. However, the assessment was to find an alternative local feed resources suitably as fodder for livestock or wildlife. Moisture content, ash, protein, crude fibre, crude fat and carbohydrate were determined.

2.7 PROPERTIES OF BAMBOO

Bamboo properties differ with species, topography, external factor and climate (Soeprajitno *et al*. 1988). As a result, information on properties of bamboo at different ages and height level is required for suitable end-use. Bamboo matures at three years old. At the age of two years and below they are considered young (Abd. Latif *et al*., 1990; Sattar *et al*., 1992; Liese and Weiner 1997; Norul Hisham *et al*., 2006). Research has shown that the basal portion showed significantly longer fibre compared with the middle and top portions of the two ages of *G. levis* culms. This could be due to the correlation between fibre length and internode as longer fibres were found in the basal portion of the culm with the longest internode. The increasing trend of density from the basal towards the top has also been observed in *G. scortechinii* (Jamaluddin & Abd. Latif 1993; Anwar *et al*. 2005) and *B. vulgaris* (Razak *et al*., 2010). According to the researchers, the top portion of the bamboo culms showed higher proportion of fibres which contributed to the higher density. This may be due to the fact that wall thickness decreased from bottom to top of the culm with no reduction in the amount of fibres in the cross-section of the culm. Liese (1985) and Espiloy (1987) also reported that the density increased along the culm due to the increment of vascular bundles from basal to the top. As larger amount of vascular bundles is massed in a smaller space, it reduces the total air volume within a given area, and thus the wood substance and density increase (Abd Latif and Liese 1995).

2.7.1. Physical properties of bamboo

Biomass fuels vary in physical appearance because the complex hydrocarbon molecules of each are quite different, despite the similarity of their constituent elements (Maker, 2004). The composition elements of bamboo are suitable for producing biofuel. Despite the species, bamboo has similarities on the chemical and physical-mechanical properties (Huang, 2014).

2.7.2 Energy content of the fuel

One of the factors that determine how easily biomass fuels can burn depends on the molecular structure (Maker, 2004). The complex molecules that make up biomass are comparatively difficult to break down to simple carbon and hydrogen. That's why, biomass requires high temperatures and a long combustion zone (or flame path) for clean, efficient burning. Energy density is a term used to describe the amount of energy stored per unit volume, often expressed in MJ/m^3 or BTU/ft^3 (Clarke and Preto, 2011). Bulk density of materials is directly proportional to their energy density. The calorific value determines the final energy content of the fuel (Maker, 2004). Bamboo chips have lower bulk density than wood chips (Papadopoulos et al., 2004).

2.7.3 Determination of Density of bamboo samples

Bamboo is a porous material and the density is defined as weight per unit volume. The higher the density of bamboo is the more the strength it has in the same culms (Utilisation of bamboo, 2009). Bamboo densities are grouped into basic density, fresh density, air dried density and absolute dry density. Density of solid bamboo is determined using ISO 3131 standard. Many researchers observed the presence of higher number of vascular bundles and higher proportion of fibrous tissue at upper portion of the culm resulted in the density of bamboo culm (Janssen, 1981; Espiloy, 1987; Liese, 1998; "Bamboo Structure", 2013; Santhoshkumar and Bhat 2014). In addition, investigators also noted the variation in density in relation to height levels of the culm. The basic density of the culm increased with increasing height levels of the culms (Liese, 1986; Espiloy, 1987; Santhoshkumar and Bhat 2014). Studies also depicted that the outer portion of the culm wall gradually decreasing to the inner region of the culm wall (Espiloy, 1987; Liese, 1998; Santhoshkumar and Bhat 2014). Hamdan *et al*., (2009) declared that a dead bamboo culm might undergo trends involving consistent increases in culm volume density and Nitrogen content from the bottom to the top of the culm. Montaño (2014) compared the densities of bamboo culm (500-700 kg/m^3) to cane bagasse (150-200 kg/m^3), wheat straw (160-300 kg/m^3) and wood (200-500 kg/m^3).

2.7.4 Bulk Density of Bamboo Samples

Bulk density is a measure of the mass of particles of the material divided by the volume they occupy. The volume includes the space between particles. A biomass with higher bulk density has more mass of fuel in a given volume. Wood pellets (660kg/m^3) have a higher bulk density than wood chips (250kg/m^3) (The Carbon Trust, October 2009). Bulk density is used for piles of wood fuels (log woods and wood chips) that create voids among the wood pieces which may be bigger or smaller depending on the size and shape of the latter. It is expressed in kg/stacked m^3 or kg/bulk m^3, depending on whether the pile is stacked or bulk (Francescato *et al*., 2008). Bulk density is not intrinsic to a material because the same piece of wood could have different bulk densities if processed into logs, pellets or woodchips (The Carbon Trust, 2009). Bulk density of biomass increases during transportation, handling, and storage which can be caused by compaction due to vibration, tapping, or normal load (Emami and Tabil, 2008). Bamboo chips have lower bulk density than wood chips (Papadopoulos *et al*., 2004). Bulk density of materials is directly proportional to their energy density. Biomass bulk density is lower than that of fossil fuel and coal (Scurlock, 1994). The bulk density reduces the cost of production, transportation, conversion and distribution of the biomass (WWI, 2006). Bulk density has significant effect on material handling and storage aspects in a biorefinery, and depends on material composition, particle size, shape and distribution, moisture content, specific density and applied pressure (Lam *et al*., 2007). The greater the change in a material's bulk density from initial fill to final consolidated bulk density, the less likely that the material will flow (Hebert, 2011).

Method of Measuring the Bulk Density: Loose-filled bulk density of biomaterials such as grains, pellets and ground particles is typically determined using containers having a capacity of 500 cm^3 per standard methods (Chevanan *et al*. 2007). The container used to determine tapped bulk density per an ASTM E873 and other standards have a capacity of only 250 cm^3. The container with biomass was tapped on a wooden platform 50 times with approximate amplitude of 20 mm. Reduction in height of the top biomass surface was measured using a Vernier caliper (±0.01 mm). The reduction in volume of biomass was calculated as an imaginary cylindrical volume having inside diameter of the container and height of average settled distance. Tapped bulk density was calculated as Tapped bulk density.

$$\text{Loose filled bulk density} = \frac{\text{Mass of the biomass}}{\text{Volume of the biomass}} \qquad \textit{Equation 2.1}$$

The bulk densities of some seasoned and dry wood about 10^3 kg/m^3 (1b/ft) are as follows; Alder 0.4 – 0.7; Afromosia 0.71; Agba 0.65; Apple 0.65 – 0.85; Ash, white 0.54; Ash, black 0.54; Ash, European 0.71; Bamboo 0.3 – 0.4; Mahogany, Africa 0.5 – 0.85; Teak, Africa, 0.98; Utile 0.66; Walnut 0.65 – 0.7 (Engineers' Toolbox, 2013). Guang Pu et *al*., (2012) reported bamboo bulk density as 0.03 – 0.4 kg/m^3.

2.7.5 FUEL PROPERTIES OF BIOMASS

2.7.5.1. Moisture content (MC)

MC is a very important property which affects the burning characteristics of the biomass (Yang *et al*., 2005). It affects both the internal temperature within the solid biomass, due to endothermic evaporation, and the total energy that is needed to bring the solid up to the pyrolysis temperature (Zaror and Pyle, 1982). Moisture content is one of the important property fuels of bamboo. There is a significant variation of bamboo for green and air-dry conditions [Lee 1994; Chung and Yu 2002]. In solid fuels, moisture can exist in two forms: as free water within the pores and interstices of the fuel, and as bound water which is part of the chemical structure of the material (Borman and Ragland, 1998). During combustion, moisture in the biomass will absorb heat by vaporisation and heating of the resulting vapour, significantly reducing the heating value of a given fuel. The result is that there is less heat to drive the pyrolysis reactions, resulting in lower combustion temperatures. This can result in incomplete combustion of the volatiles and the removal of carbon not burnt in the form of smoke (Maker, 2004). Biomass with moisture content of 15% or lower can be fed directly into the compactor without going through the dryer. Moisture content of green wood ranges from 67 - 150%; dry wood 17%; straw 17%; stalks and cobs 17%, and bagasse 2.30% (Miles, 1982). Other researchers reported the following base of some bamboo species (dry basis): 15 - 20% (Scurlock, 1999) and the top, middle and bottom as 13.7, 13.5 and 13.0% (Ganesh, 2003).

In conclusion, Moisture content increases heat loss, due to evaporation and superheating of vapour. Dry biomass has a greater heating value or net energy potential than green biomass as it uses little of its energy to evaporate any moisture. The % moisture content of a plant species varies according to location, season and age of the sample.

2.7.5.2. Determination of Calorific value of biomass fuels

The calorific value or heating value is the standard measure of the energy content of a fuel. It is defined as the amount of heat evolved when a unit weight of fuel is completely burnt and the combustion products are cooled to 298K (B. S. Institution, 2005). When the latent heat of condensation of water is included in the calorific value it is referred to as the gross calorific value (GCV) or the higher heating value. The heat of combustion of a fuel is defined as the amount of heat released by a specified quantity (initially at 25°C) when combusted and the products have returned to 25°C. A bomb calorimetric technique is used in its determination. There are two values for the heat of combustion, or calorific value, for every fuel. They are higher heating value (HHV) and lower heating value (LHV) of combustion. The difference between the two calorific values is equal to the heat of vaporization of water formed by combustion of the fuel. The heating value can be measured as calorimetric value (higher heating value, e.g. HHV) by ASTM D2015 – 85. The higher heating value (dry) of bamboo culm is similar to that of wood which ranges from 17 to 20 MJ/kg whilst cane bagasse is 18 to 20 MJ/kg and wheat straw is 16-19 MJ/kg (Montaño, 2014). The net calorific value of bamboo is comparable or higher than other wood species like beach, sprue, eucalyptus and poplars range from18.0 - 19.7% (Fieden, 1999). Bamboo has low ash content, low alkali index and lower heating value. The calorific values of bamboo are higher than most Agricultural residues, grasses and straw. Meanwhile, it is lower than many woody biomasses (Scurlock *et al*., 2000; Huang, 2014). However, the calorific value of dry bamboo is about 16 MJ/kg and the moisture content is around 13 % (Huang, 2014).

2.8. CHEMICAL PROPERTIES OF BAMBOO AGE GROUPS

The combustion of biomass has variable released, depending on the type and quality of fuel used, combustion technologies and operating conditions (Luque *et al*., 2008). According to NESCAUM (2013) the quality of the fuel depends mainly on its chemical composition, including water and ash contents, plant species, where it grows (origin), fertilizers and pesticides used, harvesting practices, transport, handling and processing, and blending of plant species type. The fuel properties in bamboo are determined by elemental and ultimate analyses. The ultimate analysis of a bamboo component typically involves the determination of the percent of carbon (C), hydrogen (H), oxygen (O), nitrogen (N), sulfur (S) and ash (RENEW, 2003). Carbon is the largest chemical constituent in wood, which comprises 45 to 50 percent of its mass, followed by hydrogen, at roughly 6 percent (Telmo *et al*., 2010).

2.9 PROXIMATE AND ULTIMATE ANALYSES

The following properties are generally useful on volatility of the feedstock, elemental analysis and heat content. They are water content, proximate (thermo-chemical behaviour) and ultimate (elemental composition) analysis, heats of combustion and ash analyses (RENEW, 2003). A biofuel is primarily described by its proximate analysis and ultimate analysis (Hustad and Barrio, 2001). The procedures below describe how to undertake a basic combustion characterisation.

2.9.1. Determining volatile matter in bamboo

The volatile matter is determined by heating a dried ground sample of biomass in an oven at 900°C for 7 minutes (B. S. I., 2009). The volatiles consist of permanent gases like methane (CH_4), carbon dioxide (CO_2), carbon monoxide (CO) and vapours, which form the bio-oil after condensation. The first part in nitrogen atmosphere shows the loss of moisture and volatiles. In almost all biomass, the amount of volatile matter is higher than in bituminous coal and ranges from 70-86% of the weight of the dry biomass compared to coal, which contains only about 35% volatile matter. Consequently, the fractional heat contribution of the volatiles is more for biomass. This makes biomass a more reactive fuel than coal (Loo and Koppejan, 2008), giving a much faster combustion rate during the devolatisation phase.

The volatile content has been shown to influence the thermal behaviour of the solid fuel (Loo and Koppejan, 2008), but this is also influenced by the structure and bonding within the fuel, and is therefore hard to quantify. Low-grade fuels, such as dung, tend to have a low volatile content resulting in smouldering combustion. The consequences of this for cooking on a woodstove are that the hot gases are less likely to impinge on the bottom of the pan and there will be less radioactive heat transfer (because of the lack of flames), reducing the heat transfer efficiency (Burnham-Slipper, 2008).

After the volatiles and moisture have been released, ash and fixed carbon remain. Volatile Matter proportionately increases flame length, and helps in easier ignition of coal. It sets minimum limit on the furnace height and volume. Again, it influences secondary air requirement and distribution aspects. Finally, influences secondary oil support.

The following values are recorded for volatile matter at different species of bamboo; 63 - 75% (Nordin, 1994); Also, Ganesh (2003) 79.6 – 80.6% and volatile matter contents are nearly high up to 80% (Huang, 2014).

2.9.2. Fixed carbon content in bamboo

Fixed carbon content of biomass is the solid fuel left in the furnace after the evaporation of moisture content, volatile matter and the ash content at the ignition temperature of 750° to 900°C (Scurlock *et al*., 1999). Fixed carbon differs from the ultimate carbon content of the biomass because some carbon is lost in hydrocarbons with the volatiles. The relative proportion of volatiles, moisture, fixed carbon and ash are often quoted for biomass fuels. The percentage of fixed carbon is normally determined by difference from the other quantities (Demirbas, 1999). The proximate analysis determines the moisture, volatile matter, and (by difference) fixed carbon content of a fuel (RENEW, 2003), using standard ASTM E872/897 tests. The proximate analysis is calculated by;

$M + VM + FC + A = 100\ \%$ *Equation 3.7*

where M = Moistur content

VM = Volatile matter

FC = fixed carbon

A = ash

The results of various experiments to determine fixed carbon contents are shown below; Scurlock *et al.,* (1999) worked on three bamboos based on their age type, the results were *Phyllostachys nigra* 1yr (16.78), 2 yr (16.68) and 4-5 yrs (13.7); *Phyllostachys ambusoides* 1yr (13.8), 2 yr (15.73) and 4-5 yrs (14.38); *Phyllostachys bissetti* 1yr (17.16) 2 yr (16.32) 4-5 yrs (12.14). The fixed carbon content of a bamboo culm is around from height distance top (15.6%), middle (15.6%) and bottom (14.9%). The fixed Carbon of bamboo dust at 11.1% moisture content was 15.9% (Ganesh, 2003) whereas the Huang (2014) stated 15 %.

2.9.3. Determining the ultimate analysis

The ultimate analysis of a bamboo component typically involves the determination of the percent of carbon (C), hydrogen (H), oxygen (O), nitrogen (N), sulfur (S) and ash (RENEW, 2003). Carbon is the largest chemical constituent in wood, which comprises 45 to 50 percent of its mass, followed by hydrogen, at roughly 6 percent (Ni *et al*., 2006; Telmo *et al*., 2010). Scurlock *et al*., (1999) stated that the carbon and hydrogen contents of the bamboo samples were all very similar, at about 52% C and 5% H. The variation in the nitrogen content of the bamboo samples was larger, ranging from 0.2-0.5%. Experiment conducted by Ganesh (2003) shows those parts of bamboo culms ranges from 42.9 to 55.8 carbon 4.8 to 6.7 hydrogen; nitrogen (0.4 to 1.3) and nil for sulphur. The results clearly show that N had a very low content and would be helpful in terms of minimal fuel-bound nitrogen conversion to NO_x if bamboo were used as a boiler fuel

(Scurlock *et al*., 1999). The sulfur content of the bamboo samples is very low compared to coal, and like many woody biomass materials, is also lower than many herbaceous biomass feedstocks, grasses, and straws (Scurlock *et al*., 1999).

Finally, Ultimate analysis is useful in determining the quantity of air required for combustion, the volume and composition of the combustion gases. This information is required for the calculation of flame temperature and the flue duct design.

2.9.4. Carbon deposits in biomass and uses

Carbon is the largest chemical constituent in wood, which comprises 45 to 50 percent of its mass, followed by hydrogen, at roughly 6 percent (Telmo *et al*., 2010). Carbon materials play an indispensable role in almost all electrochemical devices, to name a few, batteries (Endo *et al*, 2000), super capacitors (Pandolfo and Hollenkamp, 2006) and fuel cells (Dicks, 2006).

Bamboo *(bambusoidae)* was used for producing activated carbon by adopting a physico chemical method of activation using KOH as well as CO_2 as activating agents at an activation temperature of 1123 K (Hameed *et al*., 2007). Another method for producing activated charcoal was by using KOH on bamboo at 1073 K in Ar atmosphere (Kim *et al*., 2006). The carbon filament that was originally used was from biomass (Dickinson, 1937).

Many researchers gave different values of carbon in biomass. The carbon content of biomass is around 45%, whereas coal contains 60% or greater (Demirbas, 2007). Scurlock *et al* (1999) investigated the carbon contents in three bamboos based on their age as *Phyllostachys nigra* 1yr (51.89), 2 yr (51.19) and 4-5 yrs (51.39); *Phyllostachys ambusoides* 1yr (52.28), 2 yr (51.84) and 4-5 yrs (50.85); *Phyllostachys bissetti* 1yr (51.22) 2 yr (51.7) 4-5 yrs (51.07). Other researchers reported the following; 48.5 - 50% (Nemestothy, 2002); 42.9 – 55.8% (Ganesh, 2003) and 43 - 55% (Vessia, 2006). Higher carbon content leads to a higher heating value (Clarke and Preto, 2011).

2.9.5. Hydrogen deposits in biomass

Biomass has the potential to accelerate the realisation of hydrogen as a major fuel in the future (Hofbauer, 2000; Zhou *et al*., 2013. The hydrogen content in biomass is low to begin with (approximately 6% versus 25% for methane) and the energy content is low due to the 40% oxygen content of biomass. Since over half of the hydrogen from biomass comes from splitting water in the steam reforming reaction, the energy content of the feedstock is an inherent limitation of the process (Hofbauer, 2000; Riis *et al*, 2005). Several technologies are already available in the marketplace for industrial productions of hydrogen. Among them are chemical, biological, electrolytic, photolytic and thermo-chemical (Aznar, 1997; Riis *et al*, 2005). The hydrogen content of biomass is around 6% (Jenkins, 1998). Scurlock *et al* (1999) studied the Hydrogen contents in three bamboos based on their age as *Phyllostachys nigra* 1yr (5.21), 2 yr (5.29) and 4-5 yrs (5.25); *Phyllostachys ambusoides* 1yr (5.09), 2 yr (5.18) and 4-5 yrs (5.40); *Phyllostachys bissetti* 1yr (4.90) 2 yr (5.00) 4-5 yrs (4.51). Higher hydrogen content leads to a higher heating value (Clarke and Preto, 2011).

The carbon and hydrogen in fuel whether it is solid, liquid, or gaseous provide energy. The following three fuel characteristics help to calculate a system's efficiency: the ultimate analysis of the fuel; how much energy the fuel can release when burned (called the calorific value of the fuel), and the fuel's moisture content (Marker, 2004).

2.9.6. Nitrogen deposits in biomass

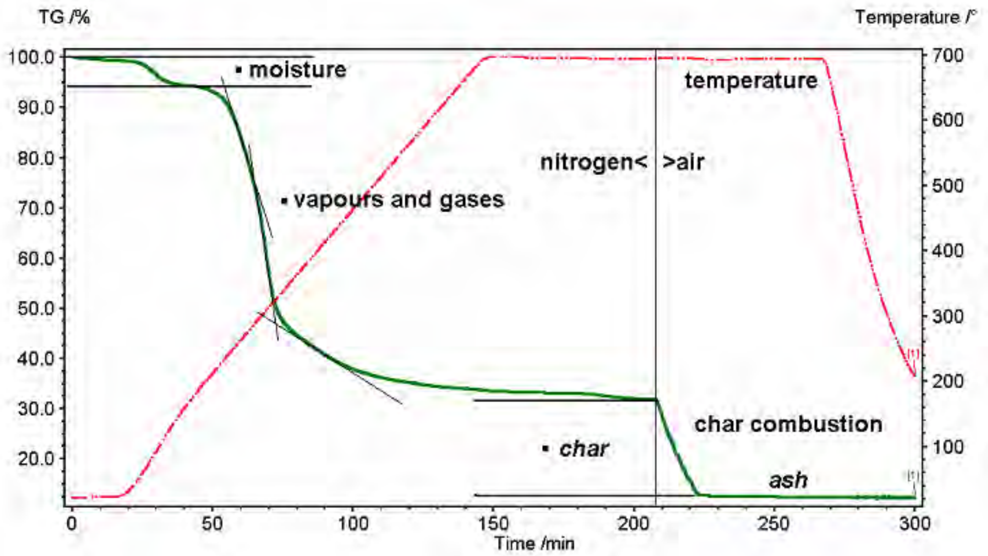
Nitrogen content in wood biofuels is relatively low, whereas it is much higher in cereal and highest in oilseed rapes (rapeseed cake); this bears a direct impact on the formation of nitrogen oxides (NOx) which, during combustion, become gasiform and do not remain in the ashes (Francescato *et al*., 2008). It has increased substantially in recent decades, primarily as a result of an increase in the use of fertilizer and the burning of fossil fuels. Increased nitrogen in soil and water can lead to loss of species and shifts in the species composition of plant communities (Wedin and Tilman, 1996); for example, the conversion of heath lands to species-poor grasslands in the Netherlands (Vitousek and others, 1997).

The Nitrogen content of biomass ranges from 0.2% to more than 1% (Jenkins, 1998). Ganesh (2003) reported that the Nitrogen content of bamboo culms varies from 0.4 to 1.3%. The results of Scurlock *et al* (1999) experiments show that the nitrogen contents in three bamboos based on their age were *Phyllostachys nigra* 1yr (0.4), 2 yr (0.29) and 4-5 yrs (0.21); *Phyllostachys ambusoides* 1yr (0.59), 2 yr (0.6) and 4-5 yrs (0.38); *Phyllostachys bissetti* 1yr (0.55) 2 yr (0.3) 4-5 yrs (0.32). Nitrogen in fuel feedstock is responsible for most nitrogen oxide (NOx) emissions produced from biomass combustion. Lower nitrogen content in the fuel should lead to lower NOx emissions (Clarke and Preto, 2011). Cofiring with bamboo as a fuel could offset some of the input fuel-bound Nitrogen, because bamboo has lower Nitrogen contents than many coals used for power production. Similarly, co-firing with bamboo may also have other NO_x benefits caused by differences in flame structure and temperature that reduce thermal NO_x formation (Scurlock *et al*., 1999).

2.9.7. Thermogravimetric analysis (TGA) of bamboo

Hustad and Barrio (2001) reported that the proximate analysis can be obtained by means of thermogravimetric analysis (TGA). This technique can also give information about the rate of devolatilisation and the rate of char oxidation.

Thermogravimetric analysis (TGA) is an instrument used to measure the weight of a biofuel sample inside an oven under controlled temperature. Figures 2.1 show how the sample weight decreases as the temperature rises in the oven. The sample first dries and then loses its volatile components (devolatilisation or pyrolysis) at around 300-600°C. The solid residue after devolatilisation is called char and contains mainly carbon (fixed carbon) and ash. The char oxidises at 800-1200°C in presence of oxygen (Hustad and Barrio, 2001).



Source: Stahl et al., 2004

Figure 2.2. Slow pyrolysis of wheat straw in a thermo-balance Sample 230 mg, heating rate 5 K/min, pyrolysis in nitrogen, combustion in air, both 70mL/min

2.9.8. Ash content in *Bambusa v. vulgaris*

Ash is the non-combustible component of biomass and the higher the fuel's ash content, the lower its calorific value (Vessia, 2006; Loo and Koppejan, 2008). Wood ash is very alkaline, with pH of 12 (Taipale, 1996). The differences may be greater between different wood fuels than between different biofuels. Ash contents are formed from mineral matter bound in the carbon structure of the biomass during its combustion. This is called the inherent ash (Ragland and Aerts, 1991). It is also present in the form of particles from dirt and clay introduced into the fuel during harvest, transport and processing. This is called the entrained ash (Loo and Koppejan, 2008). The ash content of biomass is affected by the plant type, plant fraction, growing conditions, harvesting time and method, handling, pretreatment and conversion systems. The lower the ash content the lesser problems it poses depending on the quality of the ash produced in boilers in terms of the constituent chemical elements (Bakker and Elbersen, 2005). Higher ash content in some bamboo species can adversely affect the processing machinery. Ash can cause slagging, fouling and has the tendency to increase the rate of corrosion of metal in combustion systems (Loo and Koppejan, 2008). One reason for this is naturally differences in the combustion and flue gas cleaning efficiencies in power plants (NBF 2001; Taipale 1996).

The internode of solid bamboo has significantly higher ash than the nodes (Mabilangan *et al*., 2002). However, differences between the major chemical composition of node and internode fraction of bamboo are small (Scurlock, 2000). The ash content varies based on the type on of biomass. For example; the ash content of groundnut shells varies between 0.8% (Jekayinfa and Omisakin, 2005) and as high as 23% for rice husks while pine wood has around 1% ash content (Demirbas, 1999). Generally, the ash content of wood or woody biomass ranges from 0.5 to 3 percent dry weight (dw). A few studies have also found ash levels as high as 10 percent dw (Reimann *et al.,* 2008). The results of some bamboo culms ash investigated by some researchers were as follows; top – 5.2%; middle – 3.9% and bottom – 4.5% (Ganesh, 2003) and 0.158 – 0.475% (Scurlock, 2000) . Scurlock *et al* (1999) experimented to determine the ash contents of three bamboos based on their age type were as shown; *Phyllostachys nigra* 1year (0.86%), 2 year (0.87%) and 4-5 years (0.41%); *Phyllostachys ambusoides* 1year (0.66%), 2 yr (0.84%) and 4-5 years (0.53%); *Phyllostachys bissetti* 1year (1.14%) 2 years (0.78%) 4-5 years (0.9%).

In conclusion, in the course of burning bamboos at the temperature of about 900ºC for biofuels, ash is also produced. The ash produced is non combustible. The higher the ash contents in the bamboo or wood the lower the calorific value. More ash is produced in herbaceous plants and tree barks. Dirt and clay are sometimes accumulated on the biomass during handling and transporting the biomass. Ash contents in the biomass can cause slagging, fouling and increase corrosion of the metal container during combustion for biofuels.

2.10. BAMBOO ASH ELEMENTALS (MINOR AND HEAVY METALS) ANALYSES

The inorganic ash content of biomass or bamboo is determined by the composition of mineral constituents in the source fuel and on the combustion process (Masahiro *et al*., 2004). Ash is the non-combustible component of biomass and the higher the fuel's ash content (Vessia, 2006; Loo and Koppejan, 2008). It is both formed from mineral matter bound in the carbon structure of the biomass during its combustion (Ragland and Aerts, 1991) (the inherent ash), and is present in the form of particles from dirt and clay introduced into the fuel during harvest, transport and processing (the entrained ash) (Loo and Koppejan, 2008). The compound of the ash exist in the form of potassium oxide, silicon (exist in silica), phosphate exists as phosphorus pentoxide and others (Ye *et al*, 1989). The minor elements found in biomass ash are mainly calcium (*Ca*), potassium (*K*), sodium (*Na*), magnesium (*Mg*), iron (*Fe*), aluminum (*Al*) (Telmo *et al*., 2010; Huang, 2014) and manganese (*Mn*), silica (*Si*) (Huang, 2014). The major elements or the heavy metals include: cadmium (*Cd*), chromium (*Cr*), copper (*Cu*), nickel (*Ni*), arsenic (*As*), mercury (*Hg*) and lead (*Pb*) (Telmo *et al*., 2010), zinc (*Zn*) and Ti (Huang, 2014). Characterisation for Thermochemical Conversion research conducted by Ganesh (2003) gave ash elemental analysis of bamboo parts along the height as in Table 2.3.

Table 2.2 Ash analysis of bamboo:

Location in the culm	Si (%)	Fe (%)	Mg (%)	Na (%)	Ca (%)	K (%)
Top	1.05	0.05	0.15	0.003	0.12	0.11
Middle	0.86	0.04	0.13	0.01	0.07	0.15
Bottom	1.13	0.04	0.23	0.02	0.09	0.26

Ash (Overall) deformation temperature 1000ºC - 1100ºC
Ash (Overall) fusion temperature > 1100º 110C

The ash content of wood reflects its inorganic content and is highest in the parts of trees where growth occurs (e.g., stem bark and branches). However, the ash content of the bamboo is relatively low as compare with that of the agricultural materials such as, grasses and straw (Huang, 2014).

2.10.1. Effects of heavy metals in plants (wood or bamboo)

Heavy metals include mercury (*Hg*), cadmium (*Cd*), arsenic (*As*), copper (*Cu*), zinc (*Zn*), nickel (*Ni*), chromium (*Cr*), and lead (*Pb*) (Wang, 1987; Environmental Protection Administration, 1991; Telmo *et al*., 2010). *Hg, Cd*, and *As* have received more public concern as they were shown to be associated with some widely spread human diseases. On the other hand, plant injuries caused by these three species were not as frequent as those caused by the other five species – *Cu, Zn, Ni, Cr*, and *Pb* (Sun, 1994; Wang, 1987).

Application of ash to agricultural land offers an opportunity for the recovery of essential plant nutrients (Zhang *et al*., 2002), for the reason that this residual material contains chemical elements with considerable fertilizer value (Insam *et al*., 2009). Heavy metals can be absorbed from the soil by plants (Wong and Selvam, 2006; Duffy *et al*., 2009; Chiroma, 2012). Heavy metals have the potential to cause severe damage to crops or the ecosystem; through related products, they may pose serious risks to humans as well (Foy *et al*., 1978). The presence of heavy metals is a restraining factor for the use of wood ash (Obernberger and Supancic, 2009). Wood ash content depends on the age of plant, growing site, distance from the source of pollution, etc. (Saidur *et al*., 2011). Heavy metals enter the food chain causing both human health and environment concerns.

Cadmium (*Cd*) accumulated in the wood ash varies between 1 and 20 $\mu g\ g^{-1}$, can cause concern for environmental risks (Korpilahti *et al.,* 1998). Cadmium when dissolved to soil is easily taken up by plants and enriched especially in protein compounds where it replaces zinc (Kabata-Pendias and Pendias, 1984; Stevenson and Cole, 1999). High concentration of cadmium in fly ash is due to the fact that cadmium sublimates or reacts by forming gaseous compounds during the combustion process. Afterward, when the flue gas is cooled, it forms aerosols and agglomerate or condense on fly ash particles and the concentration of cadmium in fly ash can be about 27 times higher than in the bottom ash (Obernberger *et al*., 1997). The lower cadmium content in the bottom ash allowed for agriculture use in some countries as a complex Ca-fertilizer (Ribbing, 2007), however fly ash from wood combustion can consider a threat to the environment (Hansen *et al*., 2001).

Many researchers have proved that Lead (*Pb*) has long been known as a potential health hazard to human beings (Arshad *et al*. 2008; Cecchi *et al*. 2008; Uzu *et al*. 2010; Grover *et al*. 2010; Shahid *et al*. 2011). A number of studies have determined lead concentrations in dust, soil, particulates and leaf samples in different urban areas around the world (Brandvold 1996; Angima and Sullivan 2008; Uzu *et al*. 2009). Dust is a significant source of lead and can raise the blood lead levels in humans, particularly in children (Langlois *et al*., 1996). Lead exists naturally in soils at levels of 10 to 50 parts per million (*ppm*). However, they are higher in areas near existing or former smelters, tailings from metal ore mines, fossil fuel-fired electrical power plants, or cement factories often have elevated soil lead levels. Also, lead does not readily accumulate in the edible parts of vegetable and fruit crops (e.g., corn, beans, squash, tomatoes, strawberries, and apples) (Angima and Sullivan, 2008).

Copper (*Cu*) is a micronutrient, which means plant really doesn't need a whole lot of it. Most crops will remove 0.1kg Cu/ha per year whilst removal of nitrogen by more harvested field crops can remove over 50 kg/ha (Schulte and Kelling, 1999). If copper levels in the leaves increase to levels of 20 – 30 *ppm*, toxicity symptoms may appear including interveinal cholorsis (pale green stripes in corn leaves) and stunted root growth (Jones Jr., 1998). Plants have different tolerances to high copper levels as well as have varying abilities to accumulate copper (Flis, 2008).

Arsenic (*As*) is considered as phytotoxic to some plants if the amounts greater than 2 parts per million (*ppm*) (dry weight). Arsenic compounds such as methylarsonic acids, dimethylcalciumpropylarsonate, Calcium me-thylarsonate, and dimethyl arsenic acid have been widely used as pesticides, insecticides, herbicides, soil sterilants, silvicides, and dessicants in agriculture and forestry (Pais and Jones 1997; Pettry and Switzer 2001). Arsenic is not highly mobile in soils and it has a moderate bioaccumulation index (Pais and Jones, 1997).

Nickel (*Ni*) is an "*essential*" nutrient for plants (Epstein and Bloom, 2005). Brown *et al.* (1987, 1990) discovered this fact, and it was validated by Wood *et al.*, (2004) with their discovery that pecan could not complete its life cycle without *Ni*. *Ni* potentially improves the health of crops attacked by root knot nematode (Monti *et al.*, 2008). The Nickel (*Ni*) concentration in the bamboo samples were similar to that of wood ash investigated by Kopecky *et al.* (1995).

In conclusion, the ash elementals or the inorganic elements produced during combustion of biomass may damage the conversion plant not to work effectively by causing slagging, fouling and corrosion. Slagging is connected to the low melting point of deposits, which creates a glassy layer that must be removed. Fouling is the accumulation of unwanted materials on the surfaces of processing equipment leading a decrease on the exchanger efficiency. Corrosion is caused by the interaction between deposits and metal surface of the exchanger, which involves extra costs in maintenance (Monti, Di Virgilio and Venturi, 2008). The lower concentration of the ash content and the elementals will increase the conversion plant life-span (Reumerman and Berg, 2002).

2.10.2. Effects of the minor metals in plants (wood or bamboo)

The minor metals found in wood or bamboo plants include the following calcium, potassium, magnesium, phosphorus, sodium, aluminium and iron.

Zinc (*Zn*) is a micronutrient essential for plants at trace levels, but high concentrations can be toxic (Marschner, 1995). Toxicity symptoms in plants include stunting, chlorosis, induced *Fe* deficiency, leaf folding, and stem splitting (Davis and Parker, 1993). Studies have shown that increasing Zn environmental pollution has originated from several anthropogenic sources

(Popovic et al., 2001; Konstantinou and Albanis, 2004; Mathur et al., 2005; Pruvot *et al*., 2006; Kong and White, 2010). European Commission (2002) identified the sources as mining and extraction as part of the heavy metals will end up in tailings and other waste products; further processing of the metals; lost from the products during use by corrosion and wear, and the discarded products.

The need for Manganese (*Mn*) among the trace elements for plant growth is particularly acute in cool temperate agricultural systems, on soils of high pH, with high organic matter and high carbonate content (particularly in those systems growing cereals and soya bean). Wood ash has great quantities of *Mn* in it, being higher from conifers than broadleaves (Hakkila, 1989).

Potassium (*K*) is mainly to be found in agricultural biofuel, lowers the melting point of the ashes, thus favouring the formation of slag in the grate that are the cause of considerable problems for the combustion process (Francescato *et al*., 2008).

The quality of the bamboo ash elements can lower the net energy output considerably, both limiting the effectiveness of the conversion plants (Jenkins *et al*., 1998) and lowering the heating value (Monti, Virgilio and Venturi, 2006). Ashes and inorganic elements produced clogged ash during combustion. The clogged ash may cause a number of serious problems to power plants through slagging, sintering, deposition, erosion, corrosion, fouling and pollutant emissions that are mainly created by the presence of alkali metals and alkaline earth metals in the ashes (Quaak, Knoef, H. and Stassen, 1999; Wang *et al*., 2008; Vamvuka, 2009). Fouling is the accumulation of unwanted materials on the surface of processing equipment leading to a decrease in the exchanger efficiency. Slagging is related to the low melting point of deposits which causes the formation of glasses layer that must be removed. Corrosion is caused by the interaction between deposits and metal surface of the exchanger, which involves extra costs in maintenance whilst significantly decreasing the plant life span (Reumerman and Van den Berg, 2002).

2.11. PRE-TREATMENT OF LIGNOCELLULOSIC BIOMASS

Studies have shown that lignocellulosic materials are potential for producing biofuels such as transportation fuel, heat biopower and chemicals (McMillan, 1994; Hamelinck, 2005; US Department of Energy, 2012). Converting lignocellulosic biomass to produce bioethanol is complicated. Hydrolysis or fermentation of lignocellulose is much more complicated than just fermentation of sugars, and fermentation converts these sugars to bioethanol (Hamelinck, 2005). Pretreatment is used to breaks down the tough, fibrous cell structures of lignocellulose biomass and make the cellulose easier to hydrolyze by heating with an acid or base to soften the biomass (US Department of Energy, 2012; Hamelinck, 2005). Pretreatment removes lignin and hemicellulose, reduces the crystalline of cellulose, and increase the porosity of the lignocellulosic materials. The pretreatment must meet the following requirements: (1) improve the formation of sugars or the ability to subsequently form sugars by hydrolysis, (2) avoid the degradation or loss of carbohydrates, (3) avoid the formation of byproducts that are inhibitory to the subsequent hydrolysis and fermentation processes, and (4) be cost-effective (Kumar *et al*., 2009).

Three major hydrolysis processes are typically used to produce a variety of sugars suitable for ethanol production: dilute acid, concentrated acid, and enzymatic hydrolysis (Broder *et al*., 1995).

The processes of pretreatment also include screening, size reduction, and drying (Faaij 1998). The particle size of the biomass is reduced by mechanical or physical methods such as chipping, grinding and milling (Harmsen *et al.*, 2010). These methods reduce crystalline elements and to make material handling easier and increase surface/volume ratio. Pellets as feedstock should have small particle sizes and low water content to ensure that products have better physical characteristics such as strength, durability and final density (Núñez *et al*., 2012). Pretreatment routes for the Production of Biofuels are as follows;

2.11.1. Mechanical Pretreatment

Mechanical pretreatment is usually carried out to reduce the particle size to make material handling easier and to increase surface/volume ratio. This can be done by chipping, milling or grinding.

Chipping is generally the first step in biomass preparation. The fuel size necessary for fluidized bed gasification is between 0 and 50 mm (Pierik and Curvers, 1995). Total primary energy requirements for chipping woody biomass are approximately 100 kJ/kg of wet biomass (Katofsky 1993) or 240 kW for 25 – 50 tonne/h to 3x3 cm in a hammer mill, which gives 17 – 35 kJ/kg wet biomass (Pierik and Curvers 1995).

Milling is usually carried out to reduce the particle size to make material handling easier and to increase surface/volume ratio. Smaller biomass particle size will provide more surface area and porous structures per unit biomass to facilitate heat transfer and biomass conversion during the gasification process. However, in most gasifiers, the biomass feed has to withstand the flow of gasifying agent with an appropriate size and weight; feed particle sizes are most often in the range of 20 to 80 mm (McKendry, 2002). Particle size of biomass should be as much as 0.6 cm for a profitable combustion process. Biomass is much less dense and has significantly higher aspect ratios than coal. It is also much more difficult to reduce to small sizes (Demirbas, 2010).

After milling, biomass was disposed for natural drying (Núñez *et al*., 2012). The fuel is dried to 15 % or 10% depending on the gasifier applied. Drying consumes roughly 10% of the energy content of the feedstock (Arkay and Blais 1996; Minister of Natural Resources Canada 2001 – 2005). The heat of vaporisation of water is 2250 kJ/kg. In practice more heat is needed

(McKendry, 2002). Drying biomass can improve the efficiency of gasification, but also reduces the hydrogen content in the gas product, which is unfavorable in the following Fischer–Tropsch synthesis. Drying can reduce the moisture content of the biomass feedstock to 10%–15% (McKendry, 2002).

2.11.2. Homogenising the Reaction Mixture

The reaction mixture has to be homogenised in some way at least during the initial stages of the reaction. Transesterification does not proceed properly unless samples are homogenised. In methanolysis, the alcohol is a poor solvent for fatty acids. This has been found to be successful in the batch and continuous processes of biodiesel production (Darnoko and Cheryan, 2000). One way of homogenisation is vigorous mixing of reactants. Other methods of attaining homogenisation are by the application of low frequency ultrasonic irradiation and supercritical methanol. The advantage of these two methods which do not involve the use of an alkaline catalyst is that the product does not require washing if free of soaps. Also FFAs 29 present are converted directly to methyl esters thus there is no need for de-acidification. The use of supercritical methanol is advantageous for feed stocks that contain water (like crude vegetable oils and waste oils) because water does not have a negative effect on conversion in transesterification with supercritical methanol (Kusidiana and Saka, 2004). However, high temperatures and pressures required, as well as alcohol to oil ratios of up 42:1 are major challenges for commercial application of this method in biodiesel production (Mittelbach and Rernschmidt, 2004).

Torrefaction is mild pretreatment of any biomass (including bamboo) at a temperature between 200 and 250° C. During torrefaction the properties of bamboo undergo changes, wherein the end product has much better fuel quality compared to biomass for combustion application. The decomposition reactions during this process results in bamboo becoming completely dry and loose its tenacious structure, also the hygroscopic nature of the biomass is changed to hydrophobic material. Besides this, the process increases the calorific value of the end product (ABETS and CGPL, 2006).

2.11.3. Chemical Pretreatment

Chemical pretreatment involves liquid hot water, weak acid hydrolysis, strong acid hydrolysis, alkaline hydrolysis and oxidative delignification for disruption of the biomass structure.

Biomass pretreated with Liquid hot water (LHW) requires high temperature and pressure. Terms used in liquid hot water are hydrothermolysis, hydrothermal pretreatment, aqueous fractionation, solvolysis or aquasolv (Mosier *et al*., 2005).

Weak Acid Hydrolysis is hydrolysis of hemicellulose that releases monomeric sugars and soluble oligomers from the cell wall matrix into the hydrolysate. This method removes hemicellulose by increasing porosity and improves enzymatic digestibility, with maximum enzymatic digestibility usually coinciding with complete hemicellulose removal (Chen *et al*., 2007).

Dilute acid treatment is mostly sulphuric acid treatment, is one of the most effective pretreatment methods for lignocellulosic biomass. Other alternatives to inorganic acids are organic acids such as maleic acid and fumaric acid can be used for dilute acid pretreatment (Kootstra et al, 2009).

Strong acid hydrolysis is a concentrated strong acid hydrolysis for pretreatment. For example, hydrochloric (HCl) and sulphuric acid (H_2SO_4) have been widely used for treating lignocellulosic materials because they are powerful agents for cellulose hydrolysis (Sun and Cheng, 2002), and no enzymes are needed to subsequent the acid hydrolysis. Presently, some companies are developing commercial strong acid hydrolysis of lignocellulosic biomass for microbial fermentation purposes (BlueFire Ethanol, 2010; Biosulfurol, 2010).

Alkaline Hydrolysis is a method of removing lignin from the biomass and to improve the reactivity of the remaining polysaccharides. It also removes acetyl and the various uronic acid substitutions on hemicellulose that lowers the accessibility of the enzyme to the hemicellulose and cellulose surface (Chang and Holtzapple, 2000). In addition, alkaline hydrolysis mechanism is based on saponification of intermolecular ester bonds cross linking xylan hemicelluloses and other components such as lignin (Sun and Cheng, 2002). Usually lime (calcium hydroxide) or sodium hydroxide is used for the hydrolysis (González *et al*., 1986). The addition of oxygen or air to the reaction mixture makes the delignification better, especially highly lignified materials (Chang and Holtzapple, 2000). Also, aqueous ammonia at high temperatures reduces lignin content and removes some hemicellulose while decrystallising cellulose (Kim *et al*., 2003; Kim and Lee, 2005; Kim *et al*., 2008).

Organosolv is method of using an organic solvent or mixtures of organic solvents with water to remove of lignin before enzymatic hydrolysis of the cellulose fraction. This leads to improve enzymatic digestibility of the cellulose fraction. Common used solvents for the process are ethanol, methanol, acetone, and ethylene glycol (Ghose *et al*., 1983; Sun and Cheng, 2002).

Oxidative Delignification is the process of delignifing lignocellulose by treating the material with an oxidising agent such as hydrogen peroxide, ozone, oxygen or air (Harmsen *et al*., 2010).

2.11.4. Combined Chemical and Mechanical Pretreatment

The methods of combining mechanical and chemical action for pretreatment include steam explosion, Ammonia fibre explosion (AFEX), Carbon dioxide explosion and biological pretreatment.

Steam explosion can be uncatalysed or catalysed for pretreatment. High-pressure saturated steam is introduced into a ba+tch or continuous reactor filled with biomass at the temperature between 160-260 ºC. Subsequently, pressure is suddenly reduced to the biomass for it to undergo an explosive decompression with hemicellulose degradation and lignin matrix disruption. The outcome of the steam-explosion pretreatment depends on residence time, temperature, particle size and moisture content (Sun and Cheng, 2002). Restrictions of steam explosion include the formation of degradation products that may inhibit downstream processes (Garcia-Aparicio *et al.,* 2006).

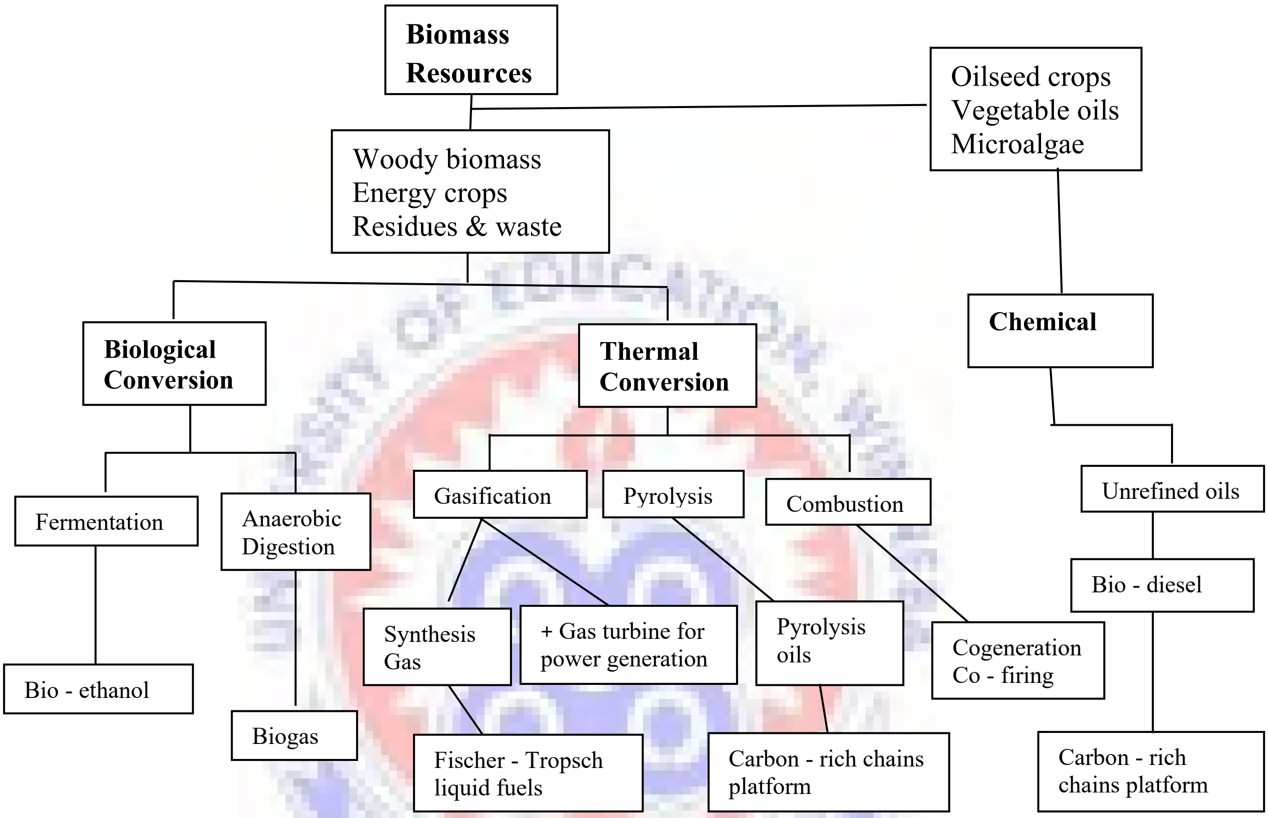
Ammonia Fibre Explosion (AFEX) is the procedure of treating biomass with liquid ammonia at high temperature and pressure (Teymouri *et al.*, 2005). This method reduces the lignin content and removes some hemicellulose while decrystallising cellulose. The ammonia recovery during the process increases the cost of the pre-treatment (Holtzapple *et al.*, 1991 & 1994), although ammonia is easily recovered due to its volatility.

Carbon dioxide Explosion is the process which is similar to steam and ammonia fibre explosion; high pressure CO_2 is introduced into the batch reactor and then released by an explosive decompression. It is believed that CO_2 reacts to carbonic acid (carbon dioxide in water), thereby improving the hydrolysis rate. The outcome of CO_2 explosion are lower than those obtained with steam or ammonia explosion, but they are higher than those reached with enzymatic hydrolysis without pretreatment (Sun and Cheng, 2002).

Biological Pretreatment is a method which uses microorganisms such as white, brown and soft rot-fungi to degrade hemicellulose and lignin. Biological hydrolysis is typically very low, so this pretreatment requires long residence times, however it requires low energy situation and mild operation conditions (Cardona and Sanchez, 2007; Sun and Cheng, 2002; Tengerdy and Szakacs, 2003).

2.12. BIOENERGY CONVERSION TECHNOLOGY OPTIONS

Biomass, mainly in the form of wood, is the oldest form of energy used by humans. Biomass is used to meet a variety of energy needs, including generating electricity, heating homes, fueling aviation and vehicles, and providing process heat for industrial facilities. Figure 2.3 below is the platforms that produce a wide range of both energy and industrial products.



Source: UNIDO, 2007.

Figure 2.3 Biomass platforms used for the production of energy and industrial products.

2.12.1. Direct Combustion

Combustion produces heat which can be used directly or used to produce steam for industrial processes or power generation (Preto, 2010). Wood, twigs, leaves, grasses, crop leftovers, other vegetation, and dung are sources of energy in the form of plant and animal matter that are directly burned or converted into a low quality gas in small, low-tech anaerobic tank digesters or fixed-bed gasifiers (Patzek and Pimentel, 2006). Wood for cooking and heating has been from time immemorial; however, the efficiency of this energy source varies according to production systems. Open fires convert only about 5 percent of wood's potential energy. Traditional wood stoves increase this efficiency to about 36 percent, and charcoal-based systems are between 44 and 80 percent efficient, depending on the furnace design and charcoal production method. The modern wood pellet stove delivers about 80 percent efficiency for residential use (Mabee and Roy, 2001; Karlsson and Gustavsson, 2003). Direct combustion includes co-firing, combustion – combined peat and Power (CHP) and Cogeneration.

Co-firing is defined as the combustion of multiple fuels in the same energy system (Massachusetts Sustainable Forest Bioenergy Initiative 2008). This usually means mixing a small percentage of wood with coal to fuel a large power plant. Co-firing has been evaluated for a variety of boiler technologies including pulverized coal, cyclone, fluidized bed and spreader stokers. For utilities and power generating companies with coal-fired capacity, co-firing with biomass may represent one of the least-cost renewable energy options (Lawrence *n.d.*). Burning wood in a coal plant can increase equipment performance and reduce pollution. In most scenarios the wood must be low cost to justify modifying the power plant (Massachusetts Sustainable Forest Bioenergy Initiative, 2008).

Combustion – Combined Heat and Power (CHP) is term for "cogeneration" and "combined heat and power" which refer to the production of both electricity and usable heat from a single system using a single fuel (Maker 2004). Generally these systems have higher efficiencies than do power only systems, and so represent a more cost-effective way to produce electricity. The residual wood solids are mostly lignin, which can be burned for heat and power (US Department of Energy, 2012). CHP plant is designed to produce both heat and electricity from a single heat source (Preto, 2010). Much of today's biopower is provided by CHP facilities located at forest product industry sites. CHP, also called cogeneration, achieves high efficiencies by using both the power and the excess heat from burning the biomass (Maker, 2004). A plant using natural gas produced about 427g. Steam-turbine power boilers designed to work primarily with bark can be added to sawmill as an alternative to beehive burners or other apparatus to dispose of waste. Heat from power boilers can generate steam, which can be used for electricity generation using turbines or to meet process requirements. Recovery boilers are used in a similar way in pulp and paper mills, to recycle black liquor and recover pulping chemicals, as well as to produce steam to drive the pulping process. The efficiency of a steam-turbine power boiler is generally about 40 percent (Karlsson and Gustavsson, 2003).

Cogeneration is another combustion system used to produce both thermal and electrical energy. In most settings, steam produced in a boiler heats an exchange device and spins a turbine to generate electricity. The conversion efficiency of electricity generation alone is only about 35%, implying, the greater part of the energy is lost as heat during combustion. When this “waste heat” is used, a combined heat and power system (CHP) can exceed 80% efficiency (Massachusetts Sustainable Forest Bioenergy Initiative, 2008).

2.12.2. Thermo-Chemical Platform

Thermal processes functions best using biomass feedstocks with less than 50% moisture content. The thermo-chemical platform consists of Gasification and Pyrolysis (Preto, 2010; Bain, 2010).

Gasification technology has been suggested as a means to provide small-scale power delivery suitable for villages and small-scale industry. Small-scale plants represent an appropriate technology, since they are cheaper, spare parts are more easily accessible, and repairs can be carried out on site (Preto, 2010; IRENA, 2012). In Cambodia, Abe *et al*. (2007) found that although biomass gasification provided cheaper power than diesel generators, consistent supply and barriers to growing wood were key constraints. The profitability of the small-scale plants set up as commercial enterprises has also been found to be marginal, and highly dependent on both energy prices and biomass input costs (Preto, 2010). Wu *et al.* (2002) suggested in China, that medium-scale plants may be more appropriate where financial considerations are of principal importance.

Gasification is another process which involves partial combustion of biomass. It converts of solid fuels into combustible gas mixture called producer gas (CO + H_2 + CH_4) (Chaudhuri, 2009). Gasification generates a mixture of low molecular gases known as syngas, which can be used to synthesize renewable fuels, polymers and commodity chemicals (Preto, 2010). There are four distinct processes in the gasifier. They are drying, pyrolysis, combustion and reduction (Chaudhuri, 2009). Feedstocks for biomass gasification include all types of firewood, forest waste, tree pruning and plantation wood; bamboo and bamboo wastes; coconut shells, groundnut shells and various other nutshells; rice husk, mustard stalks, soya dunnage, maize cobs etc. and many other agricultural and agro-industrial residues with appropriate fuel preparation (Mckendry, 2002).

One of the promising thermo-chemical conversion ways is **pyrolysis**. Biomass is thermally converted to charcoal, wood-oils, tars, and gases in the absence of oxygen. Through pyrolysis, solid bamboos are converted to charcoal, vinegar (liquid) and bamboo gas (Yang *et al* 2006; Preto, 2010; Bain, 2010; Pilon and Jean-Michel 2011). Oasmaa *et al.*, (2003) also presented three main energy products that biomass generates through Pyrolysis in different quantities as coke, oils and gases. The bamboo gas, which can be used as fuel is obtained from bamboo pyrolysis, is mainly consisted of carbon dioxide, carbon monoxide, methane, ethylene and hydrogen, etc. (Meyers 2004; SRI International 2007). Pyrolysis offers a wide range of products than gasification, ranging from transportation fuel to chemical feedstock (Meyers 2004; SRI International 2007; IRENA, 2012). Pyrolysis is also the process of exposing fairly small biomass particles (> 5 mm) biomass to temperatures of 350ºC to approximately 500^0C in absence of oxygen (Preto 2010; Scurlock *et al.,* 2000). Pyrolysis however is connected to the many energy and non-energy products than can potentially be obtained, particularly liquid fuels and solvents, and also the large number of chemicals (e.g. adhesives, organic chemicals, and flavouring) that offer companies good possibilities for increasing revenues (Oasmaa & Kuoppala 2008).

The end products of pyrolysis and the composition of gases depend on some variables such as temperature, biomass species, particle size, heating rate, operating pressure and reactor configuration, as well as the extraneous addition of catalysts (Yang *et al,* 2006; Pilon and Jean-Michel, 2011). Bio-oil is a polar and high density oxygenated liquid that can be used as a fuel and for the production of chemicals (Yang et al., 2006; Senzor et al., 2006; Amin and Asmadi, 2008; Misson *et al*., 2009; Khor *et al*., 2009; Razuan *et al*., 2010; Gou *et al*. 2011; Arami-Niya *et al*.2012). There are slow pyrolysis, flash pyrolysis and fast pyrolysis. The slow pyrolysis process has traditionally been used for the production of charcoal (Yaman, 2004). Flash pyrolysis gives high oil yields, but still needs to overcome some technical problems needed to obtain pyrolytic oils (Oasmaa *et al*., 2003). Fast Pyrolysis is the thermal decomposition of carbonaceous material in the absence of oxygen (Oasmaa *et al*., 2003; Yaman, 2004; Bridgewater 2007) to produce char, gas, and a liquid product rich in oxygenated hydrocarbons. In general, pyrolysis is performed using a range of temperatures and residence times to optimize the desired product (Bridgewater 2007; Bain, 2010).

2.12.3. Electrochemical Conversion to Produce Electricity

After hydropower, biopower provides a larger share of the world's electricity than any other renewable energy resource (International Energy Agency, 2007). Electricity can be generated from a wide range of biomass, which is any organic matter like wood, plants, agricultural waste, and other materials (Reijnders and Huijbregts 2008; Berggren *et al*. 2008).

Feedstocks for Generating Biopower (Electricity): **-** Studies by various researchers indicated that in practice; wood, animal wastes, harvest residues, municipal and industrial organic wastes, landfill gas, 'energy' grasses (such as reed canary grass) and vegetable oils have been used in power generation (Reijnders and Huijbregts 2005; Berggren *et al*. 2008; Heinimö

2008; Junginger *et al*. 2008; Reijnders and Huijbregts 2008). Agricultural, milling byproducts and wood pellets are co-fired with coal to make electricity (Ontario Power Generation, 2008; UNEP, 2009). Sewage sludge and wastewater treatment sludge are also applied, though these tend to be net users instead of net producers of energy due to their high water content (Wang *et al*. 2008).

Electricity can be generated in power plants fired by biomass and stored in batteries. Also, electricity can be generated by onboard fuel cells fed with, for example, H_2 derived from biomass or H_2-producing organisms. Hydrogen used in fuel cells is, from a life cycle perspective, more energy efficient than the application of H_2 in Otto or diesel motors (EUCAR *et al*. 2007). Fuel cells may also be used for the propulsion of ships and airplanes (Lapeña-Rey *et al*. 2008; Sanderson 2008). Introduction of hydrogen as a major transport fuel requires concerted action of many stakeholders (Ni *et al*., 2006) and includes large changes in fuelling infrastructure and a major effort to reduce fire and explosion risks (MacLean and Lave 2003; Agnolucci 2007; Astbury and Hawksworth 2007). Also, major advances in several key components of motorcars are necessary for a successful large-scale introduction of all-electric or H_2-powered cars (Chalk and Miller 2006; Lache *et al*. 2008; Samaras and Meisterling 2008).

Technology application of biopower generation systems: - Biomass can be converted into electricity using processes similar to those used with fossil fuels. Biopower, or biomass power, is the use of biomass to generate electricity. There are six major types of biopower systems: *direct-fired*, *cofiring*, *gasification*, *anaerobic digestion*, *pyrolysis*, and *small modular* (International Energy Agency, 2008; US Department of Energy, 2010). These biomass technologies generate varying amounts of electricity depending on the size of the technology deployment and the biomass resource itself. Biomass can also be used in combined heat and power (CHP) systems to produce both heat and electricity. With system efficiencies as high as 60-80% (International Energy Agency, 2008), CHP is an effective use of biomass and enables recovery of waste heat for use in heating or cooling. Modular or small systems provide power on a scale that is appropriate for use by communities, farms, commercial buildings, and small industry (US Department of Energy, 2010). In 2008, the United States generated more than 11,000 megawatts of biopower from landfill gas, sorted municipal waste, wood residues, and other sources—primarily for use by the forest products industry, utilities, and large institutions (Energy Information Administration, 2010).

Benefits of Using Biopower: - Bioelectric power is able to provide a steady flow of power regardless of external conditions. The US Department of Energy (2010) stated the following benefits of biopower:

- Provides a clean, domestic, transmittable renewable source of power for the nation (life-cycle basis)
- Revitalizes rural economies
- Reduces impacts on the environment and climate (biomass can be carbon neutral and has lower sulfur content than coal)
- Provides energy on demand (the energy can be stored in the biomass until needed)
- Promotes healthy forests and use of residue, with little competition for agricultural land Creates diversified job market in agribusinesses, utility and power plant vendors, and equipment suppliers
- Increases the diversity of the U.S. energy supply

The following challenges were identified during the biopower generation by the US Department of Energy, (2010). The production cost is high; there is lack of consistent feedstock supply; there are impacts such as corrosion and inefficiency of feedstock on existing boilers; lack of a national renewable Portfolio Standard; uneven tax parity for different renewable energy sources; lack of well-characterised, techno-economic impacts on life cycle and systems; lack of demonstrated performance for all technologies to enhance investor confidence. However, technologies have now been developed which can generate electricity from the energy in biomass fuels. Biomass technologies can be small enough to be used on a farm or in remote villages, or large enough to provide power for a small city.

In conclusion, electricity can be produced from a wide-ranging biomass, for example; herbaceous plants, woody plants, animal wastes, agricultural wastes (harvest residues), agricultural milling byproducts, municipal and industrial organic wastes, landfill gas, 'energy' grasses (such as reed canary grass) and vegetable oils. The electricity from biomass is clean and environmental friendly electricity and carbon neutral. It supports healthy forests and use of residue. It also gives life to rural economies and increases the diversity of energy supply. Biomass technologies can generate varying amounts of electricity depending on the size of the technology set up and the biomass resource itself. These technologies include; *direct-fired*, *co-firing*, *gasification*, *anaerobic digestion*, *pyrolysis*, and *small or modular systems.* For example; wood pellets are co-fired with coal to make electricity, combined heat and power (CHP) systems is used to produce both heat and electricity. Modular or small systems provide power on a scale that is appropriate for use by communities, farms, commercial buildings, and small industry. Power from biomass can be stored in batteries, or can be generated by onboard fuel cells fed with, for example, H_2 derived from biomass or H_2 – producing organisms. Fuel cells may also be used for the propulsion of ships and airplanes.

2.12.4. Liquefaction

Biomass can be converted to liquefied products through a complex sequence of physical structure and chemical changes. In the liquefaction process, biomass is decomposed into small molecules. These small molecules are unstable and reactive, and can repolymerize into oily compounds with a wide range of molecular weight distribution (Demirbas 2000; Dowe and McMillan, 2008; IEA/OECD, 2008; de Klerk, 2011). Liquefaction can be accomplished directly or indirectly.

Direct Liquefaction involves rapid pyrolysis to produce liquid tars and oils and/or condensable organic vapours (Demirbas 2000; IEA/OECD, 2008). Indirect Liquefaction involves the use of catalysts to convert non-condensable, gaseous products of pyrolysis or gasification into liquid products (Demirbas 2000; IEA/OECD 2008). Alkali salts, such as sodium carbonate and potassium carbonate, can act as catalysts for the hydrolysis of cellulose and hemicellulose, into smaller fragments. The degradation of biomass into smaller products mainly proceeds by depolymerisation and deoxygenation. In the liquefaction process, the amount of solid residue increases in proportion to the lignin content. Lignin is a macromolecule consisting of alkyl phenols, and has a complex three-dimensional structure. It is generally accepted that free phenoxyl radicals are formed by thermal decomposition of lignin above 500 K and that the radicals have a random tendency to form a solid residue through condensation or repolymerization (Demirbas 2000; IEA/OECD, 2008). The changes during liquefaction process involve all kinds of processes such as solvolysis, depolymerisation, decarboxylation, hydrogenolysis, and hydrogenation. Solvolysis results in micellar-like substructures of the biomass. The depolymerisation of biomass leads to smaller molecules. It also leads to new molecular rearrangements through dehydration and decarboxylation. When hydrogen is present, hydrogenolysis and hydrogenation of functional groups, such as hydroxyl groups, carboxyl groups, and keto groups also occur (Demirbas 2000; IEA/OECD, 2008; de Klerk, 2011).

2.12.5. Introduction to the Fischer-Tropsch (FT) process

History and Development:- The FT-reaction was discovered in the 1920s by Franz Fischer and Hans Tropsch and first applied as an alternative way to convert various gaseous products (mainly syngas) into a wide variety of hydrocarbon products (Bain, 2010), but further adjustments and developments were needed in order to make it relevant for a commercial use (Fatih Demirbas, 2009).

Fischer-Tropsch Synthesis is a catalyst supported polymerisation which converts CO and H_2 into a wide range of liquid hydrocarbons (Yuan et al., 2011; Reichling and Kulacki, 2011; Lu and Lee, 2007). These hydrocarbons can be further upgraded and converted in motor fuels and other chemicals. However, there are four main reasons behind the fact that FT-synthesis has not been widely utilised yet: 1) a wide range of hydrocarbons is produced due to a limitation in selectivity, 2) the catalyst is deactivated easily 3) the capital costs are high and 4) the carbon and thermal efficiency are lower than other syngas applications (Lu and Lee, 2007).

The conversion of biomass-to-liquids (BTLs) process and waste-to-liquids (WTLs) process can likewise be considered. Collectively, all of these processes are referred to as feed-to-liquids (XTLs) conversion processes (de Klerk, 2011). The raw feed material limits the technology selection for the feed-to-syngas conversion step, but not for the subsequent steps. Once the feed has been converted into syngas, which is a mixture of carbon monoxide (CO) and hydrogen (H_2), the syngas can be conditioned to serve as feed for any syngas-to-syncrude conversion technology. Fischer–Tropsch synthesis is not the only possible technology for the conversion of syngas into a synthetic crude oil (syncrude), but together with syngas-to-methanol conversion (Olah *et al*, 2006; IEA/OECD, 2008). Fischer–Tropsch synthesis is industrially the most relevant. The process can be divided into three steps (Figure 2.4): feed-to-syngas conversion, syngas-to-syncrude conversion, and syncrude-to-product conversion. Generically, this is called *indirect liquefaction*, because the feed is first transformed into synthesis gas (syngas) and the syngas is then transformed into products (IEA/OECD, 2008; de Klerk, 2011).

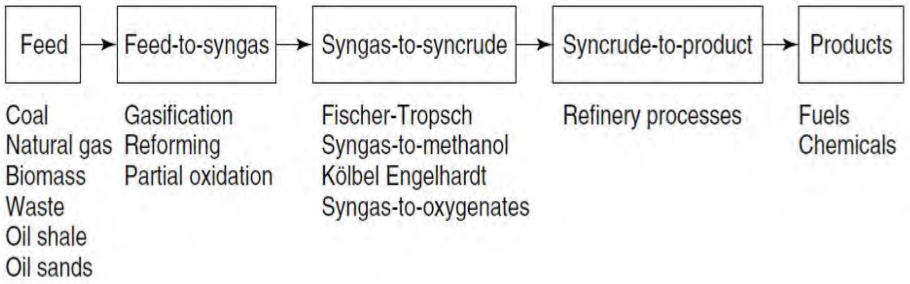


Figure 2.4 Overall Indirect Liquefaction Processes for Feed-to-Liquids (XTL) Conversion.

Feed-to-syngas conversion is an energy-intensive operation and also the most expensive step in indirect liquefaction. Many of the advantages that are related to the feed-to-syngas conversion step do not depend on subsequent processing. It is these advantages that make indirect liquefaction attractive, despite its poorer energy efficiency than direct liquefaction (Nowacki, 1979; Mangold *et al*., 1982; De Malherbe *et al*., 1983).

2.12.6. Physical Extraction

Oils derived from oilseeds and oil-bearing plants can be used directly in some engines or can also be blended with petroleum diesel in limited amounts. There are some restrictions on the use of the seed and plant oils depending on the type of engine. Also, measures are needed to avoid solidification of the fuel in cold climates, because a variety of oils differ in their freezing points (Johnson and Rosillo-Calle, 2007). Production of oilseed crops is globally more widespread than sugar crop production. Oilseed crops are used in the production of biodiesel through a process known as transesterification. Europe has dominated the biodiesel industry to date, generating around 90 percent of global production using rapeseed oil as the main feedstock (FAO, 2007; IEA/OECD, 2008). The development of biofuels and the palm oil industry is particularly relevant in Malaysia and Indonesia. In Southeast Asia, 27 percent of oil-palm plantations are located on drained peat lands (Hooijer *et al*., 2006). Lately, the use of other oilseed plants, such as *Jatropha spp*., has been explored as a feedstock for biodiesel production in the Philippines and India (IEA/OECD, 2008).

2.12.7. Biological Conversion

Biological conversions involve the utilisation of biological enzymes or living organisms to catalyze the conversion of biomass into specialty and commodity chemicals. Overall, it is considered to be the most flexible method for conversion of biomass into industrial products

(McMillan, 2004). Carbohydrates are processed into sugars, which can then be converted into biofuels and bioproducts through fermentation and use of microorganisms and other catalysts. Potential fuel blend stocks and other bioproducts include the following: renewable gasoline, ethanol and other alcohols, alkanes and renewable diesel (US Department of Energy, 2012). Lignocellulosic source can be used as feedstock, by hydrolysing it, thus breaking it down into its components. The reaction is catalysed by enzymes or acids; acid hydrolysis offers the more mature conversion platform, but enzymatic hydrolysis appears to offer the best long-term option in terms of technical efficiency. Lignocellulosic conversion would greatly increase the supply of raw materials available for bio-ethanol production (UNIDO, 2007). The processes involve Anaerobic Digestion and enzymatic fermentation.

Anaerobic Digestion involves the breakdown of organic compounds by micro-organisms in the absence of oxygen to produce methane and carbon dioxide gases (Ueda *et al*., 1996; Bush and Hall, 2006). Anaerobic digestion can also be used to treat some forms of biodegradable waste, such as animal slurry, livestock manure, sewage sludge, the organic elements of municipal solid waste, by-products of industry, food processing wastes and milk (DEHLG, 2006). When the waste is digested it can be separated into solid and liquid fractions. The products are usually a mixture of methane and carbon dioxide rich gas (biogas) in almost equal proportions (UNIDO, 2007; Chisti, 2007; IRENA 2012). The methane produced can be used as a source of energy for heat or electricity. The liquid portion can be spread safely on agricultural land, supplying nutrients, and the solid part can be used as highly nutrient compost (Ueda *et al*., 1996; Bush and Hall, 2006; Mata Teresa, Martins Antonio and Caetano Nidia, 2010).

Enzymatic fermentation was important for preserving and processing food and beverages for thousands of years. Only in the last several decades, however, has biotechnology been used to bring to market a wide variety of fermentation-based products, including antibiotics, amino acids, organic acids, and various agro-industrial feedstocks and chemical substitutes (Fischer *et al*., 2004; Chiang *et al*., 2005). In other to produce of essential enzymes (Hong *et al*., 2004; Chiang *et al*., 2005) and other proteins (Liu *et al*., 2005), carbohydrates (Sahrawy *et al*., 2004) and lipids (Qi *et al*. 2004), plants have been used as ''green bioreactors'' while needing minimal inputs of raw materials and energy (Teymouri *et al*. 2004). Production of bio-molecules in plants, considered as molecular farming, is one approach to improve the economics and increase the low-cost production efficiency of these biomolecules (Fischer *et al*., 2004).

Hydrolysis: - Lignin is the biofuel-blocking polymer in biomass conversion (Sticklen, 2006). As a result, one might also produce ligninases within the crop biomass similar to when the laccase produced in maize seeds (Bailey *et al*., 2004) to reduce the needs for pretreatment processes (Sticklen, 2006). When all these enzymes are produced at a very high level (Ziegler *et al*., 2000) in plants, this could well compete with the full range of commercial hydrolysis enzymes currently used in ethanol production. Furthermore, research is needed to ensure that lignocellulosic conversion enzymes produced within the plants will survive pretreatment, harvest, storage and transportation (Dowe and McMillan, 2008; IEA/OECD, 2008). Current systems use acid hydrolysis to convert cellulosic biomass to easily fermentable sugars. Acid hydrolysis involves the breaking up of lignocellulose to cellulose and hemicellulose, then finally into glucose and pentoses (mainly xylose) (IEA/OECD, 2008).

2.12.8. Biochemical Conversion

In biochemical conversion, chemical agents convert biomass into liquid fuels. Also, biochemical conversions refer to processes which directly convert biomass to chemicals at high temperature and pressure and in the presence of a catalyst (Brigewater, 2007; IEA/OECD, 2008). Straight vegetable oil (SVO) - oils derived from oilseeds and oil-bearing plants can be used directly in some applications. Some restrictions are necessary depending on the engine type and also measures are needed to avoid solidification of the fuel in cold climates, since the various oils differ in their freezing points. SVO can be blended with petroleum diesel without damaging the engine and/or its associated parts. The refined versions of SVOs, on the other hand, can potentially be fully interchangeable with petroleum diesel, and are therefore preferred for international trade. Equivalently, the raw oils can be imported and the refining done locally, as is the case with petroleum. The chemical refining process is referred to as trans-esterification, since it involves the transformation of one ester compound into another, a process that also transforms one alcohol into another (Johnson and Rosillo-Calle, 2007; IEA/OECD, 2008). Another set of options associated with these bio-chemical conversion processes relates to the creation of various carbon-rich compounds from glycerol and the fatty acids that comprise it. The carbon-rich chains form building blocks for a wide variety of industrial products that could potentially be produced, which are to some extent bio-degradable and/or the result of biological processes. Such platforms might be based on the carbon chains C2 and C3, which would in some respects lead to bio-refining processes that are analogous to the petroleum refining process (van Dam *et al*., 2005).

2.13. PRODUCTS OF BIOENERGY FROM BIOMASS

The continuous depletion of worldwide fossil fuel oil deposits, driven by factors such as oil price hikes, awareness in greenhouse gas emissions during combustion of fossil fuels and potential impacts of this activity on global warming has generated interest in the use of alternative fuel sources. The production of second generation biofuels (e.g., cellulosic ethanol) or third generation biofuels (e.g., hydrogen) from renewable lignocellulosic biomass will result in a new industrial revolution from a fossil fuel-based economy to a sustainable carbohydrate economy (Lynd *et al*., 2008; Zhang, 2008, 2009). Biofuels include fuels derived from biomass conversion are solid, liquid fuels and various biogases (FAO, 2004; Demirbas, 2009). The composition of biomass used for the production of biofuels varies to a great extent. Sugar and starch-rich biomass like corn and sugarcane are examples of easily degradable biomass that, upon hydrolysis, yield mostly glucose and sucrose. Lignocellulosic biomass has a more complex structure and thus requires additional pretreatment in the form of heat, strong acids or bases, or enzymes such as cellulases and hemicellulases (Kosaric *et al*., 2001; IEA/OECD, 2008).

Charcoal is a preferred cooking fuel in many urban areas in developing countries (Schlag and Zuzarte, 2008). There are a number of reasons why people in dense urban settlements favour charcoal over wood: it has a higher energy density, it burns more cleanly (which reduces exposure to harmful pollutants), and it is easier to transport, handle, store, resists attack by insects, burns in a controlled fashion without much smoke or flame, (FAO, 1983; van der Plas, 1995). However cooking with biomass fuels in traditional stoves emit sever gaseous pollutants like CO, CO_2, SO_2, NO_2 and even PM. Those pollutants are highly hazardous for human health especially for women and children who are exposed to that air for a long time. Mature bamboo with 3-4 years are be used for charcoal production (Asada *et al*., 2002; Ohe *et al*., 2003; Mingjie, 2004). To get maximum yield in charcoal production, moisture content of bamboo should be around 20-25%, accordingly freshly cut bamboo should be stored for 15-20 days to lower down the moisture content. One of the bye-products of bamboo charcoal production is bamboo vinegar. The volatiles coming out from bamboo charcoal production is condensed to produce bamboo vinegar (Choy *et al*., 2005). Bamboo vinegar is used as organic fertilizer, preservative, for relief of pains etc. (Mingjie, 2004).

It is used as a solid fuel by hotels, laundry and for cooking in rural areas. Charcoal can be further value added by pulverizing (for use in incense stick making) and briquette forming (for space heating). It also finds use in space heating as fuel in metal works during forging (Mingjie, 2004). The price of charcoal varies depending upon the properties and availability. The chars can be treated using various chemicals and over a range of temperatures to produce a selection of activated carbons for various uses (Wu *et al*., 1999; Asada *et al*., 2002; Ohe *et al*., 2003). Bamboo-based activated carbons can be expected to be used as: (1) a potential commercially available activated carbon for the treatment of gaseous pollutants and (2) a potential commercially available activated carbon for the treatment of liquid pollutants in industrial effluents and in drinking water filtration applications (Choy *et al*., 2005).

Biodiesel is defined as a fuel of mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats, designated B100. A "mono-alkyl ester" is the product of the reaction of a straight chain alcohol, such as methanol or ethanol, with a fat or oil (triglyceride) to form glycerol (glycerin) and the esters of long chain fatty acids. Biodiesel can be used as B 100 (neat) or in a blend with petroleum diesel. A blend of 20 % biodiesel with 80 % petro diesel, by volume, is termed "B 20". A blend of 2 % biodiesel with 98 % petro diesel is "B 2", and so on (Van Gerpen *et al.,* 2004). Production of biodiesel is mainly from oil rich plants such as rape oil and soybeans (Hill *et al*., 2006). The production of biodiesel from algae is a potential viable option. Algae species can range from small single-celled organisms (microalgae) to a multi-cell organisms with complex structures. All algae are autotrophic organisms that produce energy through photosynthesis. Microalgae have mainly been used for biodiesel production and often contain high levels of lipids and fatty acids in their cells membranes or as reservoir material. The ratio of lipid/oil by weight of algae varies widely (from 2 to 70%) but is among the highest ratio found in living organisms (Chisti, 2008). Almost all biodiesel production is carried out by catalytic transesterification of oils with a strong base which is cost-effective and does not require high temperatures or pressure. Biodiesel has theoretically 5-8% less energy compared to conventional diesel but because of better lubrication properties the actual energy difference is only 2% lower, or about 35 MJ L-1 (Hill *et al*., 2006). The successes chalked by Malaysia and Indonesia in becoming formidable world players in this industry are there for Africa to learn from. These countries have been able to turn their primary goods/raw materials into finished and semi-finished biofuel products mainly for export in the EU and USA and generating income and employment (Hagan, 2007; Gyasi, 2008; Ahiataku-Togobo and Ofosu-Ahenkorah, 2009).

Biofuel production has recently grown due to **biobutanol** as a good candidate as a biofuel for its interesting features (Dürre, 2008; Lee *et al*., 2008): lower vapour pressure, blending with either gasoline or diesel at any fraction, energy content close to that of the gasoline, fuelled to current configuration of engines without any retrofitting. Sugar in corn is fermented by using yeast to produce bioethanol. Similarly, biobutanol is produced by fermenting corn by using *Clostridia* (a bacterium) instead of yeast. New processes may ferment cellulose derived sugars (McCormick, 2006). The technological process of clostridial solvent fermentation is described as the second largest industrial fermentation process besides yeast-based production of ethanol until it failed to compete with the booming oil industry in the 1980s. This process is usually referred to as ABE fermentation, after its main components of acetone, butanol and ethanol (Antoni *et al*, 2007). Four distinct species of clostridia were identified among the industrial production strains: *Clostridium acetobutyli-cum*, *Clostridium beijerinckii*, *Clostridium saccharoper- butylacetonicum*, and *Clostridium saccharobutylicum* (Keis, 2001). Owing to its high energy content, miscibility with other fuels, octane improving power, low volatility and other attributes beneficial to combustion engines; Butanol is likely be the substitute for gasoline, diesel or kerosene, (Schwarz and Gapes, 2006).

Biomethane: - Methane is odourless gas composed of one carbon and four hydrogen atoms. Methane occurs naturally as a part of the natural gas coming up from the ground. More commonly, biomethane is produced by anaerobic digestion from wastewater and agricultural residues have been broadly applied both in pilot and large scale facilities, mainly in Denmark and Germany (Metan, 2003; Reith *et al.,* 2001). It is produced microbiologically by methanogens in anaerobic environments like swamps, in garbage dumps and in the digestive systems of many animals (Ogejo *et al.,* 2007). Methanol production also occurs via direct hydrogenation of CO, but at a much slower rate: $2H_2 + CO = CH_3OH$ (Hydrogenation of carbon monoxide) (Paisley and Anson, 1997; Engstrom, 1999).

Biomethane is lighter than air, highly flammable (Turner & Pearson, 2009; Ogejo *et al.,* 2007) and non-toxic unless presented in large amounts in confined spaces where it may cause suffocation (Ogejo *et al.,* 2007). It is also volatile and colorless is used for producing biodiesel via the transesterification reaction (Turner & Pearson, 2009). It is used as vehicle fuel (Metan, 2003; Reith *et al.,* 2001). Great technological advances have occurred in the production of methane vehicles in recent years. The third generation of methane vehicles uses only methane although it has been more common to convert cars made for petrol and convert them into methane cars (Metan, 2003). Methane is considered to be a greenhouse gas: it has 21 times more greenhouse effect than carbon dioxide (CO_2). Biogas (CH_4 and CO_2) produced in landfills has been collected for many years and used either directly as an energy source (burning) or the methane is separated from CO_2 (and other gases) and used as vehicle fuel. For example, this is done in the landfill in Álfsnes in Reykjavík, Iceland (Metan, 2003; Reith *et al.,* 2001).

Bioethanol: - Biomass is one of the most important raw materials for bioethanol production (Balat, 2008). The industries for the production of bioethanol have been growing extensively worldwide especially in the United States, Brazil and European Union countries (Ragauskas *et al*., 2006). In 2004, the production capacity of ethanol in U.S. alone reached 3.4 billion gallons (Farrell et al., 2006). Sugar and starch based agricultural crops such as sugarcane, potato, corn and wheat have been endorsed as the main feedstock for ethanol production in the world. Ethanol production has been called first generation ethanol (BioBasics, 2006; Hahn-Hägerdal *et al*., 2007). Plans are advanced to improve the economic and environmental performance of maize seed and sugarcane ethanol produced in the U.S. and Brazil (Oliveira *et al*., 2005). Lignocellulosic biomass like potato wastes, cheese whey, corn fiber, rice straw; wood,

wood wastes, urban wastes, energy crops, aquatic plants, and animal wastes are also feedstock for bioethanol (Akhtar & Amin, 2010; Alzate & Toro, 2006; Ni *et al*., 2004). Ethanol produced from lignocellulosic biomass is termed as second generation ethanol as it is made from sugars derived from cellulose and hemicellulose (Runnion & Bradley, 1985). Bioethanol produced from lignocellulose biomass is considered to be more sustainable fuel than corn and sugar based ethanol in the near future (BioBasics, 2006; Hahn-Hägerdal *et al*., 2007), even though is much less as compared to 1st generation ethanol.

Bioethanol is produced from fermentation of organic material by microorganisms. It has been in many ways the most potential resource as a renewable energy source used today (Mielenz *et al*., 2001). It has been used as fuel since 1925 in Brazil and its use became common around Europe and United States in early 1800´s. However, interest in biofuel as an alternative fuel for transportation has increased tremendously since 1980 (Balat, 2010). A number of bacteria are known to ferment most types of sugars derived from lignocellulose into ethanol some with high yields. On the other hand, there is a substantial lack of knowledge and experience with these bacteria, especially in the industrial scale (Reith *et al.,* 2001). The most excellent known thermophilic bacteria that produce ethanol belong to the genera of *Clostridium, Thermoanaerobacter,* and *Thermoanaerobacterium* (Liu *et al*., 1996; Larsen *et al*., 1997; Rani *et al*., 1997; Classen *et al.,* 1999; Lin & Tanaka, 2006; Georgieva *et al*., 2008; Koskinen *et al*., 2008). Highest yields have been reported from *Thermoanaerobacter ethanolicus*, or 1.9 mol-EtOH/mol glucose (Wiegel & Ljungdahl, 1981). Starch to ethanol plants are about 30% more expensive than cane sugar based units of similar throughput, primarily because there are more process steps, each of which has a small reduction in efficiency (Overend, 2002). Great efforts have been put forth towards improving ethanol yield and reducing its production costs (Lynd *et al*., 2005).

Currently, more focus has been on using lignocellulosic biomass for ethanol production. Over 1.7 billion tons of crop residues Worldwide are available annually and nearly half of this total is rice straw (Kim and Dale 2004) which could mostly be used for processing fuels and chemicals. It would be possible to produce 442 billion liters every year of bioethanol from lignocellulosic materials by using all complex biomass available in the world (Balat, 2010). Ethanol has both long-term economic and promising environmental advantages over fossil fuel when used as a fuel for the internal combustion of car engines, or the process of blending ethanol with other fuels is attracting so much attention (Grassi, 2000).

Biogas from Biomass: - biomass especially wood for gasification has been proven reliable and had been extensively used for transportation and on farm systems during World War II (SERI, 1979; Reed and Jantzen, 1979). During World War II, 95% of all mobile farm machinery, tractors, trucks, stationary engines, fishing and ferry boats were powered by wood gas generators (Reed and Jantzen, 1979). In addition, 40% of all motors traffic operated on gas derived from wood or charcoal. In order to analyse the use of biomass for power generation, it is important to consider three critical components of the process (IRENA, 2012):

1. Biomass feedstocks: These come in a variety of forms and have different properties that impact their use for power generation.
2. Biomass conversion: This is the process by which biomass feedstocks are transformed into the energy form that will be used to generate heat and/or electricity.
3. Power generation technologies: There is a wide range of commercially proven power generation technologies available that can use biomass as a fuel input.

Biomass can be converted into gas and liquid fuels. This is done by adding heat or chemicals to the biomass. The gas and liquid fuels can then be burned to produce heat or electricity, or it can be used as a fuel for automobiles (The NEED Project, 2011).

Feedstocks for the production of biogas include biodegradable materials such as farms residues, natural sawmill residues (bark, saw dust, pieces of wood, strands) (COM (2001) 547) and food processing industries (a creamery and brewery) located close to the plant. Similarly, poultry litter complemented with other organic fuels and almond shells (BEST PRACTICE PROJECTS YEARBOOK 1997-2000, S. 147). Wood wastes can be used in hog fuel boiler but the equipment is expensive and energy recovery is low (Eggen and Kraatz, 1976; Rajvanshi, 1986). It is therefore attractive and advantageous to convert wood wastes into more readily usable fuel like producer gas through gasification. Biomass gasification involves incomplete combustion of biomass resulting in production of combustible gases consisting of Carbon monoxide (CO), Hydrogen (H_2) and traces of Methane (CH_4). This mixture, known as producer gas, is used to run internal combustion engines generating power (Reed *et al.,* 1982; IIED, 2010). Wood gases produced by weight from the charring wood contain s approximately 20% hydrogen (H_2) 20% carbon monoxide (CO), and small amounts of methane, all of which are combustible, plus 50 to 60% nitrogen (N_2) (FEMA, 1989). The nitrogen is not combustible; however, it does occupy volume and dilutes the wood gas as it enters and burns in an engine. As the wood gas burns, the products of combustion are carbon dioxide (CO_2) and water vapour (H_2O).

In conclusion, biogas refers to a gas produced by the breakdown of organic matter in the absence of oxygen. It is a renewable energy source, like solar and wind energy. Furthermore, biogas can be produced from regionally available raw materials and recycled waste and is environmentally friendly and CO_2 neutral. It is therefore attractive and advantageous to convert wood wastes into more readily usable fuel like producer gas through gasification.

Biohydrogen: - Biomass has the potential to accelerate the realisation of hydrogen as a major fuel of the future (Hofbauer, 2000; UNEP, 2009). Hydrogen gas produced from biomass can be considered as renewable energy carrier. However, Hydrogen from biomass has major challenges. There are no completed technology demonstrations. The yield of hydrogen is low from biomass since the hydrogen content in biomass is low to begin with (approximately 6% versus 25% for methane) and the energy content is low due to the 40% oxygen content of biomass. Since over half of the hydrogen from biomass comes from spitting water in the steam reforming reaction, the energy content of the feedstock is an inherent limitation of the process (Riis *et al*, 2005). During its combustion, unlike carbon fuels, no carbon dioxide is released, only water vapour. Additionally, hydrogen has a higher energy content (120 MJ/kj) compared to the same amount of other renewable energy sources (Bromberg *et al*., 1999). Hydrogen is currently produced in large quantities via steam reforming of hydrocarbons over a nickel (Ni) catalyst at ~800^{0}C (1472^0 F) (Nieminen, *n.d*.; Risø Energy Report 3, 2004). Several technologies are already available in the marketplace for industrial productions of hydrogen among them are chemical, biological, electrolytic, photolytic and thermo-chemical (Riis *et al*, 2005; Aznar, 1997).

Biogasoline: - Bioethanol can be used directly in cars designed to run on pure ethanol or blended with gasoline to make “gasohol.” Anhydrous ethanol is required for blending with gasoline. No engine modification is typically needed to use the blend. Ethanol can be used as an octane-boosting, pollution-reducing additive in unleaded gasoline (Demirbas, 2004).

Jet Fuel from Biomass: - Producing diesel and jet fuel from biomass material are receiving increasing attention (Fischer-Tropsch Technology, 2004; EIA 2011; Burke, 2012; Milbrandt, Kinchin, and McCormick, 2013). Jet fuel is a type of aviation fuel designed for use in commercial and military aircrafts powered by gas-turbine engines. It is the third-most used fuel in the US after gasoline and diesel (Milbrandt, Kinchin, and McCormick, 2013). Jet fuel is a kerosene-based product having a maximum distillation temperature of 400ºF at the 10% recovery point and a final maximum boiling point of 572ºF and meeting ASTM Specification D 1655 (JET A and JET A-1) and Military Specifications MIL-T-5624P and MILT-83133D (Grades JP-5 and JP-8) (EIA, 2013).

Biomass feedstocks that can be used to produce jet fuel include as plant oils, animal fats, crop residues, woody biomass, dedicated energy crops, and prairie grasses (Burke, 2012; Milbrandt, Kinchin, and McCormick, 2013). Lignocellulosic biomass is pretreated, followed by enzymatic hydrolysis (saccharification) of the remaining cellulose. Then, is catalytic conversion of the resulting glucose, xylose, and other solubilised carbon components to hydrocarbon fuels in the gasoline, jet, and diesel fuel ranges (Biddy and Jones, 2013). Alcohol-to-jet fuel (ATJ) converts short carbon chain alcohols (such as methanol, ethanol, and butanol) to the longer C12/C16 alkanes of jet kerosene. The alcohol is produced conventionally (sugar/starch fermentation), thermochemically (e.g., gasification with upgrading), or through other pathways (industrial microbiology and algae) (Gevo, 2011).

There are several technologies available to convert biomass materials to alternative jet fuels (AJF) (Fischer-Tropsch Technology, 2004; Burke, 2012). For example, Fischer-Tropsch (FT) synthesis converts a mixture of carbon monoxide and hydrogen (also known as synthesis gas) into higher molecular weight hydrocarbons (Fischer-Tropsch Technology, 2004). The upgrading process produces a wide boiling range materials encompassing naphtha (gasoline boiling range), kerosene and diesel (Hemighaus *et al*., 2006). A hybrid technology is used to produce ethanol, diesel or jet fuel (Coskata, 2011).

Biokerosine: - *Biokerosine* is a biodiesel made from oils with shorter carbon chains between 12 and 14 (Chevron 2007), such as babassu, coconut, and palm-kernel oils. The lower carbon-number range required for jet fuel (than for diesel), these feedstocks have been proposed as potential sources for alternative jet fuels (Daggett et al., 2008). A biokerosine called PROSENE was developed and tested by the Brazilian government between 1980 and 1984. This type of fuel was used in an Embraer turboprop aircraft that flew from São José dos Campos to Brasília (Parente, 2006). Also, a flight test of a Boeing 747 with one engine operating on a 20-percent blend of a biodiesel made from babassu and coconut oils was conducted by Virgin

Atlantic, in collaboration with Boeing, General Electric, and Imperium Renewables (a biodiesel producer from Washington state) in February 2008 (GCC, 2008).

CONCLUSION

The rising cost of petroleum products from fossils fuel and its negative effects on the environment suggest new abundance and sustainability replacement. The topic of interest around the world today is “which of the renewable energy resources can replace fossil fuel to produce solid, liquid, gas fuels, chemicals and materials without causing pollution to the environment”? The most preferred renewable energy resource is biomass. In the local setting trees (biomass) are used in the form of firewood and charcoal in stoves and ovens for both domestic and industrial use. This is a significant source of pollution, deforestation and desertification since trees take longer period to mature. However, bamboos can be converted to biofuels – solid, liquid and gaseous fuels such as charcoal, ethanol, methanol, gasoline, diesel fuel and methane. Bamboo is the recommended feedstock for the production of biofuels because it takes about 3 to 5 years to mature.

The fuel properties from bamboo biomass were similar to some wood types and herbaceous energy crops. There is the need to find the fuel properties of *Bambusa vulgaris var vulgaris* in Ghana if they will be appropriate to used for the production of biofuels for heat, biogas, electricity and transport fuel.

The study will in effect help to produce biofuels like bioethanol, biodiesel and biobutanol to be used in internal combustion engines. The bamboos can be co-fired with coal to make electricity. Other products from the bamboo for biofuels in literature are biomethane, hydrogen (which can be used to run electricity) and charcoal in the form of solid or briquettes can be used for both domestic and industrial heating.

CHAPTER THREE

METHODOLOGY

3.1 OVERVIEW

This study was conducted to assess the physical, fuel or calorific and chemical properties of *Bambusa vulgaris* (Schrader ex Wendland *var. vulgaris*) as a feedstock for producing bioenergy in Ghana. The focus of this work was to find more renewable and sustainable feedstocks for the production of bioenergy.

3.2 THE STUDY AREAS

The samples of the bamboo were collected in their natural stands from three ecological zones in Ghana. These areas are; dry semi-deciduous zone (DSD), moist semi-deciduous (MSD) and moist evergreen deciduous (MED).

3.2.1 Dry Semi-Deciduous Zone (DSD)

The first study covered an area of a forest near *Techiman* in the Brong Ahafo region of Ghana. The area is located in transitional zone between the forest and savanna regions (FAO, 2005). The DSD zone lies between latitudes 7^0 30´ N and longitude 2^0 32´ W. The Dry semi-deciduous experience bi-modal rainfall (April–August and September–November) with the mean annual rainfall ranges from 1300 – 1400 mm (Obiri and Oteng-Amoako, 2007). The highest annual temperature is 33^0C (Duku *et al.*, 2011). Humidity is 75%. The ground elevation is between 180m – 300m above sea level (Ministry of Environment and Science, 2002). The soil is somewhat sandy, deep Lixsols and Cambisols, poor to good drainage and prone to erosion (Duku *et al.*, 2011).

There were three (3) bamboo clumps situated about five metres from the banks of River Tano. River Tano is one of the water deities in Ghana. In addition, the forest was reserve because of a shrine. According to the traditions of the people of Techiman and its environs it is prohibited to fish from the source of the river or cut trees around the shrine. However, the bamboos away from the shrine could be harvested yet the people were afraid to cut the culms of the bamboos for television poles, etc. for the fear of being harm either by the gods or the traditional leaders.

3.2.2 Moist Semi-Deciduous Zone (MSD)

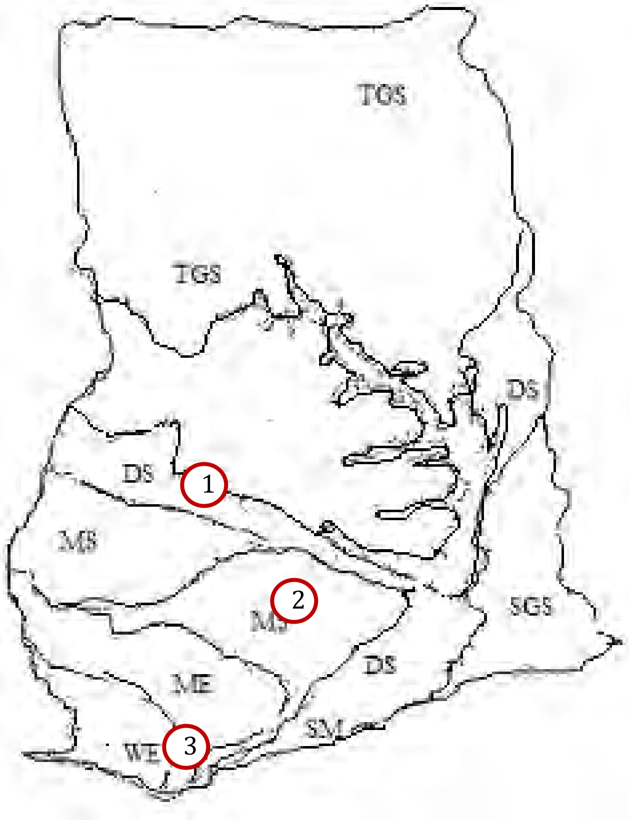
The second study site was *Owabi* forest area which is found in the Moist Semi-deciduous North-west (MSD) forest zone (Hall and Swaine, 1981). The area lies between latitudes 7^0 1′ N and longitude 2^0 3′ W in Ashanti region. MSD also has a bimodal rainfall pattern. The soil is characterised by moderately well drained Acrisols, Nitisols and Gleysols, with low organic matter content when cropped (Duku *et al.*, 2011). The mean annual rainfall ranges from 1400 – 1750 mm (Obiri and Oteng-Amoako, 2007) and temperature 31^0C (Duku *et al.*, 2011). The forest is located near river Owabi which is a protected forest under the Ministry of Lands and Forestry of Ghana.

3.2.3 Moist Evergreen – Deciduous Zone (MED)

The third site visited was forest area in *Bonsa River* Forest Reserve in the moist evergreen – deciduous (MED) zone. The reserve lies between the coordinates of Latitude 5.33 Longitude -

1.85 in the Western region of Ghana. The mean annual rainfall ranges from 1700 – 2800 mm (Obiri and Oteng-Amoako, 2007). The mean annual temperature falls within 29^0C.

The soil is characterised by highly weathered Ferrasols and Acrisol; light textured, acidic and heavily leached, high *Al* ion concentrations leading to low fertility and *P* availability; and organic matter (Duku *et al*., 2011). The area is generally undulating with few scarps ranging between 150 meters to 300 meters above sea level. Relative humidity is generally high throughout the year between 70 – 80 percent in the dry season and 75 – 85 percent in the wet season. Five clumps of bamboos were identified in the study area. The clumps were found between the forest and an abandon old rubber plantation.



Source: UNEP-WCMC (2004)

Figure 3.1. Map of Ghana showing the three Ecological zones

TGS – Tall Grass Savanna; SGS – Short Grass Savanna; DS - Dry Semi-deciduous; MS – Moist semi-deciduous; ME –Moist Evergree and WE – Wet Evergreen

Plate 3.1 Bamboo clump in DSD zone

Plate 3.2 Bamboo clump in MSD zone

Plate 3.3 Bamboo shoot in MED zone

Plate 3.4a Bamboo shoots from DSD

Plate 3.4b Bamboo shoots from MSD

Plate 3.4c Bamboo shoots from MED

3.2.4. Data Collection Procedures

The researcher personally travelled with a team consisting of three members to the selected sites between April and June 2014, to collect the samples for laboratory testing and analyses. The bamboo culms and shoots at Dry-deciduous zone were counted and tagged to avoid double counting at each clump. The sizes of the clumps were measured (Hogarth 2006). In addition, the diameters of the parts base, middle and the top of the bamboos at each stand were measured. The culms' height, internode distance, internode diameter, culms wall thickness and girth were measured from the cut base to the tip. The method used in the physical study was based on Sulthoni (1989). The result is shown in chapter four (Table 4.1).

3.3. EXTRACTION OF SAMPLES

Three clumps were randomly selected in each zone. The culms in the clumps were thoroughly inspected for defects free (plants without splits) (IAEA, 2005). In each stand, five (5) defect free culms were extracted from each zone (Table 3.2). The culms were cut at about 30 cm above the ground level. The leaves, branches were separated from the culms. In all, bamboo shoots, young culms, matured culm, dead culms, green branches, dead branches, green leaves and dead leaves were harvested and investigated. The total length of the bamboo culms were divided into three equal parts (starting from DBH) bottom (B), middle (M) and top (T) (300 mm each) in line with the recommendations of ISO standard DIS 22157 (2000). Each part was split into blocks of 25-35 cm. Samples were wrapped in airtight plastic bags for fuel assessments at the laboratory. The fuel properties of various parts of the bamboo were determined by performing experiments which lasted from April to November, 2014 in five replications.

Table 3.1: The number of samples collected from the three ecological zones in Ghana.

	Part of the Bamboo																		
	Shoot			Juvenile			Branches			Foliage			Mature			Dead			**Total**
Ecological zone	T	M	B	T	M	B	T	M	B	T	M	B	T	M	B	T	M	B	
DSD	3	3	3	2	2	2	-	-	-	-	-	-	5	5	5	1	1	1	**33**
MSD	3	3	3	2	2	2	-	-	-	-	-	-	5	5	5	1	1	1	**33**
MED	3	3	3	2	2	2	-	-	-	-	-	-	5	5	5	1	1	1	**33**
Total	**9**	**9**	**9**	**6**	**6**	**6**	-	-	-	-	-	-	**15**	**15**	**15**	**3**	**3**	**3**	**99**

T – top; M – middle and B – bottom /basal

DSD - (Dry Semi-Deciduous); MSD - (Moist Semi-Deciduous) and MED - (Moist Evergreen Deciduous)
Source: Author

3.3.1 Determining the age of the bamboo in the natural stand

Determining the age of bamboo in the natural stands is very difficult. However, Scurlock *et al*., (2000) suggest the following to find out the age of bamboo found in the natural stands; colour of the outline, status of the culm sheath, the outward appearance of culms, and the development of branches and leaves.

1-year-old bamboo has sheaths that still remain in the culms and the culm surface is covered with a clear white powder. 2-year-old bamboos possess culm sheaths that are beginning to rot, white powder on the surface of the culm disappears gradually, and the culm turns light green. In 3-year-old bamboo, the sheath has begun to drop, and the culm bottom has been invaded by mold and turns dark green. In 4-year-old bamboo, the sheath has disappeared from the surface of the culm, which is mouldy and has become yellowish green in colour. In bamboo 5 years old or greater, the culm surface is coarse, covered with mould and moss, and turns brownish green.

i. Shoots: The underground rhizomes buds swell up and appear as shoot which usually occupy the top 30-50 cm of soil and may spread for tens of metres (Scurlock *et al*, 2000). The shoot contains sheaths but without thorns, branches or leaves (Embaye *et al*., 2005) were extracted and separated to determine the potential of biomass fuel production. The shoot is below one year.

ii. The selected juvenile or young culms were having some branching, few leaves and thorns. Sheaths that were found in shoot still remain in the juvenile culms and the culm surface is covered with a clear white powder. Description of diameter at other locations ranges from 3 to 7 cm on base, middle and top of the young plants.

iii. Mature or adult culms have full of branches, leaves and thorns. In all five (5) culms or stems were used. Defect free culm samples were taken from diameter at breast height (DBH) of the mature culm which is the most commonly used variable (Yen and Lee, 2011).

iv. Dead or senescent culms were also singled out randomly from the clumps. The colour of the culm or stem of dead *Bambusa v. vulgaris* is pale yellow or brown. Sometimes they have coarse surface, covered with mould and moss. The high percentage of dead trees (10% of the stem population) and higher annual litter-fall biomass suggest that the stands have not been managed over a long period of time (Embaye *et al*., 2005). Stem and other measurements potentially are useful for the development of allometric or linear equations for predicting biomass should be given (Singh and Singh, 1999).

v. Branches were separated from the felled culm and leaf components for biomass consideration. Diameter at other locations, e.g. 0.1 m, 0.3 m, base of green crown (Yen *et al*., 2008).

vi. Green leaves (foliage) about 30gms of the green leaves were randomly sampled from each felled tree. Meanwhile, the leaf area index determination from specific leaf area (SLA) and dry leaf weight (DLW) measurements described by (Singh and Singh, 1999) were not done.

vii. Dry leaves were also taken from under the selected clumps. *Bambusa vulgaris* bamboos in Ghana are found in semi-deciduous zone as a result shed the leaves at the end of the growing season.

3.3.2 Clump Data Collection

Tape measure and rope were used to measure the circumference of the clumps. The ratio of the circumference to the diameter of a circle; approximately equal to 3.14159 (*pi*) were used to calculate the circumference of the clumps.

3.3.3 The Internode Distance (var heights)

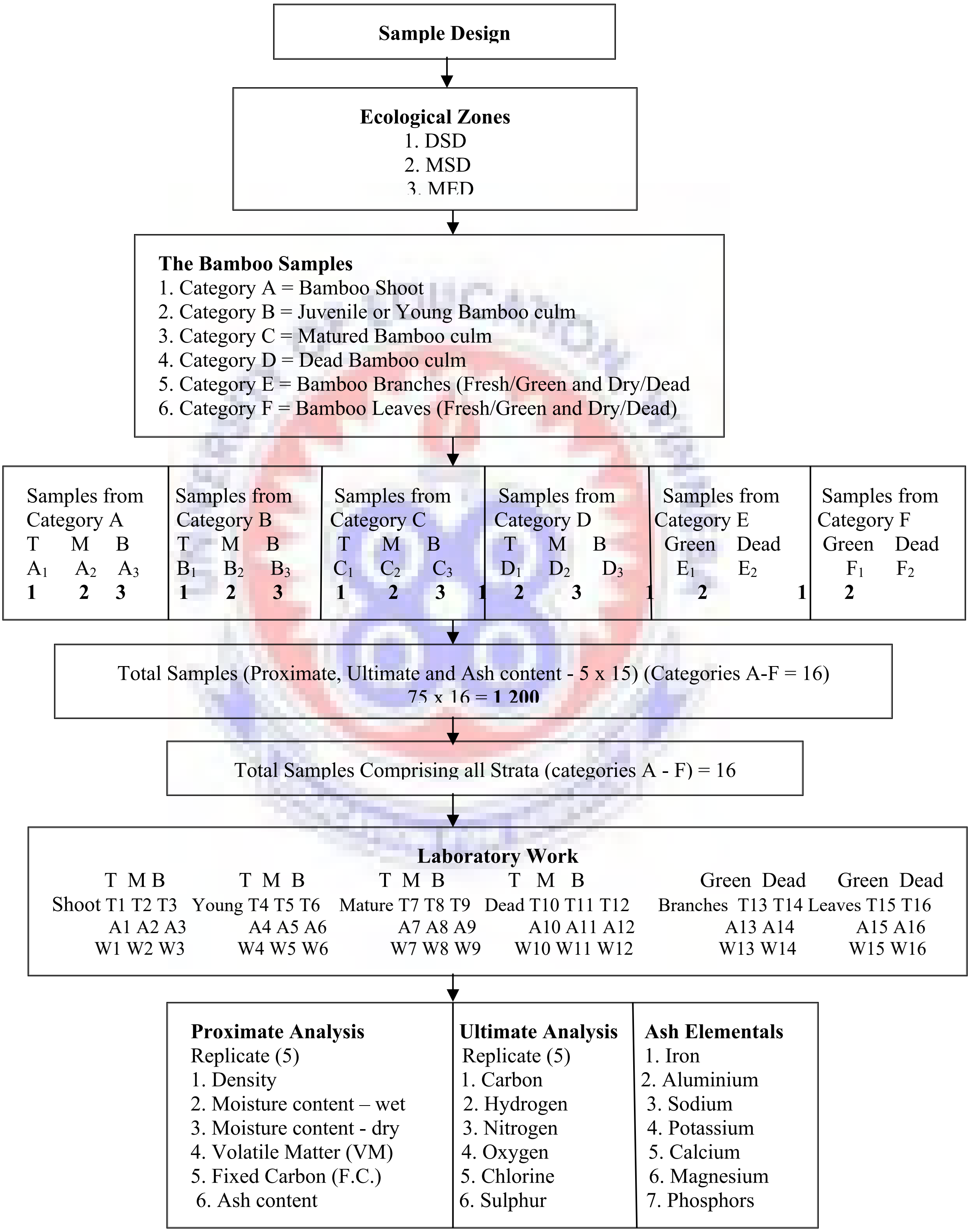
The internode distance of the bamboo culms (juvenile, matured and dead) were measured at the base, middle and the top and were recorded. The measurements were repeated in all the five (5) culms. The average internode distance and culm wall thickness are shown in Table 4.4.

3.3.4. Culm/Stem Diameter (var Heights)

The diameters of the stems were determined by using digital Veneer Caliper. The measurement began from the Base 300mm to the top.

3.3.5 Culms' Wall Thickness

Additional growth of the bamboo over the next few years comprises thickening of the walls of the culm/stem and increases in wood density (Sturkie *et al*., 1968). The thickness of the walls of the bamboo culms were measured by using digital Veneer Caliper. The summary of the sampling frame is shown in Table 4.4.



“T” = Top “M” = Middle “B” = Base/Bottom Source: the Author

Figure 3.2 Schematic Experimental Design and the Samples

3.4. PREPARATION OF BAMBOO SAMPLES

The selected samples of the bamboo were ground to fine particle size smaller than 20 meshes (-0.8mm) by using Wiley Knife mill. Any material >20 mesh was milled until it passed the 20 mesh screen (Scurlock *et al*., 2000; Templeton *et al*, 2009). The milled samples were mixed toughly to obtain homogenisation (mix to obtain uniform samples) so that the chemical analysis might be performed on material which represented the average of each sample (Scurlock *et al*., 2000). The fine particles were stored in an airtight container for chemical analysis. The mass of the specimens were weighed *and* recorded. Afterwards, the specimens were oven-dried at 103 ± 2°C and weighed again (Templeton *et al*, 2009).

3.4.1 To obtain fine powder of the bamboo leaves for the analysis

The bamboo leaves were cut into small strips, freeze to about – 80º C. The small strips of bamboo leaves were transferred to the electric coffee grinder by filling it with to half its capacity and cover the blade to obtain fine powder homogeneity. Parts of the bamboo leaves were ashed at the temperature of 400º C.

3.5 BAMBOO (*BAMBUSA V. VULGARIS*) FUEL ANALYSES

Proximate (volatile matter, fixed carbon) and ultimate (carbon, hydrogen and nitrogen) analyses were used to determine the physical, chemical and fuel properties of bamboo (*Bambusa v. vulgaris*). The tests of 1 200 samples were carried out in Agricultural Science soil and chemistry laboratory; and Calorific values at the Department of Biochemistry, all at Kwame Nkrumah University of Science and Technology - Kumasi, Ghana.

3.5.1 Fuel Analyses

The analyses were done with five (5) replications based on American Society for Testing Materials (ASTM) – moisture content; proximate analysis; ultimate analysis; calorific value; Ash and ash elemental analysis (minor and heavy metals).

3.5.2 Analysing physical properties of bamboo

The physical properties of bamboo to be determined include the moisture content, calorific values (heating values) bulk density and basic density.

Determination of Moisture Content: Moisture content was determined based on ASTM E871. Right after grinding, samples were taken to the laboratory for the determination of the moisture content. 2 g of each sample was weighed and placed in different crucibles. The crucibles were cleaned and dried in an oven and weighed on an analytical balance. These were then labeled and placed in the oven which was kept at a temperature of 105 ˚C. Each crucible and sample were taken out of the oven regularly and weighed. Gradual decreases in weight were observed and the drying and weighing continued until there was no observed change in the weights after several weighing. The samples were taken out and kept in a desiccator for them to cool down and weighed. The final weights were then recorded. The apparatus used to perform the experiment included: an oven (100 – 200ºC), Moisture can or porcelain crucibles, 20 – 25 *ml*. and desiccators. The moisture can or crucibles and samples (5.0 *g*) were weighed. Allow to dry overnight in an air oven at 105ºC for 24 hours or 48 hours and cool crucibles plus samples in desiccators and re-weigh. Calculations:

$$\text{Moisture content (dry basis)} = \frac{(M_1 - Mc) - (M_2 - Mc)}{(M_2 - Mc)} \times 100\% \qquad \textit{Equation 3.9}$$

Where:

M_1 = Initial weight of sample and crucible

M_2 = Final weight of sample and crucible

Mc = Weight of crucible

Determination of Calorific Value: The bomb calorimeter is device used to burn completely substances in excess oxygen (ASTM D 2015-85). The heat of combustion that comes out is absorbed by the calorimetric vessel in which the bomb is immersed, and results in a temperature increase D*T*. The heat capacity of the system is first determined by adding a definite amount of heat from the combustion of benzoic acid. Consequently, under the same conditions the combustion enthalpy of naphthalene is determined. The Bomb calorimeter was regulated by burning benzoic acid in the same way as the sample. The heat capacity of the calorimeter is then calculated and then used in the calculation of the calorific values of the samples. The sample to be combusted is ground with a mortar and pestle. 400 mg of the pulverised sample was then weighed into a weighing dish. About, 10 cm was cut from the iron wire and its weight recorded as M1. Place the guide grooves of the pellet press in a vertical position. Place wire 10 cm long horizontally into the pellet press. The small steel rod was positioned in the cylinder to close the bottom end of the borehole. The sample was then put in the hole within the guide groove of the pellet press with the wire in it. The larger rod was then inserted above the sample. The assembled press was then positioned in the vice and pressure applied to mould the pellet. The pellet formed was then pressed out of the borehole with the longer rod and the weight of both wire and pellet taken as M2. The difference between M1 and M2 is then calculated as the mass of sample. The heat of combustion of the wire can be ignored because it is present in both the calibration process as well as during the burning of the sample as well. Fit the two ends of the wire of the pellet to contact the lid of the bomb calorimeter. This is fit in the center of the sample vessel (beaker) so that it can burn there after the ignition wire has burned out. The bomb calorimeter is filled with oxygen, the pressure tube was connected to the oxygen cylinder pressure reducing valve and secured with a hose clip. A control valve of the bomb was opened and filled with 10 bar of oxygen whiles the calorimeter vessel was then filled with 850 ml of distilled water. Insert the sealed bomb calorimeter into the water, as well as the temperature probe. Place the magnetic stirrer bar at the bottom of the water in the vessel and the vessel put on a magnetic stirrer. Switch on the magnetic stirrer to achieve a uniform temperature distribution. Connect the contact sockets of the bomb calorimeter to the AC voltage of the power supply unit (15V). Temperature balance was attained about 3 minutes. The temperature meter was then set to determine the temperature difference ΔT over time and recorded twice per minute to an accuracy of 0.01K. Switch on the power supply unit to initiate combustion and the reaction period of the temperature curve was recorded. Record twice per minute the temperature changes until the temperature changes of the system remained fairly constant. The follows are the calculations of the system;

Heat capacity of the system

$Ccal = Q / \Delta T cal$ Equation 3.2

but $Q = -m\Delta H / M$

$\Delta H = Molar\ combustion\ enthalpy\ of\ benzoic\ acid = -3231.5\ kJ/mol$ Equation 3.3

m = Molar mass of Benzoic acid.

Plate 3.5 Determining the Calorific values of the bamboo samples using Bomb Calorific

Bulk Density Measurement: The bamboo samples were cut to 25 to 50 mm size, grind and dust sieved to 60-mesh screen (250 microns) based on ASTM E873. The mass of fresh biomass was put in a measuring cylinder with 250 cm^3 capacity. The sample was weighed by using an electronic balance (±0.01 g accuracy) (Chevanan *et al*., 2008) (W_1). The loosed biomass was tapped on a wooden platform 50 times with approximate amplitude of 20 mm and weighed again (W_2). Reduction in height of the top biomass surface was measured using a Vernier caliper (±0.01 mm).

$$\text{Loose filled bulk density} = \frac{\text{Mass of the biomass}}{\text{Volume of the biomass}}$$ *Equation 2.1*

$$Bulk\ density = W_1 - W_2/V_1 - V_2\ (g\ cm^{-3})$$ *Equation 2.2*

The oven-dry density of solid bamboo was determined by using ISO 3131 standard. The density is the ratio of the density of a test specimen to its volume. To determine the density, cut the bamboo into blocks of 10 x 30 mm x thickness of culms wall from the bottom, middle and top culms portions of the samples. Weigh the fresh blocks. The samples were oven dried for 48 hours at 105±2°C until constant weights were attained. Five replicates were used in the study. The samples were then reweighed to give the oven dried weight. The density each test specimens is calculated using Equation 3.6.

$$D = \frac{m}{v} \times 10^6$$ …………………………………… *Equation 3.6*

where;

D =density in Kg/m^3

m = the oven-dry mass in gm of the test specimens

V = the oven-dry volume of the test specimens in mm^3

3.6. PROXIMATE AND ULTIMATE ANALYSES

Laboratory tests are used to determine the volatile matter (VM) and fixed carbon (FC) contents of the biomass fuel. Fuel analysis based upon the VM content, ash and moisture, with the FC determined by difference, is termed the proximate analysis of a fuel. Elemental analysis of a fuel, presented as C, N, H, O and S together with the ash content, is termed the ultimate analysis of a fuel.

3.6.1. Proximate Analysis

The proximate analysis determines the moisture, volatile matter, and (by difference) fixed carbon content of a fuel (RENEW, 2003), using standard ASTM tests. The data are usually presented on dry basis. Moisture is analysed by the weight loss observed at 110^0C. The volatile matter is driven off in a closed crucible by slow heating to 950^0C, and the sample is weighed again. The high heating rates encountered within an actual gasifier yield a higher volatile content and a lower fixed carbon content than the slow rate used in the ASTM measurement, but char yield from the gasifier is expected to be proportional to char yield from the ASTM test. The proximate analysis is calculated by;

$M + VM + FC + A = 100\ \%$ *Equation 3.7*

where M = Moisture content

VM = Volatile matter

FC = fixed carbon

A = ash

3.6.2. Determination of Volatile Matter in Bamboo

The volatiles consist of permanent gases like CH_4, CO_2 and CO and vapours, which form the bio-oil after condensation. The first part in nitrogen atmosphere shows the loss of moisture and volatiles. Finding the volatile matter in the bamboo will be based on ASTM E872.

Volatile matter (%, moisture free (mf)*) = $(m_d - m_c)/\ m_d \times 100$ *Equation 3.8*

3.6.3. Determination of Ash Content in Bamboo

Ash is the inorganic residue obtained by burning a sample at 600°C. Burn all the organic constituents of the sample feedstock, leaving behind the non-volatile mineral elements. The temperature used for this determination may also affect some elements such as selenium and arsenic, which form volatile oxides when present. These losses can therefore be avoided by addition of known quantities of calcium oxide prior to make the ash.

Crucibles were washed with distilled water and dried in a laboratory oven for about 30 min. Two grams (2 g) of bamboo powder of each part were weighed into an already weighed crucible. The samples were weighed in triplicate into the crucibles and placed into the muffle furnace. The samples were ashed in a furnace for 2 hours at a temperature of 550 ˚C. The samples were left in the furnace until it burns completely to ashes. They were cooled in desiccators containing silica gel to room temperature. The tests were triplicated for each species. The ashed samples were weighed and the ash content was calculated based (AOAC, 2000). The apparatus for the experiment consist of muffle furnace, porcelain crucibles and desiccators with magnesium perchlorate desiccant. Remove ash crucible from oven, place in desiccators, cool and weigh. Weigh 2.0 g of sample into porcelain crucible in duplicate. Put into furnace for 2 hours at 600° C. Allow furnace to cool below 200° C and maintain this for 20 minutes. Place crucible in desiccators with stopper top, cool and then weigh. The calculation is as follows;

$$\text{Ash content} = \frac{(\text{Weight of ash and crucible} - \text{weight of crucible})\ \text{g}}{(\text{Weight of final sample and crucible-weight of crucible})} \times 100\%$$

3.6.4. Determination of Fixed Carbon Content in Bamboo

Fuel analysis has been developed based on solid fuels, such as coal, which consists of chemical energy stored in two forms, fixed carbon and volatiles: first, the volatiles content, or volatile matter (VM) of a solid fuel, is that portion driven-off as a gas (including moisture) by heating (to 950 ^{0}C for 7 min) and second, the fixed carbon content (FC), is the mass remaining after the releases of volatiles, excluding the ash and moisture contents.

According to *(ASTM E870)*, solid, combustible residue that is the final calculation of the amount present in a biomass sample after the percentages of moisture, ash, and volatile matter has been determined. So the fixed carbon will be determined by finding the difference after calculating the moisture content, volatile matter and the ash content. This is given by;

Fixed carbon (%, mf) = 100 – volatile matter (%, mf) – ash content (%, mf) Equation. 3.10

Plate 3.6 Preparing samples for titration

Plate 3.7 Titration to determining carbon content in the bamboo samples

Plate 3.8 Determining Ash elementals using Atomic Absorption Spectrograph (AAS)

Plate 3.9 Determining of Nitrogen in the bamboo

3.6.5 Ultimate Analysis in bamboo

This analysis gives the elemental composition of the biofuel, usually in moisture and ash free basis (dry ash free-daf). The basic components are carbon, hydrogen, oxygen, nitrogen and a negligible amount of sulphur. The ultimate elementals will be determined based on ASTM for the following;

3.6.6. Determination of Carbon (Walkley – black wet oxidation method)

1.0 N (0.1667 M) potassium dichromate was prepared by dissolving 49.04 g of reagent grade potassium dichromate dried at 105ºC in distilled water. The solution was made up to 1000 ml. 0.5 N ferrous sulfate was also prepared by dissolving 278.02 g of ferrous sulphate in 500 ml distilled water and 40 ml of conc. H_2SO_4 was added and the volume made up to 2000 ml. Diphenylamine indicator was also prepared by dissolving 0.5 g of diphenylamine in a mixture of 100 ml conc. H_2SO_4 and 20 ml distilled water. 0.10 g of sample was weighed into an Erlenmeyer flask. 10 ml of 1.0 N $K_2Cr_2O_7$ solution was added followed by 20 ml of conc. H_2SO_4. The mixture was swirled and allowed to stand for 30 minutes for complete digestion. 200 ml of distilled water, followed by 10 ml orthophosphoric acid and 2 ml diphenylamine indicator were added after digestion. The solution was titrated against 0.5 N ferrous sulphate solution until the color changed to dark blue and then to a green end point. The titre value for the blank solution and titre value for samples were recorded. The % C was calculated as;

$$\% \text{ C} = \frac{N\ x\ (Vbl - Vs) x\ 0.003\ x\ 1.33\ x\ 100}{g} \qquad \textit{Equation 3.11}$$

Where N = Normality of ferrous sulfate = 0.5 N

Vbl = titre value of blank solution

Vs = titre value of sample solution

g = mass of sample taken

0.003 = milli –equivalent weight of C in grams (12/4000)

1.33 = correction factor used to convert the wet combustion C value to true C value since the wet combustion method is about 75% efficient in estimating C value (100/75)

The organic matter content was determined by using the formula:

% Organic matter content = % organic carbon x 1.724 (1.724 is the Van Bemellean factor) (Nelson and Sommers, 1982; Heanes, 1984)

3.6.7. Determination of Nitrogen (Kjeldahl Method)

1.0 g of the shell/nib was weighed and transferred into a 500 ml digestion flask and 30 ml of H_2SO_4 were added (Kjeldahl 1883). The digestion flask with the mixture were heated in the DK20 heating digester block starting at a temperature of 80^{o}C and then the temperature raised to 350 ^{o}C. The content of the digestion flasks were heated until the volume was reduced to 3 – 4 ml. The content of the digestion flasks were cooled and the volume made up to 100 ml in volumetric flasks. The volumetric flasks were labelled accordingly. Ten (10) milliliters of sample digest were transferred by means of pipette into a Kjeldahl distillation apparatus after the addition of 20 ml of 40 % NaOH. Distillate was collected over 10 ml of 4 % boric acid and three drops of mixed indicator in a 250 ml conical flask for 5 minutes. The presence of nitrogen gave a light blue colour. 200 ml of the distillate was titrated with 0.1 N HCl till the colour changed from light blue to gray and suddenly flashed to pink. A blank was carried out with the solution sample. The weight of N was calculated as; 14 g of N contained in one miili-equivalent weight of NH_3

Therefore, weight of N in the sample = $\frac{14\ x\ (A - B)\ x\ concentration\ of\ acid}{1000}$ *Equation 3.13*

Where:

A = volume of standard HCl used in the sample titration

B = volume of standard HCl used in the blank titration

The percentage of Nitrogen in the sample is calculated as;

$$\%\ N = \frac{14\ x\ (A - B)\ x\ concentration\ of\ acid}{1000}\ x\ 100 \qquad Equation\ 3.14$$

3.7. DETERMINATION OF ASH ELEMENTALS IN BAMBOOS

Ash Elemental with preference to wet ashing ASTM D4278 AOAC 14.7 microwave digests. This method prepares plant tissue for the quantitative determination of the concentration of boron (*B*), calcium (*Ca*), copper (*Cu*), iron (*Fe*), magnesium (*Mg*), manganese (*Mn*), phosphorus (*P*), potassium (*K*), sodium (*Na*), and zinc (*Zn*) utilizing high-temperature dry oxidation of the organic matter (Baker *et al*., 1964) and dissolution of the ash with hydrochloric acid (*HCl*).

3.7.1. Preparation and dry Ash digestion of Plant tissues for elemental analysis

One (1.0) gram of sample was weighed into a clean ceramic crucible. An empty crucible was included for a blank in each batch of 32 samples. The samples were arranged in a cool muffle furnace and temperature ramped to 500°C over a period of 2 hours. This temperature was allowed to remain for an additional 2 hours. The samples were allowed to cool down in the oven. Samples were then removed from oven ensuring that the environment is free from breeze. Ashed samples were transferred first into already numbered 50 ml centrifuge tubes. Crucibles were rinsed with 10 ml of distilled water into the centrifuge tubes. More rinsing of the crucible with 10 ml of aqua regia was done. The samples were shaken for 5 minutes for proper mixing on a mechanical reciprocating shaker. Samples were then centrifuged for 10 minutes at 3000 *rpm* and then transferred into 100 ml volumetric flask and again made up to the 100 ml mark. The clear supernatant digest were decanted into clean reagent bottles for *P, Ca, Mg, K, Na, Zn, Cu, Mn,* and *Fe* determinations.

3.7.2. Method of determining of Iron (*Fe*)

The basic setup (air pressure = 50 – 60 psi, acetylene pressure = 10 -15 psi and voltage = 208 – 240V) of the AAS was ensured. The file for the type of analysis and hollow cathode lamp was selected with appropriate wavelength for *Fe* at 248.3 nm. A calibration curve was plotted for the element to be analyzed from the stock standards (Buck Scientific,). The prepared sample solutions from was analyzed for *Fe*. The Y in the calibration equation is absorbance of the element and X is the concentration of the element in the sample. X was calculated after substituting the absorbance reading of the sample into the calibration equation. This gave X in terms of mg/L. The total concentration of the element in the sample solution (100 ml) was calculated by multiplying the concentration in mg/L by 0.1L. This gave the total mass of the element in solution. The percentage amount of Fe was found by dividing the mass of the element in solution by initial amount of sample taken followed by a multiplication by 100.

3.7.3. Determination of Phosphorus (*P*)

A vanadomolybdate reagent was prepared by dissolving 22.5 g of ammonium molybdate in 400 ml of distilled water and 1.25 g of ammonium vanadate in 300 ml of boiling distilled water. The vandate solution was added to the molybdate solution and cooled to room temperature. 250 ml of analytical grade HNO_3 was added to the solution mixture and diluted to 1 litre with deionized water. The standard phosphate solution was also prepared by dissolving 0.2195 g of analytical grade KH_2PO_4 in 1000 ml distilled water. This solution contains 50 μg P/ml. A standard curve was prepared by pipetting 1, 2, 3, 4, 5 and 10 ml of standard solution (50 µg P/ml) in 50 ml volumetric flasks. 10 ml of vanadomolybdate reagent was added to each flask and the volume made up to 50 ml. This gave a P content of the flasks as 1, 2, 3, 4, 5, and 10 µg P/ml. These concentrations were measured on the Jenway 6051 colorimeter to give absorbance measurements at a wavelength of 430 nm. A plot of absorbance against concentration was used to prepare the calibration curve. 5 ml of the sample solution from 3.4.2.2 was put into a 50 ml volumetric flask. 10 ml of vanadomolybdate reagent was added and volume made up to 50 ml. The sample was kept for 30 minutes for colour development. A stable yellow colour was developed. The sample was read on the colorimeter at 430 nm. The observed absorbance was used to determine the P content from the standard curve. The % P was calculated as:

$$P \text{ content (g) in 100 g sample (\% P)} = \frac{C\ x\ df\ x\ 100}{1\ 000\ 000} = \frac{C\ x\ 1000\ x\ 100}{1\ 000\ 000} = \frac{C}{10} \quad \text{Equation 3.15}$$

Where C = concentration of P (µg /ml) as read from the standard curve;

df = dilution factor, which is 100 *10 = 1000, as calculated below:

1 g of sample made to 100 ml (100 times);

5 ml of sample made to 50 ml (10 times)

1 000 000 = factor for converting μg to g

3.7.4. Determination of Potassium (*K*) and Sodium (*Na*)

1.908 g and 2.542 g of analytical grade *KCl* and *NaCl* respectively previously dried in an oven for 4 hours at 105°C were each dissolved in 200 ml of deionised water. The two solutions were mixed together and volume made up to 1000 *ml*. This gave a combined standard of 1000 *ppm*. For *K*, a calibration curve (standard curve) of 200, 400, 600 and 800 *ppm* was prepared. Similarly, a standard curve of 20, 40, 60 and 80 *ppm* was prepared for sodium. All the absorbance reading was taken using the flame photometer. The sample solution from the $HClO_4$ and HNO_3 was read on the flame photometer. From the standard curve, the concentration of *K* and Na were calculated using the particular absorbance observed for the sample. Calculation is as follows;

$$K\ content\ (\mu g)\ in\ 1.0\ g\ of\ plant\ sample = C \times df$$

$$K\ content\ (g)\ in\ 100\ g\ plant\ sample,\ (\%\ K) = \frac{C \times df \times 100}{1000\,000} = \frac{C \times 100 \times 100}{1000\,000} = \frac{C}{100} \qquad Eqn.\ 16$$

Where

C = concentration of K (µg / ml) as read from the standard curve

df = dilution factor, which is 100 x1 = 100, calculated as :

g of sample made up to 100 ml (100 times)

1000 000 = factor for converting µg to g.

3.7.5. Determination of Calcium (*Ca*) and Magnesium (*Mg*)

Calcium and magnesium determination by EDTA titration involves addition of several reagents. These reagents were prepared as: *Buffer solution* – 60 g of ammonium chloride was dissolved in about 200 ml of distilled water. 570 ml of concentrated ammonium hydroxide was added and diluted to 1000 ml in a volumetric flask. *Potassium cyanide:* 10 % KCN (W/V) was prepared by dissolving 50 g of KCN in 500 ml of distilled water in a volumetric flask. This solution is complex of all cations that react with EDTA. *Potassium hydroxide:* 10 % KOH (W/V) was prepared by dissolving 100 g of KOH in a litre of distilled water. Necessary when determining Ca^{2+} since it enables it to react with EDTA. *Calcon – red (cal – red) indicator*: This indicator gives red coloration when Ca $^{2+}$ is absent but gives bluish color when Ca $^{2+}$ is present. *Triethanolamine (TEA):* 30 % (V/V) was prepared by diluting 300 ml TEA in a litre of distilled water. This is a viscous solution which is included to maintain p H. *Erichrome Black T (EBT):* 0.2 g of EBT was weighed and dissolved in a mixture of 50 ml methanol (85 %) and 2 g hydroxylamine hydrochloride. Indicator for determining Ca $^{2+}$ + Mg $^{2+}$, Gives red coloration in the absence of Ca $^{2+}$ + Mg $^{2+}$ and bluish coloration in the presence of Ca $^{2+}$ + Mg $^{2+}$. *0.02N EDTA Solution (Versenate):* 3.723 g of reagent grade disodium ethylenediamine tetra acetate dehydrate was dissolved in distilled water. It was diluted to 1000 ml and standardized against magnesium solution with EBT indicator (one ml of 0.02 N EDTA = 0.4 mg Ca = 0.24 mg Mg). EDTA complexes with Ca^{2+} and removes it from solution giving a blue end point in the presence of Ca^{2+}. *Calcium standard (0.02 N):* 1.0 g of reagent grade calcium carbonate ($CaCO_3$) was dissolved in 1 ml of conc. HCl and diluted to 1000 ml with distilled water. *Magnesium standard (0.02 N):* 2.465 g of reagent grade magnesium sulfate heptahydrate was dissolved in 1000 ml distilled water.

3.7.6. Determination of Calcium content in the bamboo

5.0 ml of sample solution from 3.4.2.2 was transferred into a 100 ml Erlenmeyer flask. 10 ml of 10 % KOH solution was added followed by 1 ml of 30% TEA. Three drops of 10 % KCN and few drops of EBT indicator solution. The mixture was shaken to ensure homogeneity. The mixture was titrated with 0.02 N EDTA solutions from a red to blue end point. Calcium in mg = Titre value of EDTA x 0.40

$$\% \text{ Calcium} = \frac{\text{mg Calcium}}{\text{Sample wt.}} \times 100 \qquad \textit{Equation 3.17}$$

3.7.7 Determination of Magnesium

5.0 ml sample solution was pipette into a 100 ml Erlenmeyer flask. 5 ml of ammonium chloride – ammonium hydroxide buffer solution was added followed by 1 ml 30 % TEA. Three drops of 10 % KCN and a few drops of EBT indicator solution. The mixture was shaken to ensure homogeneity. The mixture was titrated with 0.02 N EDTA solutions from a red to blue endpoint.

Magnesium in mg = Titre value of EDTA x 0.24

$$\%\ \text{Mg} = \frac{mg\ Magnesium}{Sample\ wt}\, x\ 100$$

Equation 3.18

3.7.8. Exchange Acidity (*Al* + *H*) and Aluminium (Titration method)

The following apparatus used were 250 ml Erlenmeyer flasks, extraction cups and Trays, filter paper (Whatman No. 2), funnels, burette and magnetic stirrer. The chemical agents used for the experiment were Potassium chloride (1.0 *N* KCl): Dissolve 74.5g KCl (AR grade) per liter of distilled water; Sodium hydroxide (0.05 *N* NaOH): (made from ampoules with concentrated volumetric solution) OR Dissolve 2.0 g of NaOH in a litre of distilled water in a volumetric flask; Sodium fluoride (3 *N*): Dissolve 126g / liter AR grade NaF in distilled water; Hydrochloric acid (0.05 *N* AR grade HCl): Dilute 5 ml of conc. HCl into a litre of distilled water in a volumetric flask and Phenolphthalein indicator: Dissolve 0.1g in 100 ml 95% ethanol.

The procedure for Exchangeable acidity: measure 5.0 ml of sample digest into a 250 ml Erlenmeyer flask; Gently pipet 10.0 ml of 1.0 *N* KCl solution into the Erlenmeyer flask. Add 5 drop of phenolphthalein indicator into the flask; titrate the mixture with 0.05 *N* NaOH to pink end point and then record the volume (ml) of NaOH used (V). The procedure for percent Aluminium in the sample was: add 4 ml of 3 *N* NaF to the titrated extract; Titrate the mixture with 0.05 *N* HCl to colourless end point and record the volume (ml) of HCl used (V). the following calculation was used;

$$= \underline{V*0.05*100} \quad = V*$$

Equation 3.19

W

Where

V = Titre volume of NaOH used (ml)

Normality of NaOH = 0.05 *N*

W = weight of sample used (1.0 g)

3.7.9. Exchangeable Aluminum (meg/100 g)

$$= \frac{V*0.05*100}{W} = V* \qquad \text{Equation 3.20}$$

where

V = Titre volume of HCl used (ml)

Normality of HCl = 0.05 *N*

W = weight of plant sample used (1.0 g)

3.7.10. Dry Ash digestion and analysis of Plant tissues

The apparatus and materials used to determine dry Ash digestion include analytical balance (readability of 0.001 g), muffle furnace, porcelain crucibles, graduated centrifuge tube (50ml) and bench top centrifuge with appropriate rotor to accommodate the centrifuge tube.

The reagent is Aqua Regia solution. In a 2 litre volumetric flask, add about1.2 Litre distilled water. Carefully add 400 ml Conc. Hydrochloric acid and 133 ml of 70 % Nitric acid. Dilute to 2 litres. The procedure to determine the dry ash was; weigh 0.5 – 1.00 g sample into a clean ceramic crucible. Record the weight to the nearest 0.001g. Include one empty crucible for a blank. Place in a cool muffle furnace and ramp temperature to 450°C over a period of 2 hours. Allow to remain at 450°C for an additional 2 hours. Allow to cool down in the oven especially when ashing is done overnight. Remove sample from oven making sure that your environment is free from breeze. Pour the ashed sample *first* into your already numbered or labelled 50 ml centrifuge tubes. Rinse crucible with 10 ml of distilled water into the centrifuge tube. Rinse again the crucible with 10 ml of aqua regia. Vortex (Shake) the samples for 5 minutes to obtain proper mix. Centrifuge samples for 10 minutes at 3000 *rpm* and decant supernatant into clean vials for macro- and micro-nutrients determination.

NOTE: This procedure can be used to analyse *P, Ca, Mg, K, Na, Zn, Cu, Mn, Fe*, and *B*. But cannot be used for *N* and *S*. The cations (*As, Cd, Cu, Fe, Mn, Ni, Pb* and *Zn*) are determined by using flame atomic absorption spectrophotometer model VGP 210 from Buck Scientific, USA.

3.7.11. Method of determining Copper (*Cu*), Cadmium (*Cd*), Nickel (*Ni*), Lead (*Pb*) and Zinc (*Zn*)

The basic setup (air pressure = 50 – 60 psi, acetylene pressure = 10 -15 psi and voltage = 208 – 240V) of the AAS was ensured. The file for the type of analysis and hollow lamp was selected with appropriate wavelengths - *Cu* at 324.8 nm, *Cd* at 228.9 nm, *Ni* at 232.0 nm, *Pb* at 283.3 nm and *Zn* at 213.9 nm. A calibration curve was plotted for each of the elements to be analyzed from the stock standards (Buck Scientific,). The prepared sample solutions were analyzed for the elements. The Y in the calibration equation is absorbance of the element and X is the concentration of the element in the sample. X was calculated after substituting the absorbance reading of the sample into the calibration equation. This gave X in terms of mg/L. The total concentration of the element in the sample solution (100 ml) was calculated by multiplying the concentration in mg/L by 0.1L. This gave the total mass of the element in solution. The percentage amount of the element was found by dividing the mass of the element in solution by initial amount of sample taken followed by a multiplication by 100.

3.7.12. Determination Arsenic (*As*) content in the Bamboo samples

Sample preparation for analysis of Heavy metals in plants was done according to (AOAC 1995; Subramanian *et al*., 2012).

The reagents include Ammonium chloride, Ammonia solution 25% (0.910), M magnesium sulphate, EBT indicator and M Titrimex III (EDTA) solution. The procedure to determine the Arsenic content comprises measuring 25ml of extractant solution into a 100ml volumetric flask. Add 1.0 g ammonium chloride. Add 5.0 ml ammonia solution. Add 25ml 0.1 M magnesium sulphate. Make up to the mark with distilled water and shake vigorously. Allow to stand for at least 15 min with repeated shaking. Filter when settled, and discard the 1st 10-20ml filtrate and then titrate 50ml of the remaining filtrate after adding a drop of EBT indicator with 0.1 M Titriplex III solution colour changes to green. The *As* is calculated by using 1*ml* of 0.1*M* Titriplex III solution = 1*ml* of 0.1*M* Magnesium Sulphate = 7.491 mg of *As*.

3.7.13. Determination of Heavy Metals by Using an Atomic Absorption Spectrometer (AAS)

The concentrations of *Cd, Cr, Cu, Mn, Ni, Pb* and *Zn* in the final solutions were determined by an atomic absorption spectrometer (AAS) (Hitachi Z-8100, Japan).

The part 1 consists of detection of Lead and its concentration based on procedure used by McGuire (2007). First, run the atomic absorption spectrometer with blanks of known concentration solution (such as the acetic acid we use to help leach the potteries), these blanks will allow us to make a calibration curves. Then, inject a small sample (about 20-50 μL) of the lead solution from the ceramic pottery into the atomic absorption spectrometer and allow the machine to analyze. The machine will first vaporize the solution by spraying the solution with acetylene flame, which will release the metal atoms from their chemical compounds and converting them into their elemental forms. A laser will pass through the flame and cause the sample vapor to absorb the energy from the light. A detector in the machine will measures the intensity of the light after it has passed through the flame and the sample vapor and compares it with the original intensity of the light. The difference is an indication of the number of light-absorbing atoms in the sample and this allow you to obtain the absorbance frequency. Since the concentration and absorbance are known for the blanks, these points can then be plotted as absorbance versus concentration on a calibration curve. By drawing a line of best fit, it will determine the concentration of a sample based on the read out of the atomic absorption spectrometer.

The part II also consists of detection of Lead based on method used by Slowinski and Masterton (1971). This is a confirmation test to confirm that lead is presence in the solution. Obtain approximately 1 mL of the solution from the ceramic pottery that has pickles place in it for 24 hours and dilute it 1 mL of distilled water. Add 2-3 drops of 6*M* HCl and 1 mL of thioacetamide (TAA – CH_3CSNH_2). Heat the solution in a water bath for 5 minutes and a PPT should form. Centrifuge the solution and decant the liquid. To the PPT, add 2 *mL* of 6*M* NaOH and 1 *mL* of TAA. Heat the solution in a water bath for 5 minutes and the PPT should not dissolves. Centrifuge the solution and decant the liquid. To the PPT, add 2 mL of 6*M* HNO_3 and heat in a water bath for 5 minutes and the PPT should dissolve. To the solution, add 6*M* NH4OH until the solution is just basic. A white PPT should form. And Centrifuge the solution and decant the liquid. To the PPT, add 1 *mL* of 6*M* HCl. A white *PPT* should form which indicates that lead is present due to *PbC*.

3.8. DATA ANALYSIS PLAN

Qualitative technique was used for in depth information data analyses while quantitative data for analysis was used to draw conclusions. The data collected were assembled, analysed and interpreted; conclusions were drawn and recommendations were made. The statistical analysis was carried out by using the statistical package for social sciences SPSS), Release 16.0 and Excel 2007. The presentation and analysis of the research findings are provided in Chapter 4.

CHAPTER FOUR

RESULTS

4.1: Compare the morphological properties of *Bambusa v. vulgaris* (bamboo) culms and their affects on the production of biofuels.

The morphological characteristics of *Bambusa vulgaris* at diameter at breast height (DBH) were determined to find variations of the morphological properties and how they affect the production of biofuels such as charcoal, transportation fuels, heat and electricity. Table 4.1: provides information on contrasting scenes on the landscape of the three ecological zones.

Table 4.1: General characteristics of the three Ecological zones natural bamboo forests in Ghana

		Ecological zone	
Parameter	***D S D***	***M S D***	***MED***
Mean annual rainfall (mm)*	1300 – 1400	1400 – 1750	1700 – 2800
Mean altitude (m)* *	180 – 300	200 – 250	150 – 300
Mean annual temperature (^{0}C) ***	33	31	29
The soil type***	Lixsols & cambisol	Acrisols, Nitisol & greysols	Ferrasols & Acrisol
Clump size (cm)	420 – 562	435 – 736	432 – 725
Mature culm height (cm)	500 – 900	1 000 – 1 200	1 000 – 1 500
Mature culm diameter (cm)	4 – 7	4 – 8	4 – 8
Internode distance (cm) culm	28 – 30	30 – 33	30 – 33
Internode diameter (cm)	4.3 – 7.5	30.2 – 33.5	30.3 – 33.5
Percentage of dead culms (%) in a clump	21.4	NA	NA

Dry Semi-Deciduous (DSD) – Techiman (Brong Ahafo Region)
Moist Semi-Deciduous (MSD) – Owabi forest near Kumasi (Ashanti Region)
Moist Evergreen Deciduous (MED) – Bonsa forest between Tarkwa and Takoradi (Western Region)
NA – not available

* Obiri and Oteng Amoako, 2007
** Ministry of Environment and Science, 2002
*** Duku *et al*., 2011
Morphology of the *Bambusa vulgaris* (bamboo) culm by the author

4.1.1. Clumps size of *Bambusa v. vulgaris* at the natural stands at the three ecological zones

The clumps size measured in the moist semi-deciduous zone recorded the highest average clump size of 622.33cm which was above the overall average of 573cm. The moist evergreen also recorded the mean value of 584.33cm. Dry semi-deciduous recorded the least value of 512.3cm.

However, the statistical test indicates that the differences were not significant at 5% significance level (Table 4.2). This means that clumps size for the three zones were almost the same.

Table 4.2

Means and standard deviations on the measure of clump size in three ecological zones

	Mean(Std deviation)	*F*	*P*
Dry semi-deciduous (cm)	512.00 ± 79.77		
Moist semi-deciduous (cm)	622.33 ± 163.46	0.517	0.620
Moist evergreen (cm)	584.33 ± 146.84		
Total	572.89 ± 126.56		

4.1.2. The culms' height of *Bambusa v. vulgaris* across the three ecological zones

The culms' heights (Table 4.3) increased consistently from dry semi-deciduous to moist evergreen for all portions investigated. *Bambusa v. vulgaris* shoots recorded the least average height among the age groups. dry semi-deciduous recorded 35.72 cm or 0.36 m), moist semi-deciduous (36.44 cm or 0.36 m) and moist evergreen (36.82 cm or 0.37 m). The values for the three zones slightly differ from one another.

The mean height for juvenile ranged from 12.94m (dry semi-deciduous), 13.06m (moist semi-deciduous) to 13.12 m (moist evergreen). The mean height of mature culms also ranged from 13.48 metres to 13.94 metres whilst the dead or over-grown culms varied from 13.10 metres to 13.88 metres. The average height of bamboo in the three zones was 10.19m. It could also be observed that the average height of bamboo in the three ecological zones to large extent does not vary from that of the population this is due to low coefficient of variations (CV) recorded, since CV of 57% was recorded for the three zones.

Table 4.3

Means and standard deviations of bamboo height (m) in three ecological zones

	Dry semi-deciduous	Moist semi-deciduous	Moist Evergreen	CV (%)	*P*
Shoot	0.36 ± 0.03	0.36 ± 0.03	0.37 ± 0.03	8	0.866
Juvenile	12.94 ± 0.27	13.06 ± 0.32	13.12 ± 0.50	3	0.748
Mature	13.48 ± 0.15	13.86 ± 0.23	13.94 ± 0.23	2	0.009
Dead	13.10 ± 0.50	13.84 ± 0.19	13.88 ± 0.19	3	0.004
Total	9.97 ± 5.70	10.28 ± 5.89	10.33 ± 5.91	56	0.000
CV (%)	57	57	57		
P	<0.000	<0.000	<0.000		

4.1.3 Culm diameter of *Bambusa vulgaris* across the three ecological zones

One-way ANOVA test (Table 4.4) shows *Bambusa vulgaris* culms' diameter in three ecological zones in Ghana.

Moist semi-deciduous zone recorded the highest average diameter of the shoot 10.28cm whilst the lowest values were found in moist evergreen (9.43cm).

The mean diameter of juvenile at the moist evergreen zone recorded the highest average value of 7.71cm, followed by moist semi-deciduous (7.47cm) and dry semi-deciduous with the lowest value of 6.67cm. The mean values for the mature samples ranged from 7.95cm at dry semi-deciduous, 8.22 at moist semi-deciduous to 8.63cm moist evergreen deciduous. The dead culms rose from 9.08cm at dry semi-deciduous, 9.13cm at moist semi-deciduous to 9.51cm moist evergreen. Generally, the highest mean diameters of the culms were recorded in moist evergreen, followed by moist semi-deciduous and the lowest found in dry semi-deciduous.

Table 4.4

Means and standard deviations on Bamboo diameter (cm) in three ecological zones

Items	Dry semi-deciduous	Moist semi-deciduous	Moist Evergreen	CV (%)	*P*
Shoot	10.03 ± 1.01	10.28 ± 1.16	9.43 ± 1.99	15	0.265
Juvenile	6.67 ± 0.67	7.47 ± 0.81	7.71 ± 0.82	12	0.002
Mature	7.95 ± 0.68	8.22 ± 0.84	8.63 ± 0.93	10	0.086
Dead	9.08 ± 0.72	9.13 ± 1.08	9.51 ± 0.86	10	0.357

It could be observed from Table 4.4 that there were no statistical significant differences among the shoot, matured and the dead mean diameters for dry semi-deciduous, moist semi-deciduous and moist evergreen. However, there was statistically significant difference among the juvenile diameters of the various ecological zones with *p*-value of 0.002.

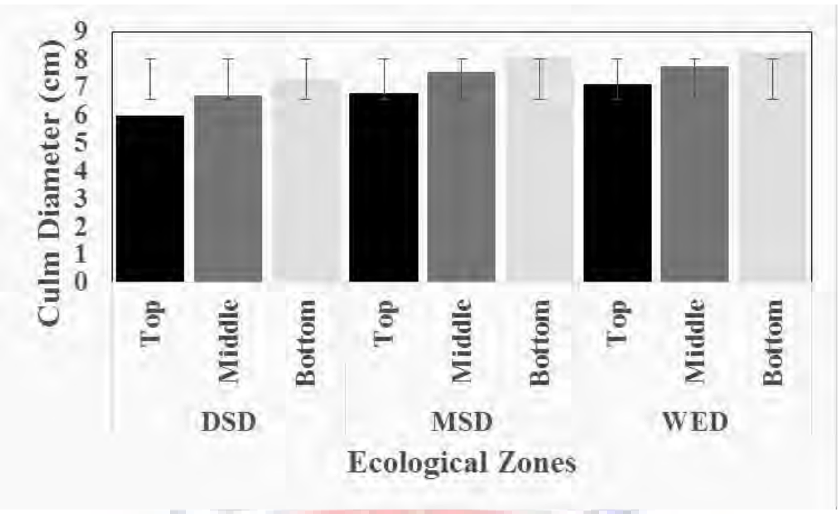


Figure 4.1a – Diameter at the various portions of Bambusa vulgaris juvenile culms across the three ecological zones.

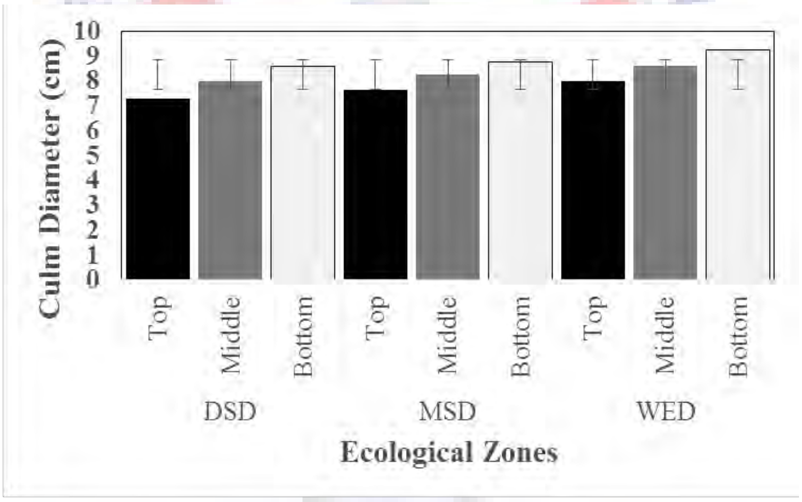


Figure 4.1b – Diameter at the various portions of Bambusa vulgaris mature culms across the three ecological zones.

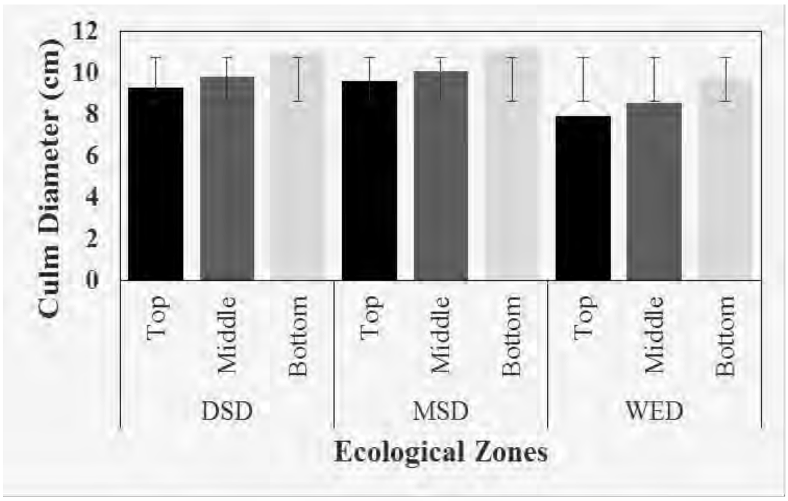


Figure 4.1c – Diameter at the various portions of Bambusa vulgaris dead culms across the three ecological zones.

The culms mean diameter at the various portions decreased from the bottom (base) to the top along the height (Figure 4.1a, b & c). The average juvenile diameter ranged from the top 6.00cm in dry semi-deciduous zone to 8.28cm moist evergreen deciduous. The average mature culms ranged from 7.28cm (from dry semi-deciduous) to 9.26 cm (from moist evergreen zone). The dead bamboo recorded the biggest diameter ranging from 8.34cm at the top in the dry semi-deciduous to 9.26cm at bottom in the moist evergreen zone.

Table 4.5

Average internode distance and culm wall thickness of the samples (bamboos)

Ecological zone	Age group/ Compartment	Internodal distance (cm) Top	Middle	Base	Culm wall thickness (mm) Top	Middle	Base
DSD	Juvenile	36.18	33.74	31.70	8.96	10.90	13.04
	Mature	37.44	34.32	30.18	7.82	11.02	13.11
	Dead	40.73	37.00	36.97	9.98	11.56	12.90
MSD	Juvenile	39.78	37.68	35.26	9.18	10.82	13.22
	Mature	39.54	35.88	32.28	9.22	11.42	13.63
	Dead	41.73	39.17	37.13	9.60	11.72	13.28
MED	Juvenile	41.12	39.40	37.06	9.38	11.16	13.36
	Mature	43.88	41.52	38.00	9.79	11.80	13.70
	Dead	42.40	39.70	38.47	9.88	12.12	14.40

Table 4.5 shows the internode distance and culm wall thickness of the age groups from the three ecological zones. The longest internode distance and the culm wall thickness were

recorded at moist evergreen deciduous zone. The mean internode distance values of juvenile ranged from 37.06 to 41.12 cm; mature culm from 38.00 to 43.88 cm and the dead culm from 38.47 to 42.40 cm. The mean culm wall thickness values of juvenile ranged from 9.38 to 13.36 mm; mature culm from 9.79 to 13.70 mm and the dead culm from 9.88 to 14.40 mm. Samples from moist semi-deciduous zone recorded the following for the internode distance; Juvenile (35.26 to 39.78cm) mature (32.28 to 39.54 cm) and the dead culm (37.13 to 42.40 cm). The culm wall thickness ranged from 9.18 to 13.22 mm (juvenile), 9.22 to 13.63 mm (mature) and 9.60 to 13.28 mm (dead culms). Moist evergreen deciduous zone recorded the following for the internode distance; Juvenile (31.70 to 36.18cm) mature (30.18 to 37.44 cm) and the dead culm (36.97 to 40.73 cm). The culm wall thickness ranged from 8.96 to 13.04 mm (juvenile), 7.82 to 13.11 mm (mature) and 9.98 to 12.90 mm (dead culms).

4.1.4. DBH, Culm Wall Thickness and Internode Distance of *Bambusa v. vulgaris* from Three Ecological Zones in Ghana

The variation of diameter at breast height (DBH), culm wall thickness and internode distance of *Bambusa v. vulgaris* at different ages, ecological zones and bamboo compartments are shown in Table 4.5. A comparison of mean DBH, internode distance and thickness of culms at different ecological locations was examined by ANOVA. Across different ecological locations, no significant differences were detected for the mean DBH (p=0.369) and thickness (p=0.742) of the culm, suggesting that these morphological properties of *B. vulgaris* are not affected by the geographical locations. Mean internode distance, on the other hand, was significantly different across different locations (p=0.005). The shortest and longest internode distance was found in the culms from the dry semi-deciduous and wet evergreen forests, respectively. A pair-wise comparison shows only a significant different of internode distance of culms in the dry semi-deciduous and Moist evergreen deciduous.

Table 4.6

Means and standard deviations on the DBH, internode distance and culm wall thickness of B. vulgaris culm at different ecological zones

Items	Ecological zones			ANOVA	
	DSD	MSD	MED	*p* value	*F* value
DBH (cm)	7.90±1.21*	8.27±0.99	8.62±1.06	0.369	1.035
Internode distance (mm)	35.36ab±3.22	37.61b±2.85	40.17b±2.22	0.005	6.670
Culm w. thickness (mm)	11.03±1.87	11.34±1.77	11.69±1.77	0.742	0.302

*Mean standard deviation

Mean with different letters indicate significant difference at the 5 percent probability

Both mean DBH (*F*=5.169, *p*=0.014) and culm thickness (*F*=145.193, p<0.001)of *B. vulgaris* culms decrease significantly from bottom to top of the culm whereas internode distance increases significantly from bottom to top of culm (*F*=7.966, *p*=0.002) (Table 4.6). A pair-wise comparison shows that significant difference exists only between the bottom and top of the culm in respect of mean DBH and internode distance whereas in respect of culm thickness, pair-wise comparisons were in the sequence bottom>middle>top.

Table 4.7

Means and standard deviations on the DBH, internode distance and culm wall thickness of B. vulgaris at different culm compartments

Items	Culm compartment			ANOVA	
	Top	Middle	Bottom	*p* value	*F* value
DBH (cm)	7.56ab ±0.85*	8.27b ±0.88	8.96b± 1.02	0.014	5.169
Internode distance (mm)	40.31ab± 2.40	37.60b± 2.61	35.23b± 3.06	0.002	7.966
Culm w. thickness (mm)	9.31a ±0.66	11.39b±0.45	13.36c ±0.36	0.001	145.193

One-way ANOVA was utilized to examine the effect of culm age on mean DBH, internode distance and wall thickness of *B. vulgaris* culm (Table 4.7). Results revealed that both internode distance (*p*=0.246) and culm thickness (*p*=0.797) are not significantly different among the ages of the culm at *p*=0.05 level, implicating that these two morphological properties of *B. vulgaris* are not clearly affected by the age of the culm. On the other hand, mean culm DBH was found to be affected by culm age (*p*=0.001). Pair-wise comparisons of mean DBH across the culm ages show the following trend: dead>mature>young.

Table 4.8

Means and standard deviations on the DBH, internode distance and culm wall thickness of B. vulgaris at different culm age

Items	Culm age			ANOVA	
	Young	Mature	Dead	*p* value	*F* value
DBH (cm)	7.28a ±0.722*	8.26b ±0.61	9.24c ±0.79	0.001	17.080
Internode distance (mm)	36.88a± 3.03	37.00a ±4.37	39.26a ±2.06	0.246	1.487
Culm w. thickness (mm)	11.11a ±1.76	11.28a ±2.05	11.68a ±1.59	0.797	0.230

A linear regression model further shows that both the culm internode distance and diameter of the culm have significant effects on culm wall thickness and these two morphological properties explain approximately 70% of the variation in the culm thickness (Table 4.8). A millimeter increase in the internode distance of the culm will, on average, decrease the culm thickness by 0.28mm whereas a centimeter increase in the culm diameter will, on average, increase the culm thickness by 1.167cm.

Table 4.9

Prediction model of culm thickness of B. vulgaris

	Unstandardized coefficients		Standardized coefficient			95% Confidence	
	β	S.E	Beta	t value	Sig.	Lower	Upper
Constant	12.290	2.485		4.945	<0.001	7.262	16.761
Internode distance (mm)	-0.280	0.056	-0.536	-4.992	<0.001	-0.396	-0.193
Culm diameter (cm)	1.167	0.177	0.706	6.581	<0.001	0.910	1.495

The relation between culm thickness and internodal distance was examined with a regression analysis that used culm thickness as the predictor variable.

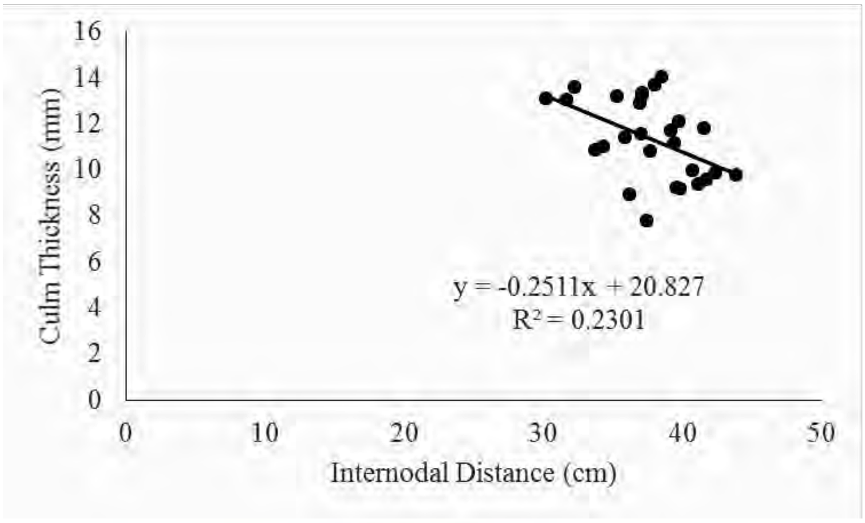


Figure 4.2: Linear Regression between culm thickness and internodal distance

Scatterplot (Figure 4.2) summarises the results at Table 4.8. The scatterplot is in the form of linear equation $Y = \beta_0 + \beta_1 X$

where:

Y = culm wall thickness of the bamboo culm

X = internode distance of the bamboo culm

β_0 is the intercept

The relationship of β_1 is negative.

In all, there was a strong, negative correlation between culm wall thickness and internode distance, $r = -0.536$ that was significant p 0.016. The linear regression analysis of the culm wall thickness and internodal distance revealed that an increase in internode distance is a decrease in culm thickness. The equation for predicting culm thickness from internode distance was predicted.

4.2. Physical and Fuel Properties of *Bambusa vulgaris* across the three zones in Ghana

The fuel properties discussed in this section include moisture content, basic density, bulk density and calorific value.

4.2.1. Variation of moisture content, density and calorific value of *Bambusa v. vulgaris* with age and ecological zone.

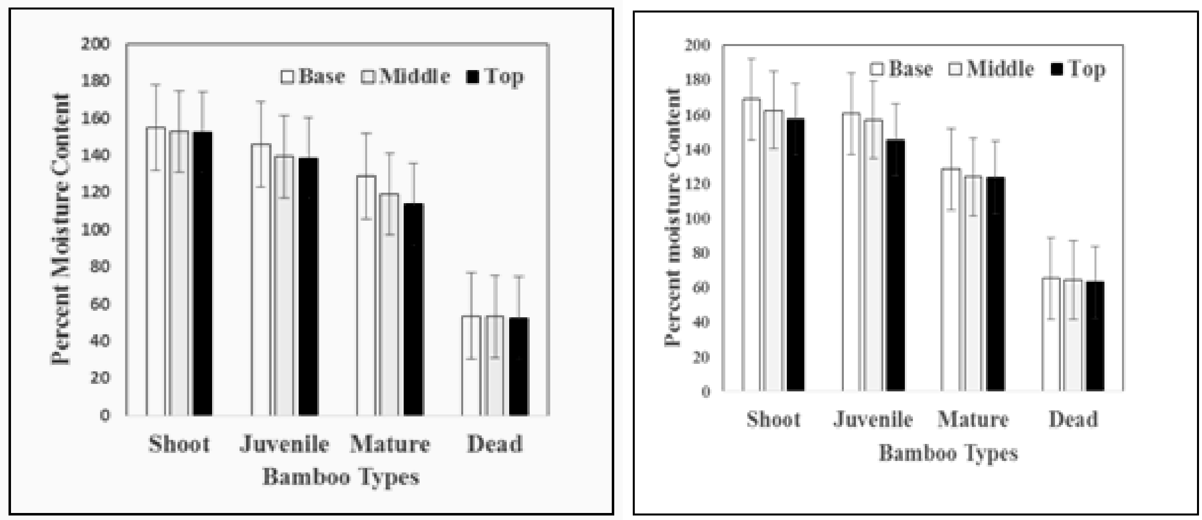


Figure 4.3a. Dry semi-deciduous Figure 4.3b. Moist semi-deciduous

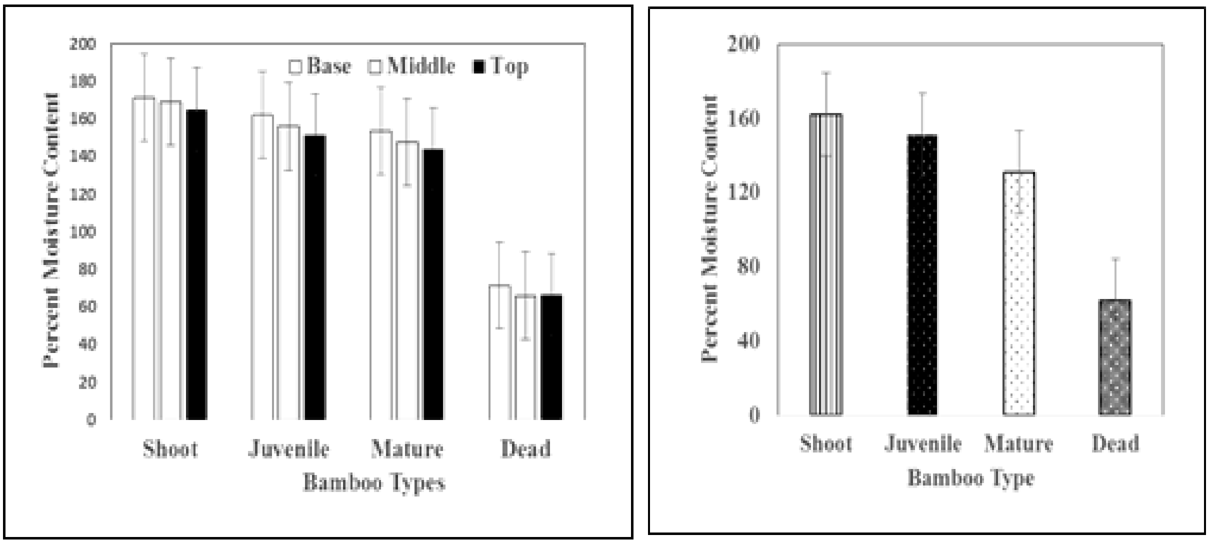


Figure 4.3c. Moist evergreen deciduous Figure 4.3d. Variation of MC with Bamboo type

Figure 4.3: Variation of moisture content (wet) with bamboo age groups

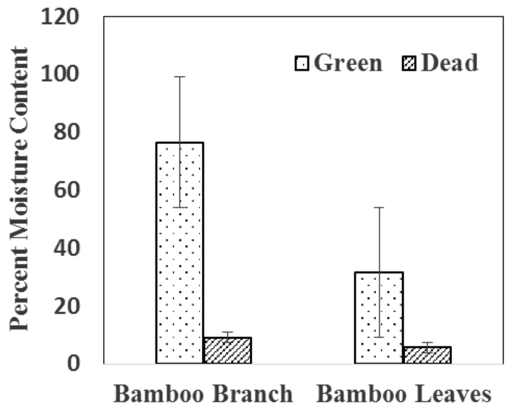


Fig. 4.4a Dry semi-deciduous

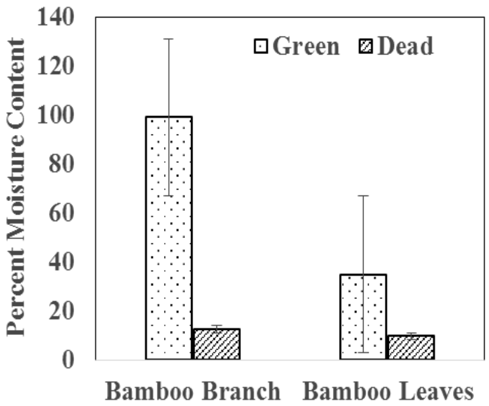


Fig. 4.4b Moist semi-deciduous

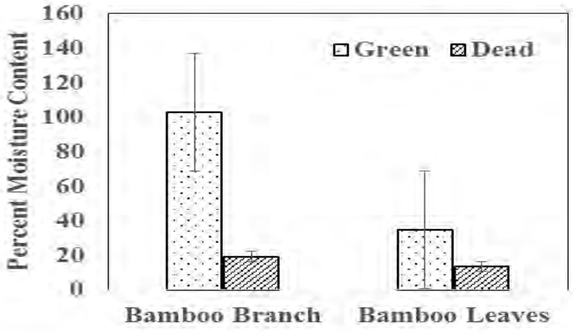


Fig. 4.4bc Moist evergreen-deciduous

Figure 4.4a,b and c Variation of moisture content (wet) with green and dead bamboo branch and leaves

The values of both branches and foliage rose from dry semi-deciduous zone to moist evergreen deciduous zone. The moisture content of the *Bambusa vulgaris* is higher at green bamboo branches ranging from 76 to 103% than the dead branches vary from 11 to 19% in all the ecological zones. The green mature bamboo leaves exhibited the highest mean values from 36 to 38% of moisture content and the dead leaves vary from 9 to 16% (Figure 4.5a,b & c).

4.2.2. The Percentage dry moisture content of *Bambusa vulgaris* across the three ecological zones

In general, the mean moisture content (dry) increased from dry semi-deciduous zone to moist evergreen deciduous zone among the bamboo age groups. Table 4.10 shows the moisture content (dry); the shoot ranged from 9.09% to 9.19%, juvenile scored 13.24% to 13.31%, mature obtained 12.93% to 13.06% and dead culm recorded 11.02% to 11.06%. It could be observed from table 4.11 that there are statistical significant differences among the shoot, matured and the dead mean diameters for all the ecological zones. The test for juvenile shows positive results for shoot (p-value = 0.055, juvenile (p-value < 0.000), matured (p = 0.002) and dead samples (p-value < 0.000).

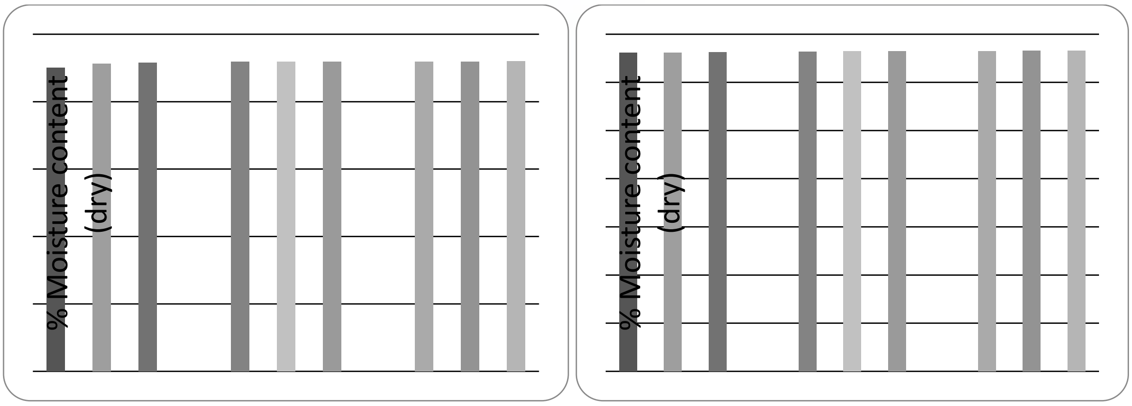
Table 4.10

Means and standard deviations on the percentage moisture content (dry) of B. vulgaris age groups at different ecological zones

Items	Ecological zone			ANOVA	
	DSD	MSD	MED	*F-value*	*p-value*
Shoot	9.09± 0.074	9.19± 0.006	9.19± 0.010	4.868	.055
Juvenile	13.24± 0.006	13.27± 0.006	13.31 ± 0.006	94.333	.000
Mature	12.93± 0.025	13.04±0.031	13.06± 0.030	19.257	.002
Dead	11.02± 11.057	11.06± .006	11.05± 0.006	55.500	.000
Foliage	9.02± 1.732	8.02± 0.012	8.01± 1.732	.571	.605
Branches	11.07± .956	11.44± 1.106	11.13± 1.351	.565	.608

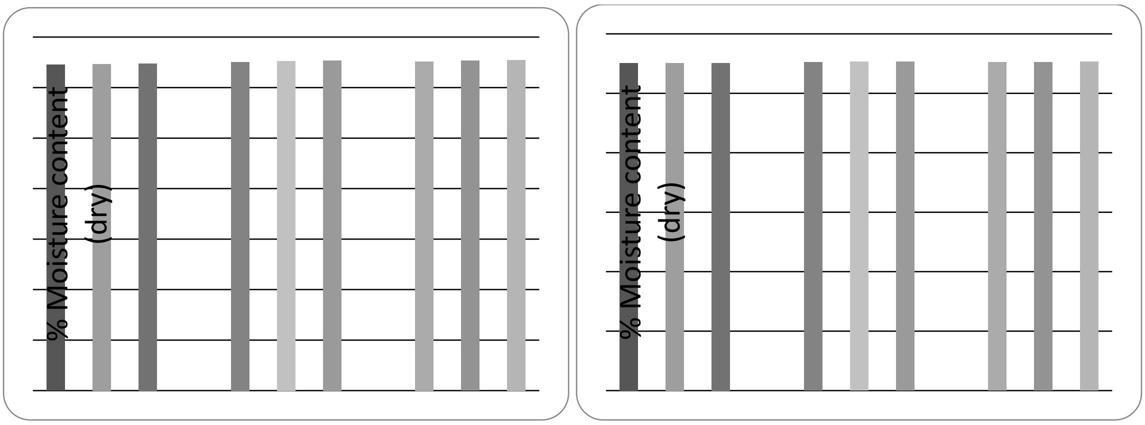
The mean values of the foliage decreased slightly from dry semi-deciduous (9.02%) to both moist semi-deciduous and moist evergreen zones (8.02%) (Table 4.10). The highest average values of the branches was recorded at the moist semi-deciduous (11.44%), followed by moist evergreen (11.13%) and the least mean value was found in dry semi-deciduous zone (11.07%). However, the values obtained were not significant.

Moisture content at various compartments (top, middle and base)



Shoot

Juvenile



Mature
Dead

Figure 4.5 Variation of moisture content (dry) with bamboo age groups

Figure 4.5 indicates the mean values of moisture content using dried samples in the various portions of the bamboo. The mean values decreased from the base to the top. The shoot recorded the least value at the top (19.01%) to base (19.20%), juvenile had 13.24% (top and middle) to 13.31 (base), mature culm obtained 12.90% (top) to 13.09% (middle and base) and the dead culm recorded 11.02% for top, middle and base to 11.06% (base).

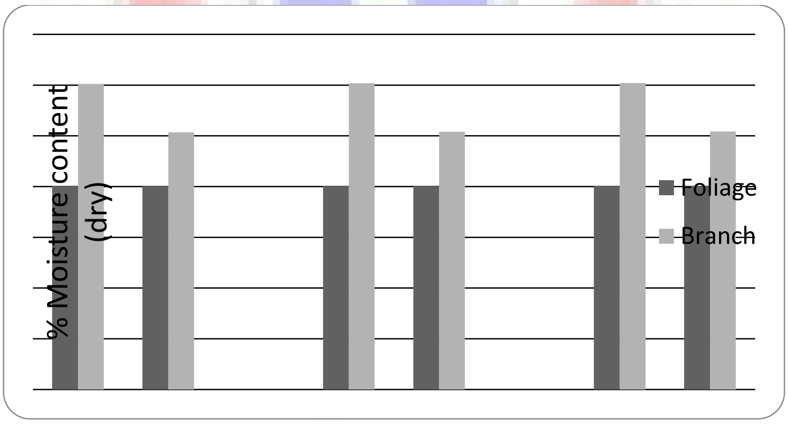


Figure 4.6: Variation of moisture content (dry) with green and dead bamboo branch and leaves

There were no variations of moisture content (dry) with green and dead foliage in all the three zones. All the zones recorded the average value of 8.03% and 8.01% for green and dead foliage respectively. There were slightly increase with the mean scores of the green and dead branches in all the zones. The green branches ranged from 12.05 to 12.08% whilst the dead branches ranged from 10.14 to 10.17% (Figure 4.6).

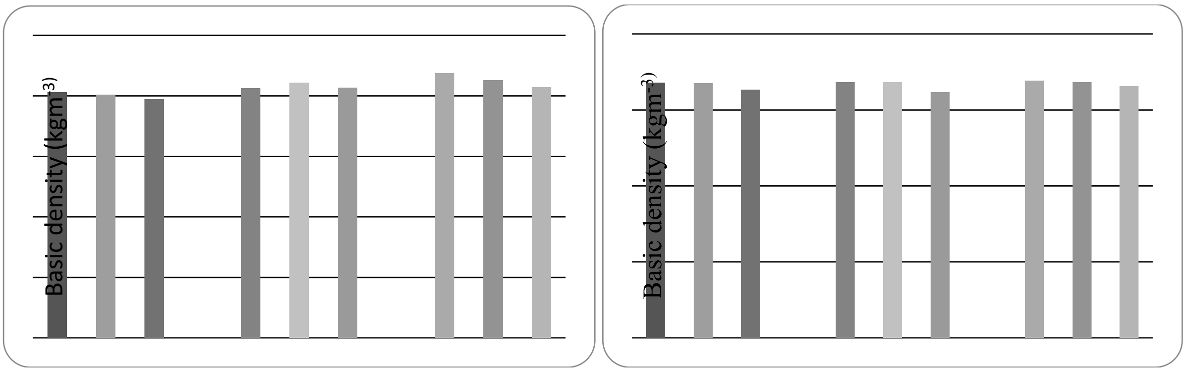
4.2.3 Density of *Bambusa vulgaris* across the three ecological zones

Maximum average density was observed at the mature age of *Bambusa vulgaris* ranging from 716kg.m^{-3} (dry semi-deciduous), 721kg.m^{-3} (moist evergreen) and 722 kg.m^{-3} (moist semi-deciduous. Mature age had marginal increases in density for samples from the three ecological zones (8%, 9%, and 8%, respectively). The mean dead culm varied from 709 kg.m^{-3} (dry semi-deciduous), 710 kg.m^{-3} (moist semi-deciduous) to 715 kg.m^{-3} (moist evergreen). Marginal reduction in density was observed for dead bamboos across the three ecological zones, implicating that as *B. vulgaris* matures, its density decreases. Increase in average density at the juvenile age was 663.62 kg.m^{-3} (moist semi-deciduous), 664.78 kg.m^{-3} for those from the dry semi-deciduous and 666.42 kg.m^{-3} moist evergreen forests. The average density for the shoot of *B. vulgaris* was 401kg.m^{-3} for samples from the dry semi-deciduous and 413kgm^{-3} for those from the moist semi-deciduous and moist evergreen forests (Table 4.11). At the 5% level of probability, the mean densities of the shoots sampled from moist semi-deciduous (413.10 ± 7.97 kg.m^{-3}) and moist evergreen (413.20 ± 13.16 kg.m^{-3}) were significantly higher than those from the dry semi-deciduous (400.77 ± 5.74 kg.m^{-3}). However, *B. vulgaris* at the juvenile age, mature age as well as over-mature ones did not show any significant difference in respect of density.

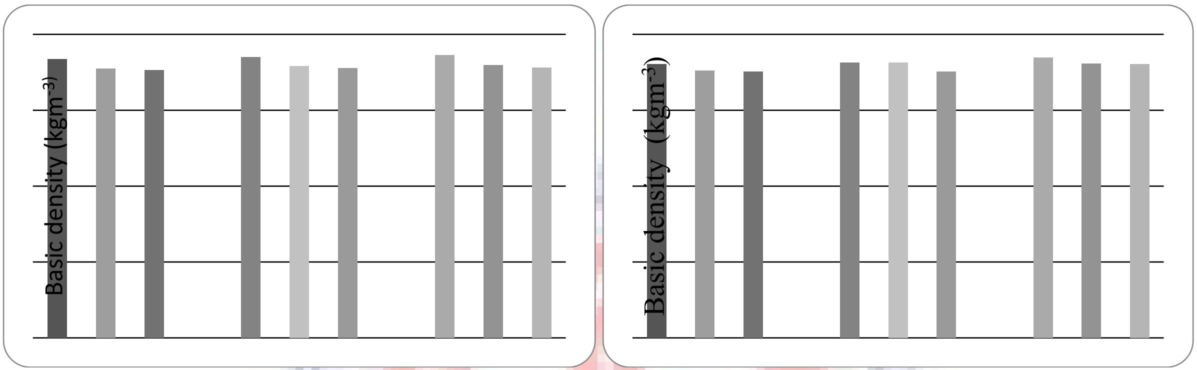
Table 4.11
Means and standard deviations on Density (kg.m^{-3}) of shoot, juvenile, mature and dead culms of B. vulgaris at different ecological zones

Items	Ecological zone			ANOVA	
	DSD	MSD	MED	F-value	p-value
Shoot	400.77a± 5.74	413.10b± 7.97	413.20b± 13.16	6.228	0.034
Juvenile	664.78 ± 10.43	663.62 ± 15.27	666.42 ± 10.54	0.342	0.723
Mature	716.84 ± 15.91	722.38 ±15.27	721.58 ± 14.50	0.222	0.808
Dead	709.01 ± 10.67	710.21 ± 13.74	715.72 ± 13.44	2.630	0.151

Density at various compartments (top, middle and base)



Shoots Juvenile



Mature Dead

Figure 4.7 Variation of densities among the compartment in different ecological zones

The density of green *Bambusa vulgaris* culms decrease from the base or bottom to the top. The mean basic densities of the bamboo shoots varied from the top 395 kg/m^3 (dry semi-deciduous) to the base 437kg/m^3 (moist evergreen deciduous). Amongst the juvenile the mean basic densities ranged from the top with the value of 646 kg/m^3 (moist semi-deciduous zone) to the base 677kg/m^3 at the moist evergreen zone. The basic densities of the mature samples differed from the top 706kg/m^3 located at dry semi-deciduous zone to the base 745kg/m^3 located at moist evergreen deciduous zone. The dead samples have the following densities, the lowest 705kg/m^3 found at the middle in dry semi-deciduous zone and the highest 738kg/m^3 located at the base at moist evergreen deciduous zone (Figure 4.7).

4.2.4. Bulk density of the *Bambusa vulgaris* across the three ecological zones

The mean bulk density exhibited more definite pattern of variation within and between all the zones (Table 4.13). The mean values increased from dry semi-deciduous, moist semi-deciduous to moist evergreen zone. The mean bulk density of shoot was from 0.13 to 0.17 gm^{-3}, juvenile from 0.17 to 0.28 gm^{-3}, mature ranged from 0.28 to 0.32 gm^{-3} and the dead recorded 0.32 to 0.52 gm^{-3}. On the whole, the samples from moist evergreen recorded the highest values. On the contrary the samples from dry semi-deciduous got the lowest values. The mean values of the juvenile and the dead culms were statistically significant.

Table 4.12

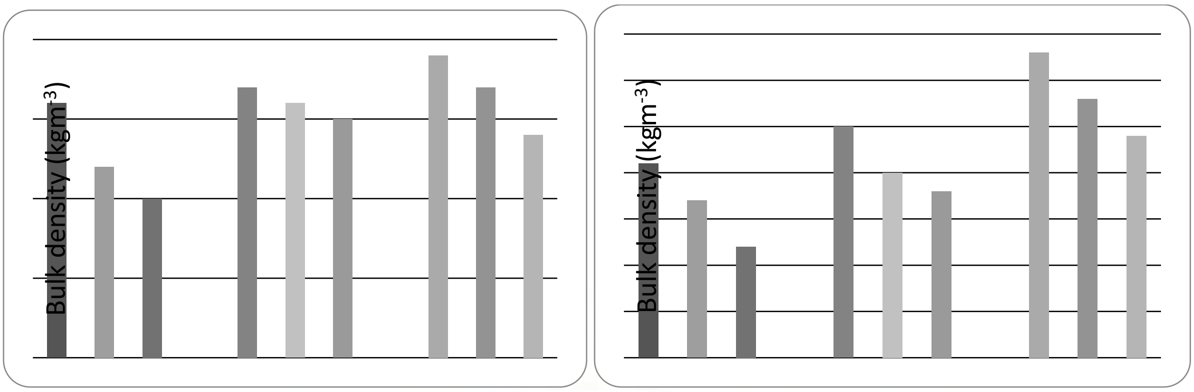
Bulk density ($g.m^{-3}$) of shoot, juvenile, mature and dead culms of B. vulgaris at different ecological zones

Items	Ecological zone			ANOVA	
	DSD	MSD	MED	*F-value*	*p-value*
Shoot	0.13± 0.031	0.16± 0.010	0.17± 0.025	2.480	.164
Juvenile	0.17± 0.045	0.21± 0.036	0.28± 0.045	5.832	.039
Mature	0.28± 0.030	0.24± 0.044	0.32± 0.030	3.892	.082
Dead	0.32± 0.036	0.38± 0.032	0.52± 0.021	32.783	.001
Foliage	0.41± 0.014	0.43± 0.014	0.51± 0.000	3.484	.135
Branches	0.32± 0.021	0.36± 0.120	0.48± 0.057	27.473	.006

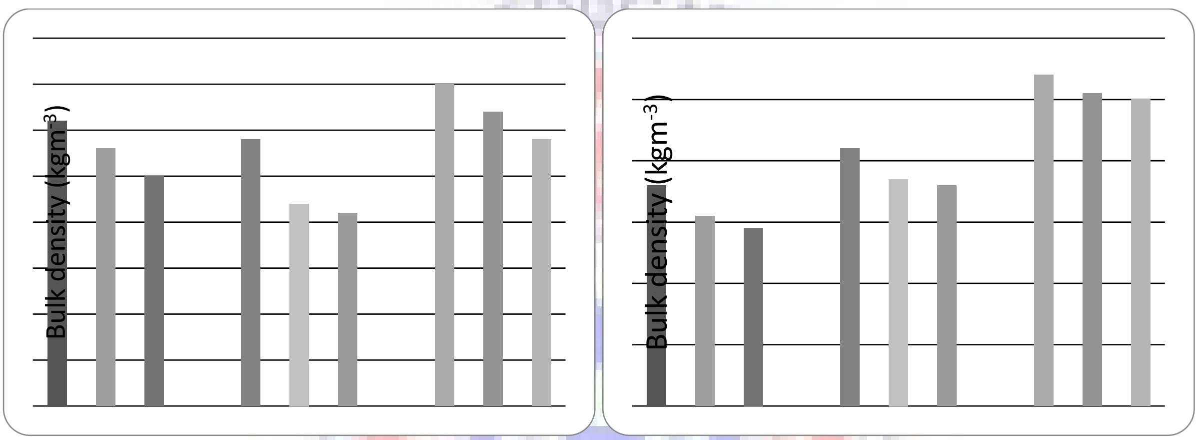
The mean bulk density of the foliage and branches of *Bambusa vulgaris* increased from dry semi-deciduous to moist evergreen deciduous zone (Table 4.12). The foliage ranged from $0.41kg.m^{-3}$ to $0.51kg.m^{-3}$ whilst the branches ranged from $0.32g.m^{-3}$ to $0.48g.m^{-3}$. There was a significant difference between the branches across the ecological zones.

Bulk densities at various compartments (top, middle and base)

For the various compartments, the moist evergreen recorded the highest mean bulk density at the base of the shoot, 0.19 g/m^3 and the lowest 0.10 kg/m^3 found at the top. The mean values of the juvenile culms ranged from 0.12 kg/m^3 found at top at dry semi-deciduous to 0.33 g/m^3 (base at the moist evergreen). The highest average bulk density of 0.35 kg/m^3 was recorded at the moist evergreen zone whilst the lowest 0.21 kg/m^3 were recorded at dry semi-deciduous zone. The moist evergreen zone had the highest bulk density of 0.54 kg/m^3 at the base and the lowest 0.29 kg/m^3 (top) located at dry semi-deciduous (Figure 4.8).



Shoot Juvenile



Mature Dead

Figure 4.8 Variation of Bulk densities among the compartment in different ecological zones

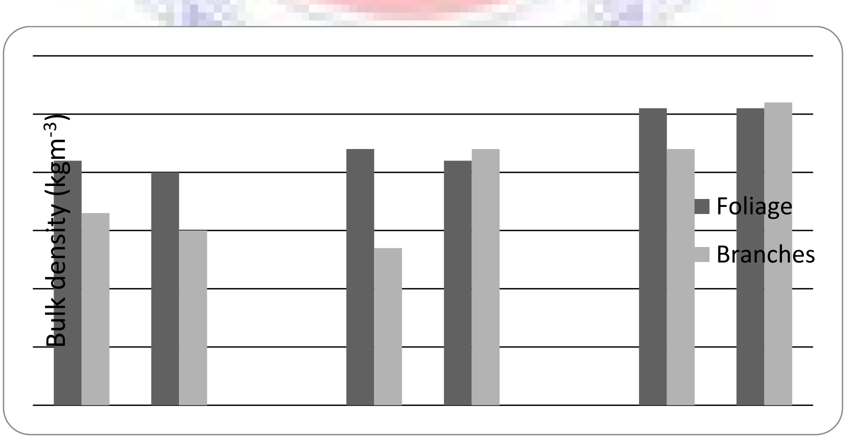


Figure 4.9 Variation of bulk density content in green and dead bamboo branch and leaves

The values of the mean bulk density of foliage and branches in the three zones. Moist evergreen deciduous zone had the highest mean bulk density in both branches and foliage. The mean bulk densities for foliage vary from 0.40 to 0.51kgm^{-3} and the mean branches ranged from 0.27 to 0.52kgm^{-3} (Figure 4.9).

4.2.5. The calorific values of the *Bambusa vulgaris* across the three ecological zones

The average calorific value of the shoot recorded for the three zones was 16.12 MJKg^{-1} with moist evergreen zone recorded the least calorific value of 15.21 MJKg^{-1}. The highest average calorific value of 17.02 MJKg^{-1} was recorded in the dry semi-deciduous (Table 4.13**)**. The mean heating value of juvenile culms ranging from 16.61 MJKg^{-}1 located at moist semi-deciduous to 17.64 MJKg^{-1} located at moist evergreen deciduous zone. The mean calorific values for the mature samples vary from 16.12 MJKg^{-1} (moist semi-deciduous) to 17.74 MJKg^{-1} (dry semi-deciduous). The highest mean calorific values for the dead bamboo samples ranged from 15.20 MJKg^{-1} (moist semi-deciduous) to 17.29 MJKg^{-1} (moist evergreen zone). The overall mean highest heating values were recorded at the dry semi-deciduous zone, followed moist evergreen deciduous zone and the lowest were found in moist semi-deciduous zone.

Table 4.13

Calorific values (MJ/kg) of shoot, juvenile, mature and dead culms of B. vulgaris at different ecological zones

Items	Ecological zone			ANOVA	
	DSD	MSD	MED	*F-value*	*p-value*
Shoot	16.14a±0.79*	16.19ab±0.09	16.59b±0.10	4.208	0.022
Juvenile	17.30a ± 0.57	16.61 b± 0.09	17.64a ± 1.17	7.222	0.002
Mature	17.74 a± 0.42	16.12b± 0.71	17.08c ± 0.08	9.848	0.001
Dead	17.28a ± 0.66	15.20b ± 0.72	17.29 a± 0.10	66.372	0.001
Foliage	12.13a± 2.38*	13.93a ± 1.26	12.41a ± 2.22	0.466	0.666
Branches	15.98a ± 0.96	14.44a ± 0.17	13.58a ± 1.79	4.377	0.129

*Mean standard deviation

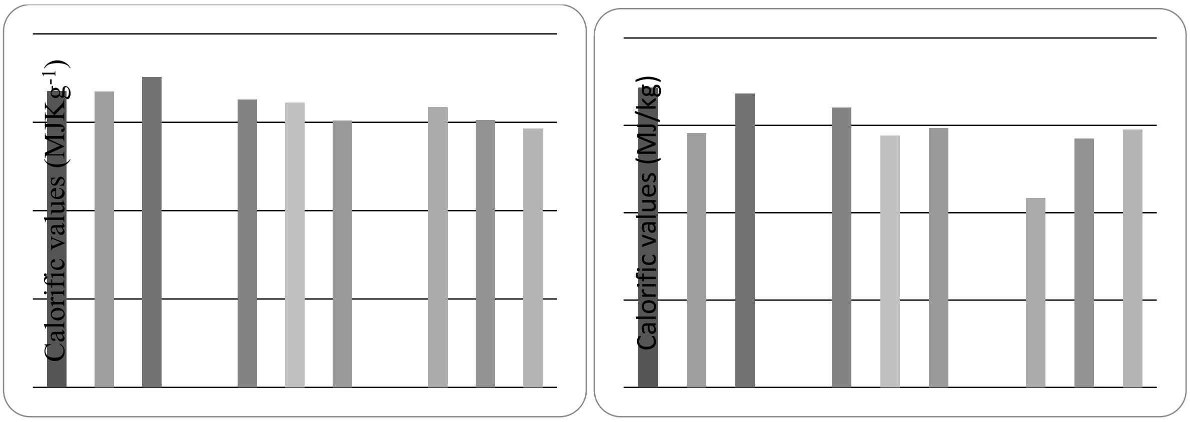
Means in the row with different letters indicate significant difference at the 5 percent probability

Significant differences were found for the culms sampled from the three zones in respect of calorific values ($F = 41.961$, $p < 0.001$). Culms sampled from both the dry semi-deciduous and moist evergreen had significantly higher calorific values than those from the moist semi-deciduous.

The average calorific value of foliage samples vary between 12.13 MJ/kg^{-3} found in dry semi-deciduous and 13.93^{-3} MJ/kg^{-3} located at moist semi-deciduous zone. The value of branches ranged from 13.58 MJ/kg^{-3} (moist evergreen) to 15.98 MJ/kg^{-3} (dry semi-deciduous). It could be observed from Table 4.15 that there were no significant differences for the foliage and branches of *B. vulgaris* sampled from the three ecological zones in terms of calorific values.

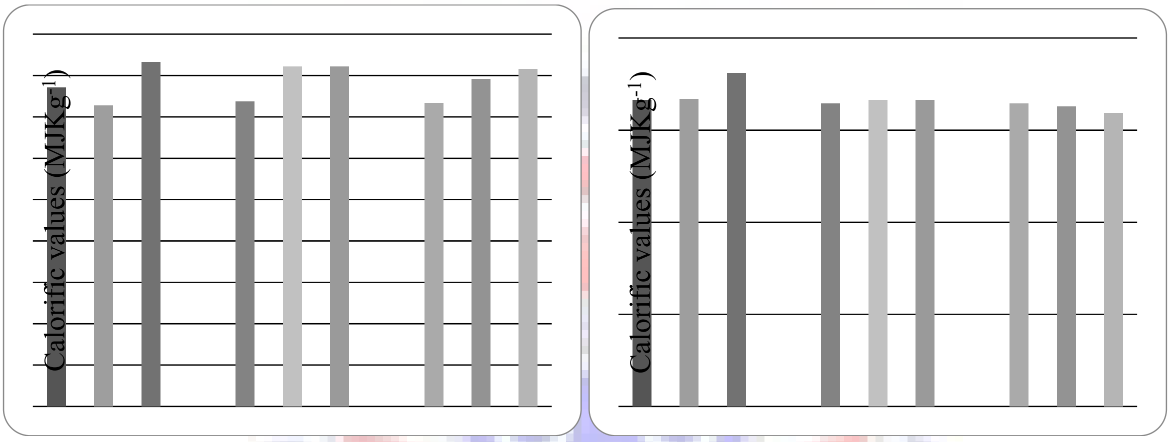
Dry semi-deciduous ecological zone recorded the highest calorific values (Table 4.13). The top portions of the shoots have the mean values of 10.83 MJKg^{-1} (at moist evergreen deciduous) to 17.55 MJKg^{-1} (top at dry semi-deciduous). The highest average calorific value for juvenile was recorded at the middle portion 14.23 MJKg^{-1} at the moist evergreen as the lowest was recorded at the base 17.16 MJKg^{-1} at dry semi-deciduous zone. The mature ranged from 14.55 MJKg^{-1} (middle at dry semi-deciduous) to 16.66 MJKg^{-1} (top at dry semi-deciduous). The dead or overgrown samples ranged from top portion 15.93 MJKg^{-1} at moist evergreen to another top portion 18.10 MJKg^{-1} at dry semi-deciduous.

Calorific value at the various compartments (top, middle and base)



Shoot

Juvenile



Mature

Dead

Figure 4.10 Variation of calorific values with bamboo age groups in the three ecological zones

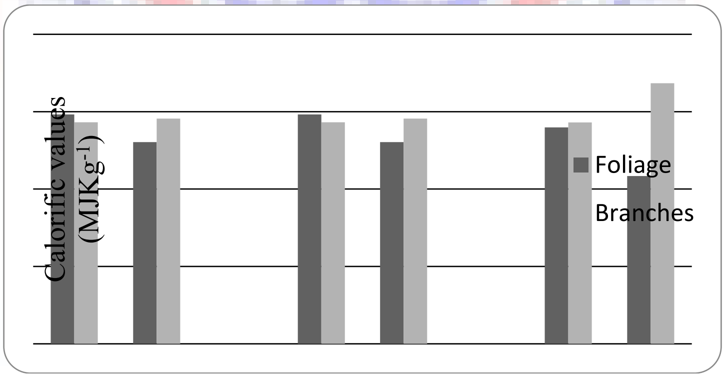


Figure 4.11 Variation of calorific values with bamboo foliage and branches in the three ecological zones.

The green foliage ranged from 13.98 MJKg^{-1} (moist evergreen) to 14.82 MJKg^{-1} (dry semi-deciduous and moist semi-deciduous) and the dead foliage ranged from 10.84 MJKg^{-1} (moist evergreen) to 13.04 MJKg^{-1} (for both dry semi-deciduous and moist semi-deciduous). There was a marginal increase in the green branches ranging from 14.31 MJKg^{-1} (moist evergreen) to 14.31

MJKg^{-1} in both dry semi-deciduous and moist semi-deciduous zones. The dead branches also ranged from 14.56 MJKg^{-1} in both dry semi-deciduous and moist semi-deciduous to 16.84 MJKg^{-1} moist evergreen deciduous zones (Figure 4.11).

4.2.6. Relationships among the internode distance, culm wall thickness, culm diameter, moisture content, density and calorific value of *Bambusa v. vulgaris*

Using a correlation analysis to examine the relationships among the morphological properties, moisture content, density and calorific value of the culms of *B. vulgaris*, it was found that culm thickness decreases with culm internode distance (r =-0.480, p=0.011) but increases with culm diameter (r=0.664, p<0.001). However, no significant correlation was detected between culm diameter and culm internode distance (Table 4.14); indicating that increase in diameter of culms would not result in linear increment of distance between internodes. There were positive significant correlations between culm thickness and density (r=0.437, p<0.05) and calorific value (r=0.453, p<0.05) of the culm, suggesting that thicker culms would have higher heating value and may burn more slowly than thinner culms. The density of the culm was found to associate with calorific value (r=0.512, p<0.05) positively and significantly, indicating that culms with more fibres would result in higher heating value.

Table 4.14

Pearson correlation matrix showing relationships among internode distance, culm wall thickness, culm diameter, *moisture content, density and calorific value*

		1	2	3	4	5	6
1	Internode distance	1					
2	Culm thickness	-0.480*	1				
3	Culm diameter	0.079	0.664*	1			
4	Moisture content	0.695**	-0.846**	-0.437*	1		
5	Density	-0.014	0.437*	0.792**	-0.312	1	
6	Calorific value	-0.361	0.453*	0.089	-0.415*	0.512*	1

*p<0.05

**p<0.01

Basic regression models were used to examine the effects of culm thickness, diameter and density on the calorific value of the culm of *B. v. vulgaris* (Table 4.15). The effect of culm thickness on the calorific value was positive and significant ($\beta=0.364$, $p<0.05$; Model 1). The thickness of the culm explained about 20.5% of the variation in the calorific value of the culm of *B. vulgaris*. Model 2 shows that addition of culm diameter to Model 1 produces a significant increase of R^2 by 8.3%. Effect of culm diameter on the heating value was negative and insignificant. Model 3 introduces culm density, explaining a significant additional 3.5% of the variance in the calorific value of the culm. In all the models, only the effect of thickness of the culm on the calorific value was significant. Thus, culm thickness appears to be a significant predictor of culms' calorific value.

Table 4.15

Effects of culm thickness, diameter and density on calorific value of the culm of B. vulgaris

	Model 1		Model 2		Model 3	
Parameter	B	t-value	β	t-value	B	t-value
Constant	11.679 (1.646)	7.093**	13.541 (1.956)	6.922**	12.322	1.524
Culm thickness	0.364 (0.143)	2.542*	0.566 (0.185)	3.054**	0.572 (0.193)	2.965**
Culm diameter			-0.503 (0.306)	-1.641	-0.557 (0.469)	-1.187
Culm density					0.002 (0.015)	0.156
F-value	6.462, p=0.018		4.796, p=0.018		5.076, p=0.048	
R^2	0.205		0.287		0.322	

4.3. Assess the ultimate and proximate values of *Bambusa v. vulgaris* age groups across the three ecological zones in Ghana for the production of biofuels

This section assesses the ash content, carbon, hydrogen, nitrogen, oxygen, volatile matter, fixed carbon in *Bambusa vulgaris* age groups such as the shoot, juvenile, mature and the dead samples. It also includes the foliage and branches of the mature culms.

4.3.1. Ash content of *Bambusa vulgaris* across the three ecological zones

The values of the mean ash contents across the three ecological zones are presented in Table 4.16. The shoot exhibited values ranging from 0.51% (moist evergreen) to 1.72% (moist semi-deciduous zone). The average weight of ash in the juvenile samples was from 1.71% (moist evergreen) to 2.01% (moist semi-deciduous zone). The mature samples ranged from 0.93% (moist evergreen) to 1.83% (dry semi-deciduous). The values of the dead bamboo samples recorded were as follows; the lowest average value recorded at moist semi-deciduous zone (1.15%) and the highest average ash content 2.17% of located at moist evergreen zone.

Table 4.16

Variation of Ash Content (mean ±SD) with bamboo type and ecological zone

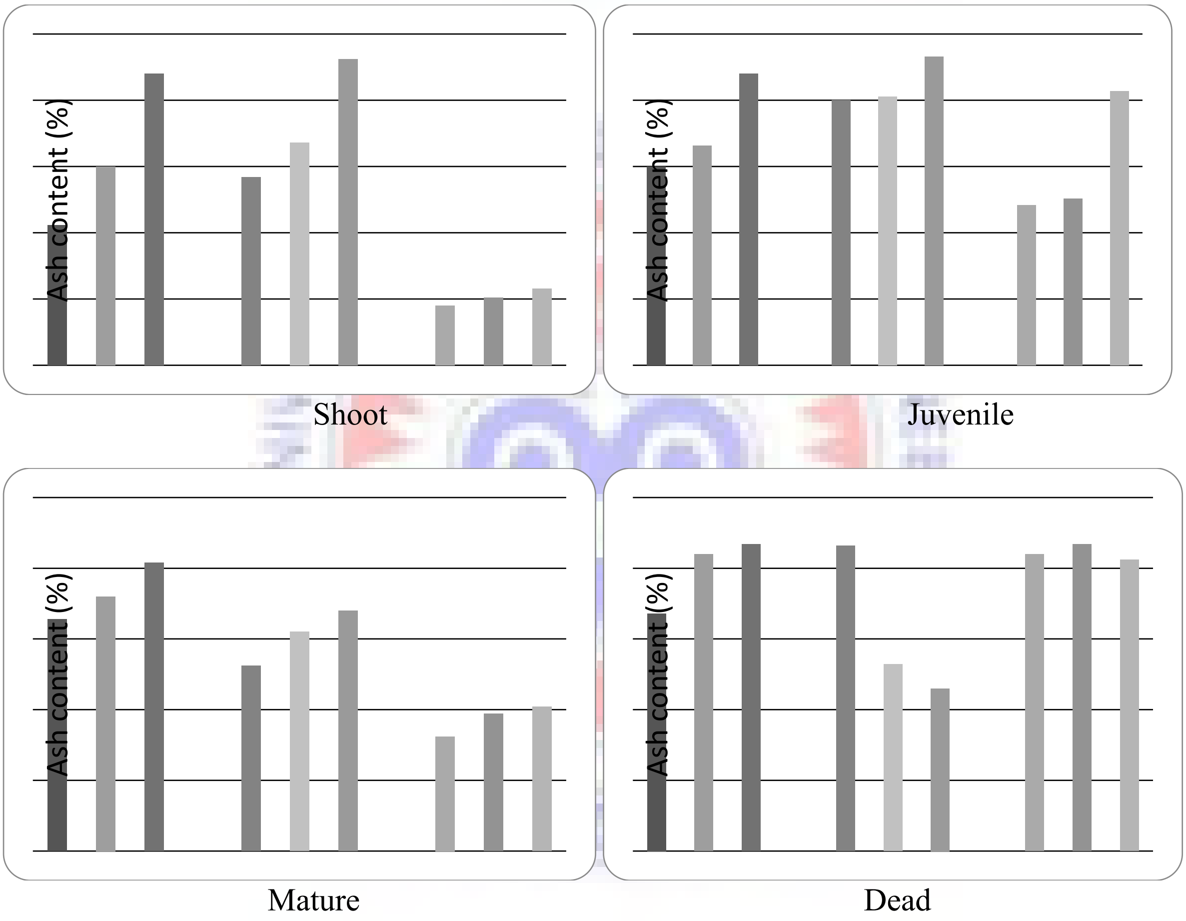
	Dry semi-deciduous	Moist semi-deciduous	Moist Evergreen	*F-value*	*p-value*
Shoot	1.59 ± 0.50	1.72 ± 0.12	0.51 ± 0.06	7.892	0.021
Juvenile	1.79 ± 0.01	2.01 ± 0.18	1.71 ± 0.11	2.073	0.207
Mature	1.83 ± 0.64	1.52 ± 0.64	0.93 ± 0.15	2.318	0.002
Dead	1.98 ± 0.27	1.54 ± 0.54	2.11 ± 0.06	2.177	0.195
Foliage	3.05± 0.61	3.80± 1.85	3.34 ± 1.32	1.552	0.281
Branches	2.67 ± 0.84	1.85 ± 0.60	0.75 ± 0.85	1.800	0.25

Significant differences were found for the shoot (F = 7.892, $p = 0.021$) and the mature (F = 2.318, $p = 0.002$) sampled from the three zones in respect of ash content.

The highest mean value of the foliage was recorded at the moist semi-deciduous (3.80%), medium mean value located in moist evergreen (3.34%) and the lowest measured in dry semi-deciduous. The mean value of the branches increased from 2.67% (dry semi-deciduous), 1.85% (moist semi-deciduous) and 0.75% (moist evergreen zone). Nevertheless, the mean values were not significant difference at the 5 percent probability.

Percentage of ash content at the various compartments (top, middle and base)

The ash content of the various compartments follows a unique pattern except the samples from the dead (Figure 4.12). The top part of the samples recorded the highest value ash content followed by the middle and the lowest found in the base across all the ecological zones. The mean values for the shoot ranged from 0.45% located at the base in moist evergreen zone) to 2.31% found at the top located at moist semi-deciduous. Juvenile also recorded 1.21% (moist evergreen) to 2.33% (dry semi-deciduous). The mean values mature culms recorded ranged from 0.81% (moist evergreen) to 2.64% (dry semi-deciduous). The mean dead samples culms ranged from 1.15% located at the top (moist semi-deciduous) to 2.17% located also at top (dry semi-deciduous) and middle portion at moist evergreen zone.



Shoot

Juvenile

Mature

Dead

Figure 4.12 Variation of ash concentration with bamboo age groups in the three ecological zones.

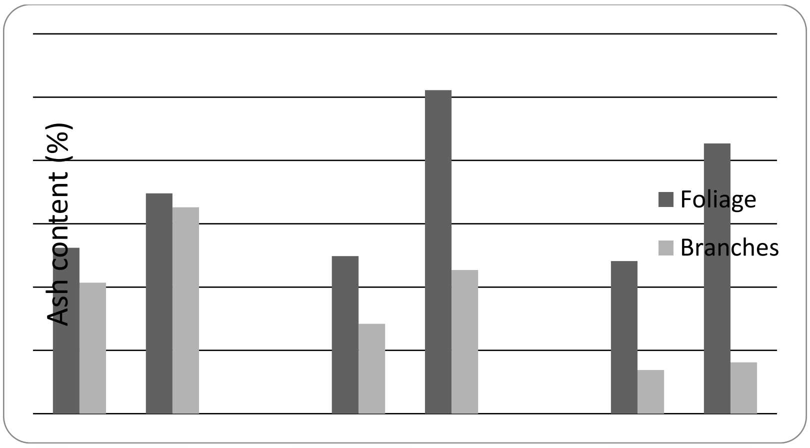


Figure 4.13 Variation of ash content with green and dead bamboo branch and leaves

The average ash content of the green bamboo foliage recorded the highest value at dry semi-deciduous zone (2.62%) and the lowest at moist evergreen (2.41%) (Figure 4.13). The mean dead values recorded ranged from 3.48% (dry semi-deciduous) to 5.11% (moist semi-deciduous). The highest mean ash content of the branches were recorded at the dead sample located at dry semi-deciduous (3.26%) whilst the lowest found in moist evergreen (0.81%). The average values for the green branches were between 0.69% (moist evergreen) and 2.07% (dry semi-deciduous).

4.3.2. Percentage (%) weight of carbon concentrations in *Bambusa vulgaris* across the three zones in Ghana

The mean highest carbon values rose from dry semi-deciduous to moist evergreen zone. The mean shoot varied a little from 49.74% in moist evergreen, 49.67% in moist semi-deciduous and 48.46% in dry semi-deciduous (Table 4.17). The percentages of the juvenile culms were generally higher at moist evergreen (53.31%), dry semi-deciduous recorded 52.52% while moist semi-deciduous zone had 50.24%. The mature culms obtained the following values 52.84% in dry semi-deciduous region, 50.82% in moist evergreen and 48.58% in moist semi-deciduous zone. Meanwhile, the dead bamboo culms have the following values 52.14%, 51.75% and 46.03% from dry semi-deciduous, moist evergreen and moist semi-deciduous respectively.

Table 4.17

The mean percentage of carbon content of bamboo types and ecological zones

Items	Ecological zone			ANOVA	
	DSD	MSD	MED	*F-value*	*p-value*
Shoot	48.46±2.42	49.67±0.19	49.74±0.22	0.574	0.591
Juvenile	50.10±1.44	52.24±0.17	53.31±2.78	1.566	0.284
Mature	48.58±1.26	50.84±1.81	52.82±0.10	5.993	0.037
Dead	52.14±1.64	52.75±1.93	53.01±0.54	9.253	0.015
Foliage	48.92±1.48	48.16 ± 2.09	52.16 ± 0.54	0.007	0.939
Branches	45.10± 0.59	36.56± 1.16	46.58 ± 1.17	0.163	0.901

Table 4.17 shows the one-way ANOVA test for mean carbon content of *Bambusa vulgaris* at three ecological zones. Only the mature (F = 5.993, p = 0.037) and the dead (F = 9.253, p = 0.015) culms were statistically significant.

The mean percentages of carbon in foliage and branches of *Bambusa vulgaris* at different ecological zones are shown in Table 4.17. The least values were recorded in moist semi-deciduous zone, while moist evergreen had the highest values for both foliage and branches. The results were; foliage ranged from 48.16 to 52.16% and branches also ranged from 36.56 to 46.58%.

The mean percentage of carbon at various the compartments (top, middle and base)

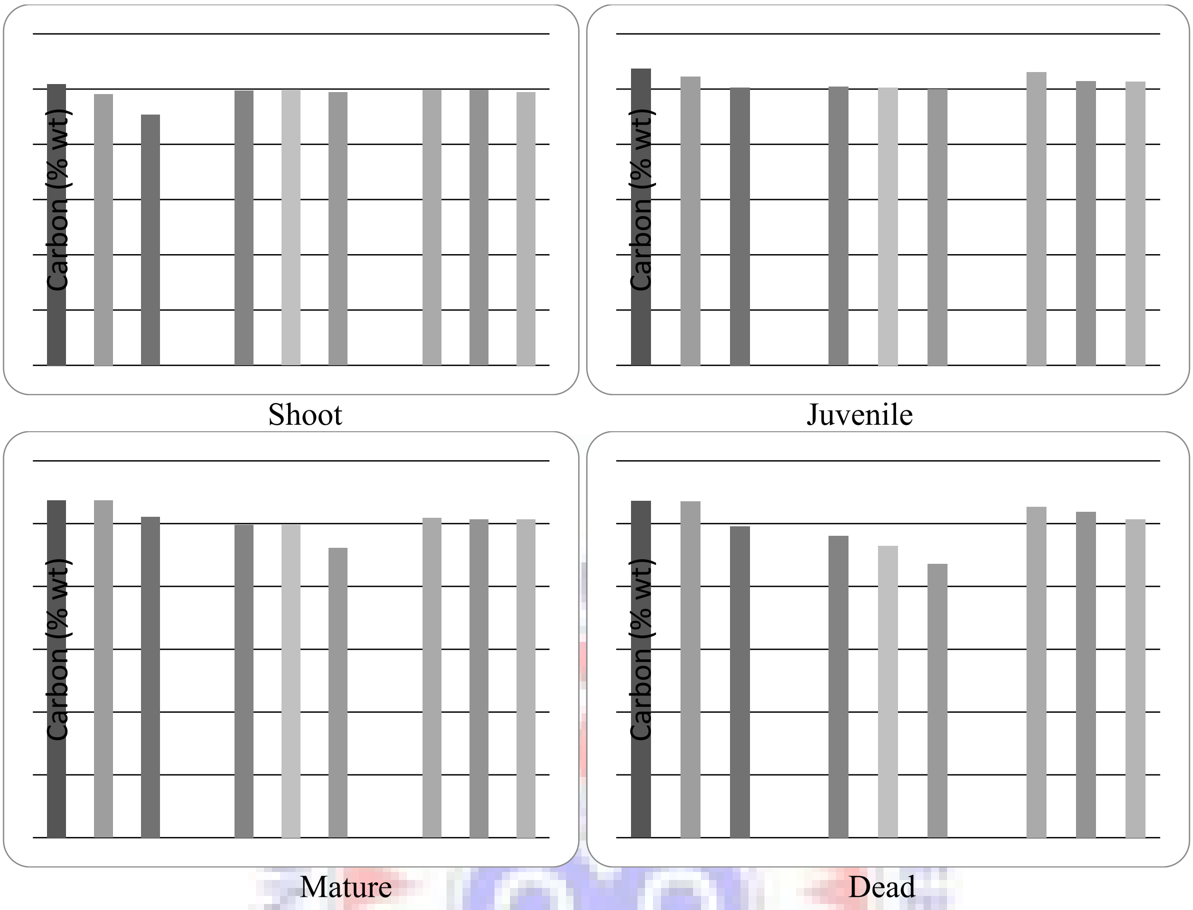


Figure 4. 14 Percentage (%) of carbon contents of Bambusa vulgaris against culm's age

The mean values of the shoot ranged from 45.34 % (top) to 50.90% (base) both located at dry semi-deciduous zones. The mean percentage of carbon in juvenile bamboo culms ranged from 50.03% (top) to 53.70% (base) located moist semi-deciduous and dry semi-deciduous respectively. The percentage carbon values for mature bamboo culms vary from the top (46.12%) at moist semi-deciduous to base (53.70%) dry semi-deciduous. The least average percentage of carbon contents in the dead bamboo culms were recorded in the moist semi-deciduous top (43.57%) and base (53.60%) parts of the bamboo (Figure 4.14).

The highest percentages of carbon were concentrated at the base whilst the lowest were found at the top of all the samples across all the ecological zones. In addition, the highest percentages were found in the dry semi-deciduous zone and the lowest were found in the moist semi-deciduous zone beside the top of the shoot at dry semi-deciduous.

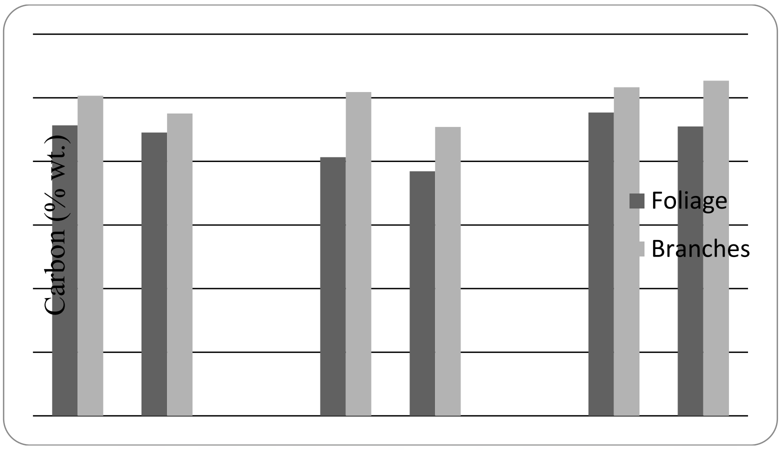


Figure 4.15 Percentage (%) of carbon contents Bambusa vulgaris branches and foliage

The mean green branches ranged from 50.32% (dry semi-deciduous) to 51.65% (moist evergreen deciduous zone) whereas the mean dead branches also ranged from 45.41% (moist semi-deciduous) to 52.68% (moist evergreen deciduous). The mean green foliage ranged from 40.66% (moist semi-deciduous) to 47.68% (moist evergreen deciduous zone) but the mean dead foliage also ranged from 38.46% (moist semi-deciduous) to 45.49% (moist evergreen deciduous) (figure 4.15).

4.3.3. Hydrogen content in *Bambusa vulgaris* across the three ecological zones

From the results in Table 4.18, shoot recorded the mean values of 6.27% (dry semi-deciduous) to 7.04% (moist evergreen). The mean percentage weight of hydrogen in juvenile samples decreases marginally from dry semi-deciduous (6.17%) to moist evergreen (6.13%). The lowest mean percentage of hydrogen (6.34%) was recorded in dry semi-deciduous zone and the moist semi-deciduous recorded the highest value of 6.56%. Meanwhile, average hydrogen weight of dead bamboo samples ranged from 5.60% at dry semi-deciduous to 6.22% at moist evergreen zone. The hydrogen level rose from dry semi-deciduous to moist evergreen zone. The highest value was recorded at the shoot (7.04%) from moist evergreen and the lowest was found in the dead (5.60%) located at dry semi-deciduous zone.

Table 4.18

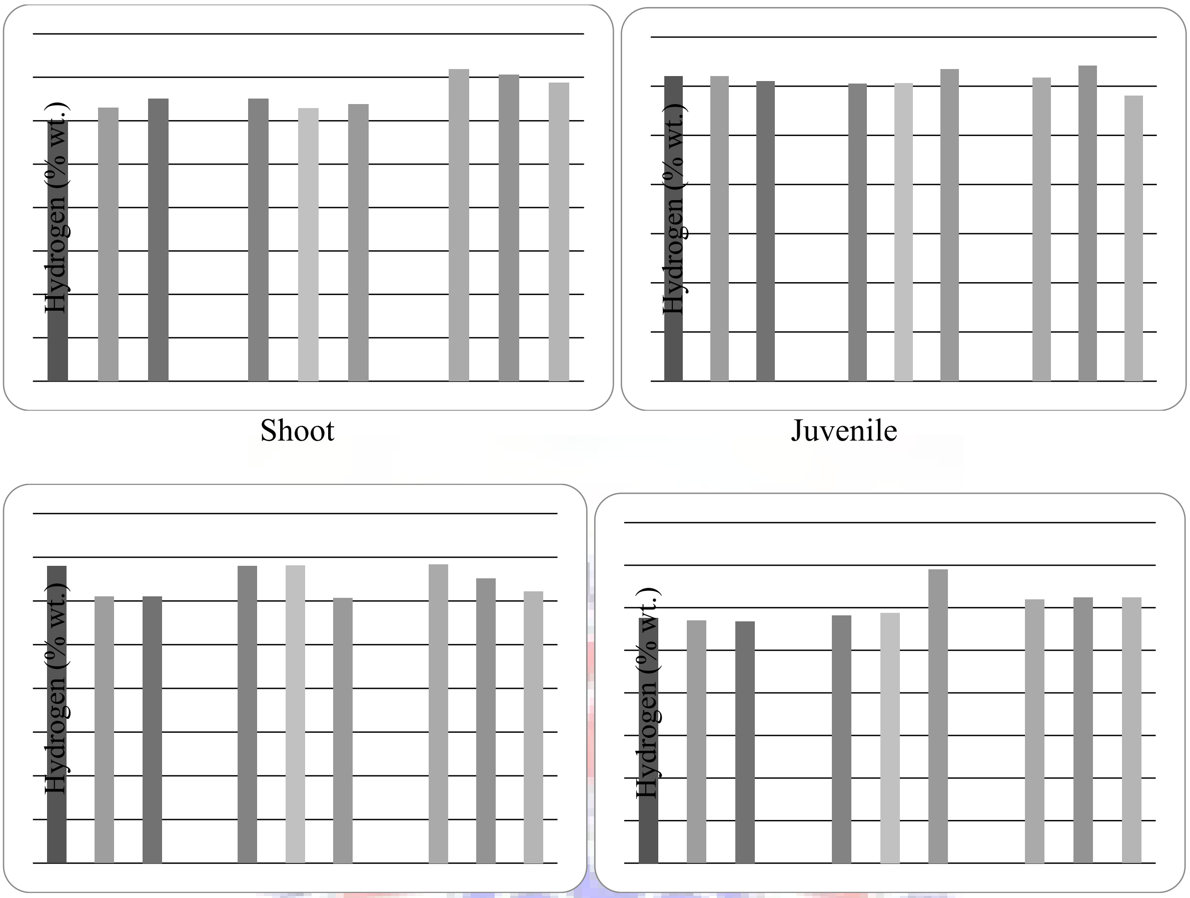
The mean percentage of Hydrogen content of bamboo types and ecological zones

	Dry semi-deciduous	Moist semi-deciduous	Moist Evergreen deciduous	*F-value*	*p-value*
Shoot	6.27±0.227	6.39±0.089	7.04±0.158	15.571	0.004
Juvenile	6.17±0.102	6.15±0.145	6.13±0.273	0.020	0.980
Mature	6.34±0.34	6.56±0.359	6.52±0.262	0.299	0.752
Dead	5.60 ± 0.51	6.20±0.513	6.22±0.024	2.028	0.212
Foliage	6.10± 0.173	6.21±0.190	6.85±0.135	0.000	1.000
Branches	5.97± 0.115	6.56±0.309	6.81±0.147	0.000	1.000

Table 4.18 shows one-way ANOVA test for the mean percentage hydrogen content in *Bambusa vulgaris* across three zones in Ghana. Only the shoot was statistically significant ($F = 15.571$, $p < 0.05$).

The hydrogen concentration in the foliage ranges from 6.10 to 6.85% and the branches from 5.97 to 6.81%, increased from dry semi-deciduous zone to moist evergreen zone. Nonetheless, there were no significant differences among the groups.

Percentage of Hydrogen at various the compartments (top, middle and base)



Shoot

Juvenile

Mature

Dead

Figure 4. 16 Percentage (%) of hydrogen contents of Bambusa vulgaris against culm's age

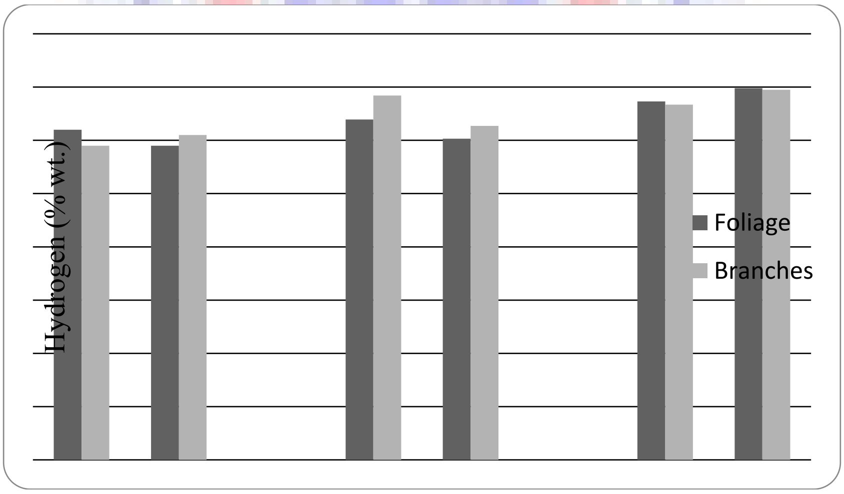


Figure 4.17 Percentage (%) of hydrogen contents Bambusa vulgaris branches and foliage

The highest percentage (%) weight hydrogen in the shoots was found in the moist evergreen zone, 7.18% at the base (Figure 4.16). The lowest hydrogen content of the shoot was found at the base (6.00%) at dry semi-deciduous zone. The hydrogen increased from the base to the top in dry semi-deciduous nevertheless, the moist evergreen zone followed the reversed. The highest hydrogen values among the juvenile culms were 6.05% to 6.42% located in the top (moist semi-deciduous) and middle (moist evergreen deciduous) respectively in the various compartments. The mature samples ranged from 6.07% located at the top portion of the bamboo found in moist evergreen zone. The dead culm also recorded 5.68% at the top found in dry semi-deciduous to 6.90% located at the top of the bamboo in moist semi-deciduous zone.

The percentage of hydrogen in green foliage increases from the dry semi-deciduous, across the Moist semi-deciduous to moist evergreen zones (Figure 4.17). The green foliage ranged from 6.20% to 6.73%. The dead foliage ranged from 5.90% dry semi-deciduous to 6.98% moist evergreen deciduous zone. The highest percentage of the green branches was recorded at dry semi-deciduous (5.90%) to moist semi-deciduous zone (6.84%). The dead samples recorded 6.10% (dry semi-deciduous) to 6.95% (moist evergreen deciduous) percentage of hydrogen.

4.3.4. Percentage (%) weight of Nitrogen concentrations in *Bambusa vulgaris* across the three across zones

The shoot from moist evergreen zone recorded the lowest mean nitrogen content at (0.65%) and the highest 2.52% from dry semi-deciduous zone (Table 4.19). Juvenile samples from moist semi-deciduous recorded the least value of nitrogen of 0.606% and dry semi-deciduous got 0.79%. The nitrogen concentration in juvenile was higher than that of the rest of the culms. The percentage weight of nitrogen for mature bamboo varies from 0.58% (moist evergreen) to 0.61% (dry semi-deciduous) and the dead samples ranged from 0.32% (moist semi-deciduous) to 0.58% (moist evergreen).

Table 4.19

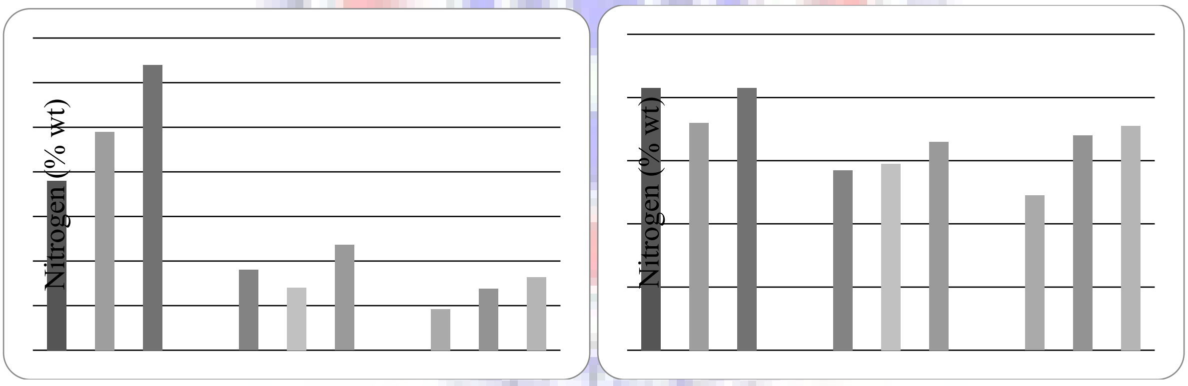
Percentage of nitrogen content of bamboo types and ecological zones

Items	Ecological zone			ANOVA	
	DSD	MSD	MED	*F-value*	*p- value*
Shoot	2.52±0.652	0.93±0.24	0.65±0.182	17.577	0.003
Juvenile	0.79±0.064	0.606±0.047	0.627±0.119	4.611	0.061
Mature	0.610±0.085	0.606±0.337	0.580±0.046	0.020	0.980
Dead	0.483 ± 0.081	0.320±0.056	0.58±0.046	9.056	0.015
Foliage	1.91± 1.05	2.07±1.310	1.90±0.51	0.926	0.390
Branches	0.52 ± 0.113	0.30±0.114	0.40±0.085	7.193	0.055

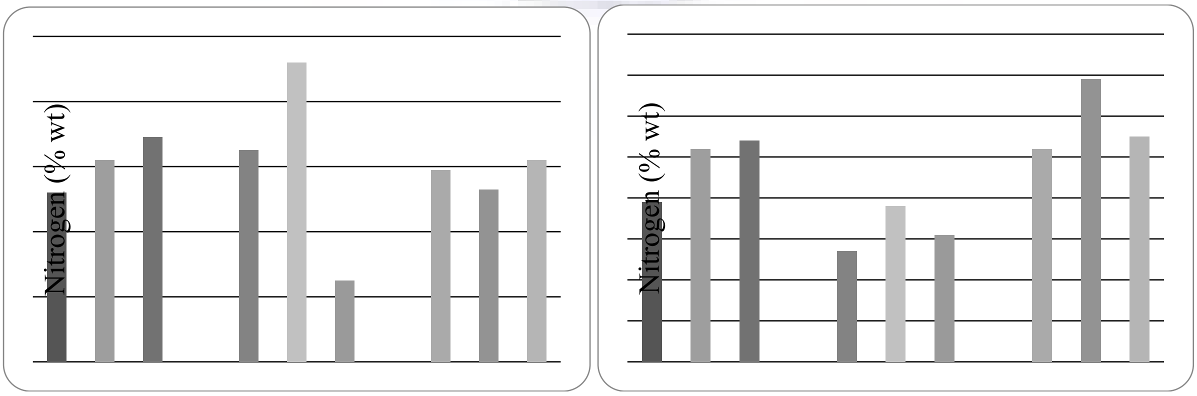
There were significant effects of amount of nitrogen on shoots (F = 17.577, p < .05) and the dead culm (F = 9.056, p < .05) of the bamboo.

The values of nitrogen for foliage and branches at different ecological zones, foliage ranges from 1.90 to 2.07% at moist evergreen and moist semi-deciduous respectively; and branches vary between 0.30 (moist semi-deciduous) and 0.52% (dry semi-deciduous). There was a significant difference among the branches at 5 percent probability.

Percentage of Nitrogen at various the compartments (top, middle and base)



Shoot Juvenile



Mature Dead

Figure 4. 18 Percentage (%) of nitrogen contents of Bambusa vulgaris against culm's age

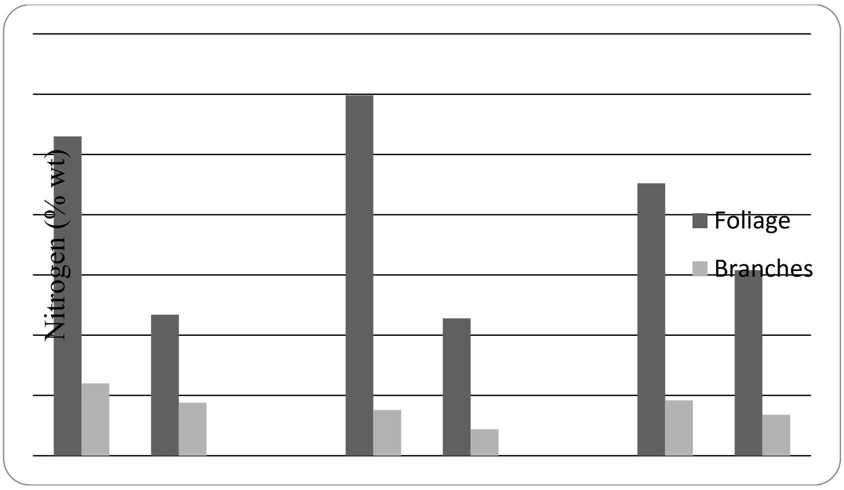


Figure 4.19 Percentage (%) of nitrogen contents Bambusa vulgaris branches and foliage

Among the various compartments the base part of the shoot recorded 0.49% nitrogen and the top (3.20%) at dry semi-deciduous. The lowest nitrogen content for the juvenile was found at the moist evergreen deciduous zone ranged from 0.49 (base) to 0.83% at both top and base (dry semi-deciduous). The mean of the mature bamboo samples ranged from 0.25% at the top from Moist semi-deciduous to 0.92% at both the middle portion of the bamboo in the moist evergreen deciduous zone. The highest value for the dead samples was recorded at the base (0.27%) whilst the lowest value was found at the middle (0.69%) at moist evergreen deciduous zone (Figure 4.18).

The foliage or the leaves exhibited the highest nitrogen contents in both green and dead state of the bamboo 2.99% in moist semi-deciduous, 2.65% in dry semi-deciduous zone and 2.26% in moist evergreen deciduous. The dead branches have smaller values as compare to the leaves 0.44 to 0.60% in dry semi-deciduous, 0.34 to 0.46% in moist evergreen and 0.22 to 0.38% in moist semi-deciduous (Figure 4.18).

4.3.5. The mean percentage weight of oxygen by calculation

The mean percentage value of oxygen and standard deviation of shoot was 40.20 ± 2.45, juvenile was 39.73 ± 1.79, mature was 41.04 ± 2.43, dead culm was 41.35 ± 4.05, foliage was 47.93 ± 3.64 and branches was 43.40 ± 2.85.

4.3.6. Relationships among the physical and ultimate properties of *Bambusa v. vulgaris* culms

Combustion analysis is part of a process intended to improve fuel economy, reduce undesirable exhaust emissions and improve the safety of fuel burning equipment (TSI Incorporated, 2004). The negative effects of some fuel properties will depend on the simultaneous presence of others. For example, the higher the moisture contents of a fuel, the lower the calorific values (Montaño, 2014).

Table 4.20 shows the correlation between the heating or calorific value and hydrogen was very strong and positive r = 0.755. The relationship between heating value and carbon was significant r = 0.724 and $p = 0.05$. There was intermediate negative correlation between heating value and the ash content r = -0.603 $p > 0.05$. There was a negative correlation between carbon content and the ash content r = -0.872 $p > 0.05$. The higher the percentage of carbon contents in the fuel the lower the ash content. The relationship between wet moisture content and dry moisture content has strong positive correlation r = 0.609 $p > 0.05$, Nitrogen is negatively related to basic density -0.755 and $p = 0.05$. This means that the more fuel the bamboo contains will take time to dry or season. There was a positive correlation between moisture content (wet) and basic density r = .145 and $p > 0.05$. The moisture content increases the weight of the bamboo. The wetter the bamboo the heavier it will be. Wet wood or bamboo produces more smoke (volatile matters) which is ineffective.

Table 4.20

Pearson's correlation test (p < 0.01 and 0.05) among Bambusa vulgaris' fuel properties.

Parameter	Ash (%wt)	Calorific value (MJkg-1)	Basic density (kg/m3)	Bulk density (kg/m3)	Moisture (wet) (%)	Moisture (dry) (%)	Carbon (%wt)	Hydrogen (%wt)
Calorific value	-0.605*							
Basic density	-0.041	0.512*						
Bulk density	0.174	0.05	0.347					
Moisture content (wet)	-0.064	-0.113	. 0.312	0.312				
Moisture content (dry)	-0.294	-0.415*	0.145	0.112	-0.755**			
Carbon	-0.872	0.724*	-0.263	0.322	-0.30	-0.294		
Hydrogen	0.003	0.755 **	-0.042	-0.01	-0.136	-0.386	0.179	
Nitrogen	0.016	0.133	-0.604*	-0.185	0.12	-0.045	0.029	0.045

** Correlation is significant at the 0.01 level (2-tailed)
 * Correlation is significant at the 0.05 level (2-tailed)

There was a positive relationship between moisture content (dry basis) and the calorific value r = .059 and $p > 0.05$. However, moisture content (wet) relates negatively with calorific value r = -.188 $p > 0.05$. There were variations between moisture contents (wet and dry bases) and ash content. There was negative correlation between moisture content (wet) and the ash content r = -.064 and $p > 0.05$ whilst the dry bamboo relates positive with ash content r = .330 and $p > 0.05$. These imply that the more moisture in the bamboo the less ash is produced. Probably most of the minerals in the bamboo are evaporated in the form of smoke and water vapour. The correlation between bulk density, wet moisture content and dry moisture content are negative r = - 0.312 $p > 0.05$. Bulk density with greater mass does not occupy more space. This is an important point because fuels with higher moisture contents will have greater masses and, therefore, have lower bulk densities (The Carbon Trust, 2009).

4.3.7. The volatile matter in *Bambusa vulgaris* across the three ecological zones

Generally, the samples from moist semi-deciduous zone recorded the highest values of volatile matter except the dead samples whilst dry semi-deciduous recorded the lowest values (Table 4.21). The mean volatile matter in the shoots ranged from 80.37 to 84.07%, juvenile rose from 83.47 to 86.06 %, mature from 82.10 to 85.74 % and the dead also recorded 80.00 to 86.33%. Post hoc comparisons using Tukey procedures were used to determine which pairs of the four group means differed. The results indicate that Juvenile (M = 84.56, SD = 1.54) got the highest value followed by Mature (M = 83.82, SD = 1.50) and dead (M = 83.38, SD = 2.25). The least value were recorded at the shoot (M = 82.82, SD = 1.85).

Table 4.21

Percentage of volatile matter of shoot, juvenile, mature and dead culms at different ecological zones

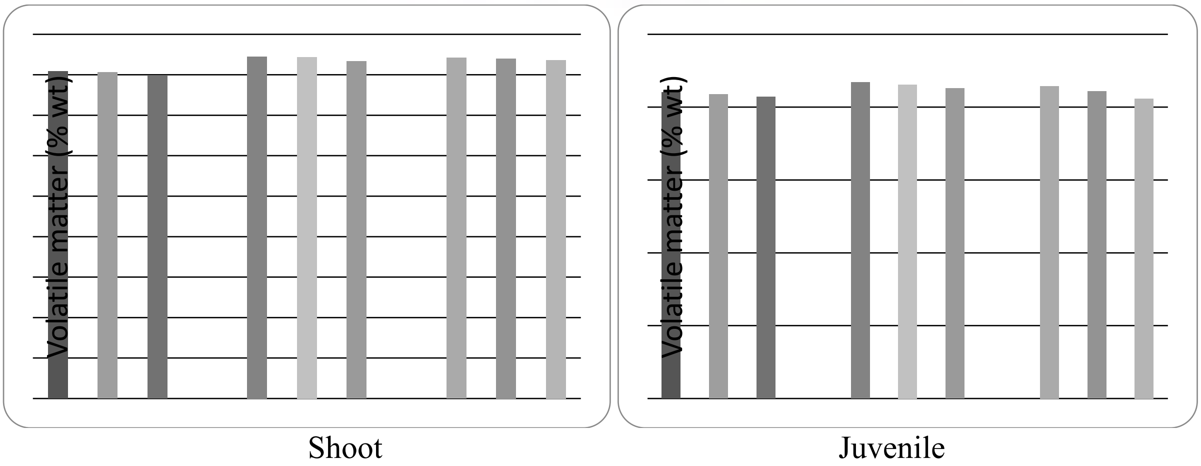
Items	Dry semi-deciduous	Moist semi-deciduous	Moist Evergreen	*F-value*	*p-value*
Shoot	80.37± 0.59	84.07± 0.66	83.95± 0.31	48.266	.000
Juvenile	83.47± 0.65	86.06± 0.81	84.15± 1.74	4.004	.079
Mature	82.10± 0.49	85.74± 0.15	83.29± 0.39	141.022	.000
Dead	82.39± 0.18	86.33± 0.18	80.00± 2.18	860.765	.000
Foliage	76.60± 0.000	71.10± 10.89	76.60± .000	1.324	.314
Branches	84.10± 1.131	82.80± 1.131	84.10± 1.131	0.301	.612

The means of volatile matter (%) in three ecological zones were unequal according to a one-way ANOVA, F (2, 33) = 24.696, p = .000. Pairwise comparisons of the means using Tukey's Honestly Significant Difference (HSD) procedure indicated dry semi-deciduous vs. moist semi-deciduous, moist semi-deciduous vs. dry semi-deciduous and moist evergreen, and moist evergreen vs. moist semi-deciduous were significant comparisons: Subjects in the moist semi-deciduous (M = 85.56) had more percentage volatile matter, followed by moist evergreen (M = 83.20) and then dry semi-deciduous (M = 82.18) reported that the tasks were significantly (p = .00), with a 95% confidence interval of the difference between means from dry semi-deciduous vs. moist semi-deciduous and moist semi-deciduous vs. dry semi-deciduous 2.2 to 4.6 and moist semi-deciduous vs. moist evergreen 1.1 to 3.6 points on a -5 to +5 scale. The other two comparisons were not significant (ps > .11).

Dry semi-deciduous and moist evergreen recorded the highest mean volatile matter of foliage (76.60%). The lowest mean value for foliage was found at moist semi-deciduous zone (71.10%). The results of volatile matter in the branches were as follows; dry semi-deciduous and moist evergreen zone obtained 84.10%, whilst moist semi-deciduous recorded the lowest mean volatile matter (82.80%). Meanwhile, there were no significant differences among the groups.

Percentage of volatile matter at various the compartments (top, middle and base)

The volatile matter decreases from the base to the top of the bamboo shoots to dead culms in all the ecological zones. The highest values of volatile matter were recorded at moist semi-deciduous (Figure 4.20). The mean values of volatile matter in shoots ranged from 79.83 (top) from dry semi-deciduous to 84.52% (base) at moist semi-deciduous. The juvenile culms recorded the highest volatile matter percentage weight in all the zones ranging from 86.80% (base portion at moist semi-deciduous) to 82.34% (top at moist evergreen-deciduous zone). The mature culms exhibited the following mean values; 82.32% found at the top in the dry semi-deciduous zone and the highest value 85.91% established at the base part in moist semi-deciduous zone. The dead or over-mature culms ranged from the top part, 81.37% (moist evergreen-deciduous) to base portion at 86.54% (moist semi-deciduous zone).



Shoot

Juvenile

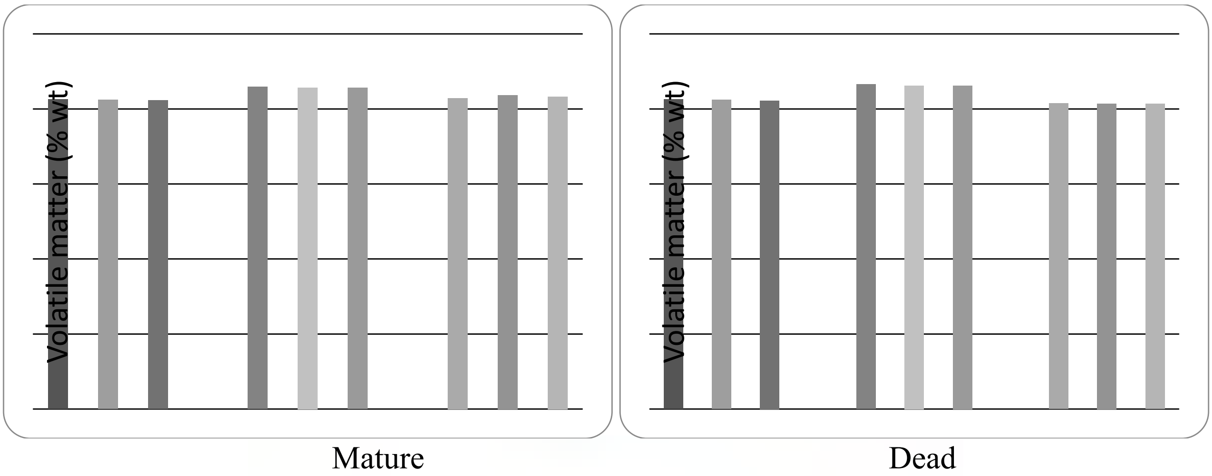


Figure 4.20 Variations of volatile matter with bamboo age groups in the three ecological zones

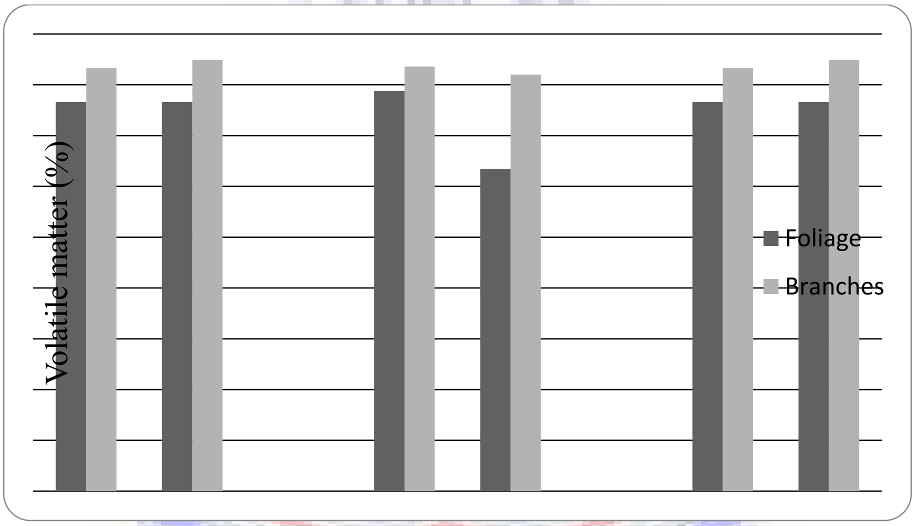


Figure 4.21 Variations of volatile matter contents Bambusa vulgaris branches and foliage

The volatile matter in the branches were greater than that of the foliage (Figure 4.21). The volatile matter in the green branches ranged from 83.6 % (moist semi-deciduous) to 83.3 % (in both moist evergreen and dry semi-deciduous), whilst the dead branches were between 84.9 % (in both dry semi-deciduous and moist evergreen) and 82.0 % (Moist semi-deciduous). The green and dead foliage (leaves) from both dry semi-deciduous and moist evergreen zones got similar values of 76.6 %. The highest value of the green foliage from moist semi-deciduous was slightly above the other values 78.8 % while the lowest average value 63.4 % was recorded at dead sample from moist semi-deciduous.

4.3.8: The Percentage (%) of Fixed Carbon in the *Bambusa vulgaris* Samples across the three ecological zones

Percentage (%) of fixed carbon contents of *Bambusa vulgaris*' shoot, juvenile, mature and dead culms increased from dry semi-deciduous zone to moist evergreen zone. The highest values of *Bambusa vulgaris* were recorded at the moist evergreen, followed by moist semi-deciduous and then dry semi-deciduous (Table 4.22). The shoots recorded highest mean values 15.34%, followed by (15.14%) and the lowest was 15.09%. The means values for juvenile varied from 13.88 to 14.40%, mature ranged 15.49 to 15.59% and the dead samples ranged from 15.85 to 16.14%. The mean values for shoots, juvenile and mature samples were statistically significant.

Table 4.22

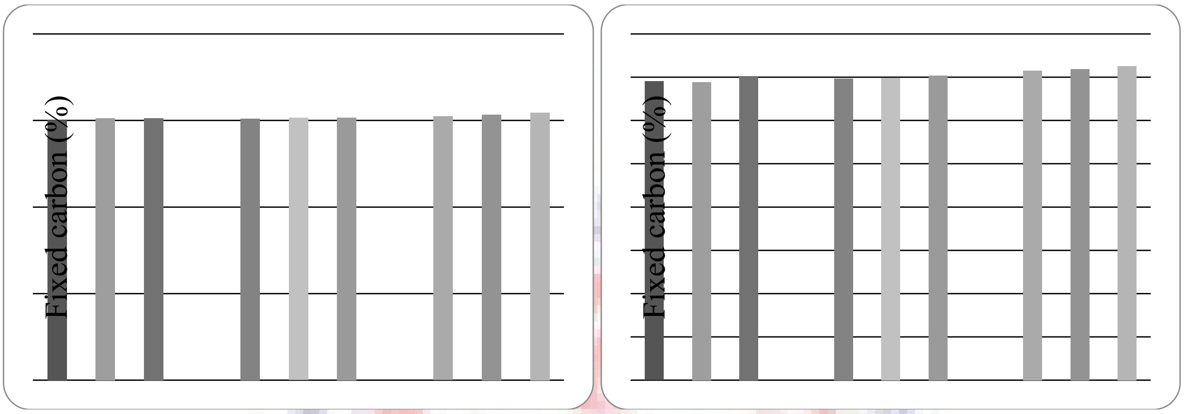
Percentage of fixed carbon of shoot, juvenile, mature and dead culms of Bambusa vulgaris at different ecological zones

Items	Ecological zone			ANOVA	
	DSD	MSD	MED	*F-value*	*p-value*
Shoot	15.09± 0. 07	15.14± 0.36	15.34± 0.11	9.157	0.015
Juvenile	13.88± 0.16	13.99± 0.79	14.40± 0.108	15.829	0.004
Mature	15.49± 0.30	15.51± 0.60	15.59± 0.020	5.143	0.050
Dead	15.85± 0.28	16.06± 0.026	16.14± 0.010	3.075	0.112
Foliage	13.95±.042	14.22± .042	14.34±.028	10.138	.033
Branches	14.75± .099	14.76± .042	14.76± .014	.393	.565

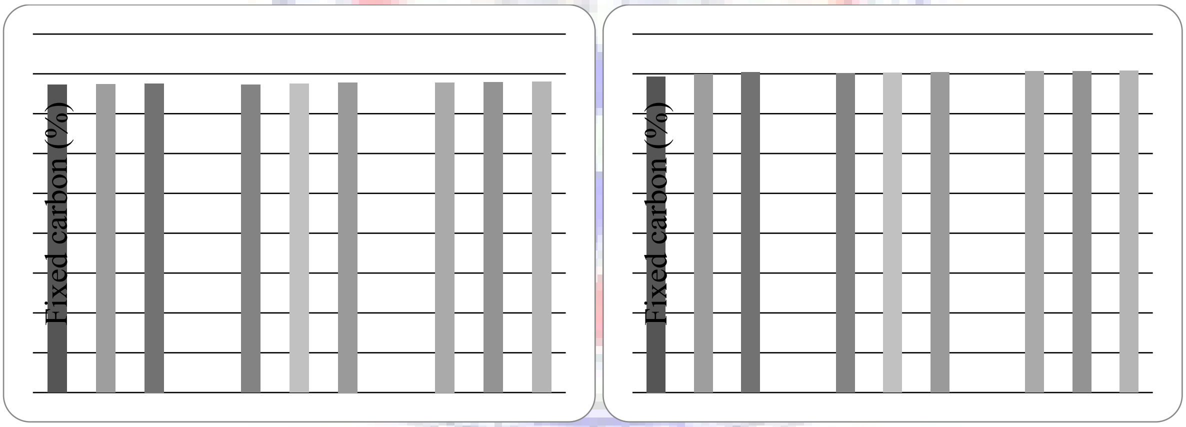
Table 4.22 shows one-way ANOVA of fixed carbon of foliage and branches of *Bambusa vulgaris* at three ecological zones in Ghana. The mean values of fixed carbon on the foliage increase from dry semi-deciduous (13.95%) to moist evergreen deciduous zones (14.34%). On the contrary, the mean values of the fixed carbon in the branches were different; dry semi-deciduous got the lowest value (14.75%) whilst moist semi-deciduous and moist evergreen got similar values (14.76%). This was a significant difference among the foliage of the bamboo across the three zones (F = 10.138, $p < .05$).

Percentage of fixed carbon at the various compartments (top, middle and base)

The highest mean fixed carbon of the culms was observed at the base portion of the dead bamboo in moist evergreen deciduous zones. The culms from the top of dead at dry semi-deciduous recorded the least value. The mean values of the various bamboo compartments decrease from the base to the top across all the zones. The shoot had (15.01% to 15.45%), juvenile (13.77% to 14.52%), mature (15.46% to 15.61%) and dead culms (15.87% to 16.15%) (Figure 4.22).



Shoot Juvenile



Mature Dead

Figure 4.22 Variations of fixed carbon contents Bambusa v. vulgaris

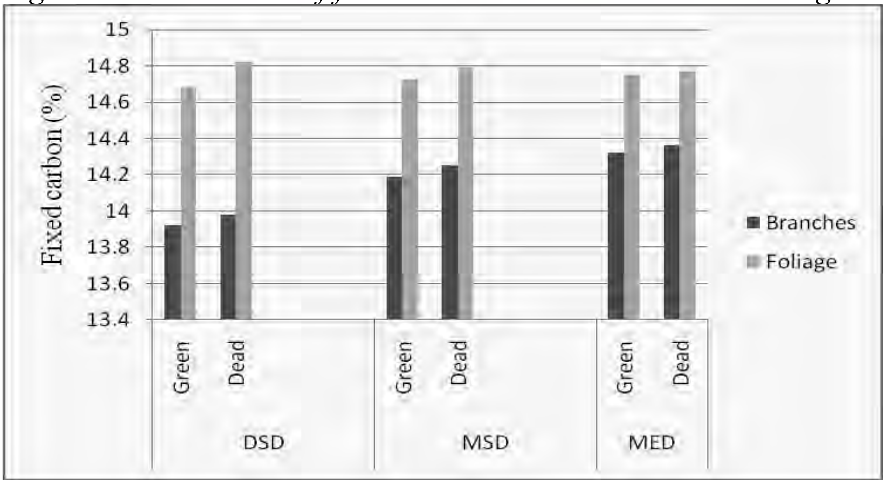


Figure 4.23 Percentage (%) of fixed carbon contents Bambusa vulgaris branches and foliage

The percentage (%) of fixed carbon contents of *Bambusa vulgaris*' foliage and branches increased from dry semi-deciduous zone to moist evergreen zone (Figure 4.23). The values for the branches varied slightly amongst the ecological zones. The green branches ranged from 13.92% to 14.32% and dead branches also ranged from 13.98% to 14.36%. The results of the fixed carbon (FC) for the *Bambusa vulgaris* green foliage ranged from 14.68% to 14.75% and the dead foliage from 14.82% to 14.77%.

4.3.9. Fuel characteristics of *Bambusa vulgaris* across the three ecological zones

The fuel characteristics of *bambusa vulgaris* in terms of ultimate analysis, proximate analysis, basic density, moisture content and calorific values was investigated (Table 4.23).

Table 4.23
Fuel characteristics of Bambusa vulgaris

	Ultimate analysis (%)				Proximate analysis (%)			BD (kgm^{-3})	MC (%)	CV ($MJkg^{-1}$)
	C	H	N	O	Ash	VMC	FCC			
Shoot	49.29 ± 1.50	6.56 ± 0.38	1.37 ± 0.90	40.20 ± 2.45	1.30 ± 2.52	82.23 ± 2.27	15.19 ± 1.17	413±13.16	161.54 ± 7.37	16.31 ± 0.49
Juvenile	51.88 ± 2.18	6.15 ± 0.18	0.67 ± 0.18	39.73 ± 1.79	1.81 ± 0.99	84.34 ± 1.27	14.09 ± 0.56	666±10.54	150.63 ± 8.85	17.19 ± 0.86
Mature	50.75 ± 2.15	6.47 ± 0.33	0.17 ± 0.03	41.04 ± 2.43	1.43 ± 0.70	83.33 ± 0.80	15.53 ± 0.30	722±14.50	131.32 ± 13.72	16.98 ± 0.82
Dead	49.97 ± 3.24	6.06 ± 0.37	0.14 ± 0.02	41.35 ± 4.05	1.88 ± 1.35	81.76 ± 1.48	16.06 ± 0.62	715±13.40	61.73 ± 6.94	16.59 ± 1.14
Foliage	43.75 ± 3.22	6.37 ± 0.39	1.96 ± 0.73	47.93 ± 3.64	3.40 ± 6.52	84.25 ± 1.13	14.76 ± 1.45	N/A	92.77 ± 3.54	12.82 ± 1.78
Branch	49.75 ± 2.55	6.45 ± 0.40	0.41 ± 0.12	43.40 ± 2.85	1.76 ± 1.04	75.72 ± 5.99	14.17 ± 0.16	N/A	33.70 ± 4.89	14.67 ± 1.26

VMC is volatile matter content; FCC is fixed carbon content; BD is basic density; MC is moisture content; CV is calorific value; N/A is not available

The mature culms exhibited the highest fuel yield, followed by dead culms in all the zones. The yardstick was based on positive attributes such as large fixed carbon, carbon, hydrogen, calorific value and high basic density. These were followed by relatively low amount of volatile matter, moisture content, oxygen, nitrogen and ash content which seem to decrease the fuel content in a substrate. The third and the fourth age groups were shoots and juvenile culms all are based on the positive and negative attributes of fuel properties. Among the mature bamboo parts, the branches showed higher fuel properties than the foliage/leaves. The leaves or foliage recorded the highest ash and mineral contents. This means the foliage may result in slagging, fouling and corrosion to the conversion plant. However, the values of the foliage were similar to some energy crops wheat straw and miscanthus.

4.4. Evaluate the concentrations of minor and heavy metals found in the *Bambusa v. vulgaris* age groups and how they affect human health and biofuel conversion technology plants

The ash mineral elements consist of heavy metals and minor metals. The heavy metals include copper, zinc, lead, arsenic, nickel and cadmium and the minor metals also include calcium, potassium, magnesium, phosphorus, sodium, aluminium and iron. The concentrations of heavy and minor metals were recorded in shoots, juvenile, mature and dead culms of *Bambusa vulgaris* at different ecological zones.

4.4.1: Evaluation of Heavy metals across the three ecological

The concentration of copper: The mean values of copper in the shoot, juvenile, mature and dead culms of *bambusa vulgaris* increased from dry semi- deciduous to moist evergreen zones (Table 4.24). The mean values for shoots were from 2.18*ppm* to 5.59*ppm,* juvenile from 1.50*ppm* to 7.48*ppm,* mature from 0.89*ppm* to 1.31*ppm* and dead culm from 1.52 to 4.79 *ppm.* On the other hand, the ANOVA report indicated that the values for shoot, juvenile and dead culms were significant. The shoot had (F = 11.837, $p < .05$), juvenile (F = 22.359*,* $p < .05$) and the dead culm (F = 8.922, $p = .016$).

Table 4.24

Concentration of copper in the shoot, juvenile, mature and dead culms of Bambusa vulgaris at different ecological zones

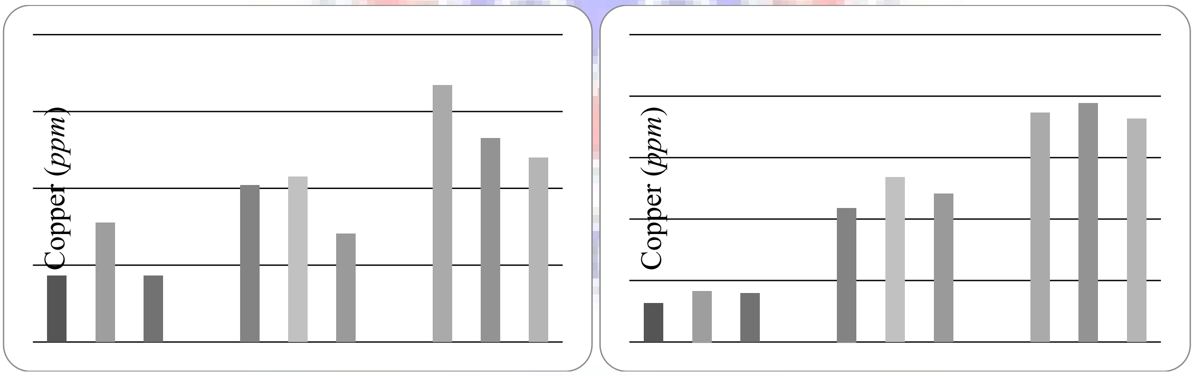
Items	Ecological zone			ANOVA	
	DSD	MSD	MED	*F-value*	*p-value*
Shoot	2.18± 0. 796	3.73± 0.799	5.59± 0.970	11.837	0.008
Juvenile	1.50± 0.212	4.85± 0.501	7.48± 0.252	22.359	0.000
Mature	0.89± 0.168	0.97± 0.600	1.31± 0.237	0.996	0.423

Dead	1.87± 0.197	2.52± 0.269	2.67± 0.027	8.922	0.016
Foliage	2.63± 1.970	3.92± 0.682	7.96± 0.481	6.934	.058
Branches	2.07± 0.099	2.19± 0.240	2.48± 0.085	.717	.445

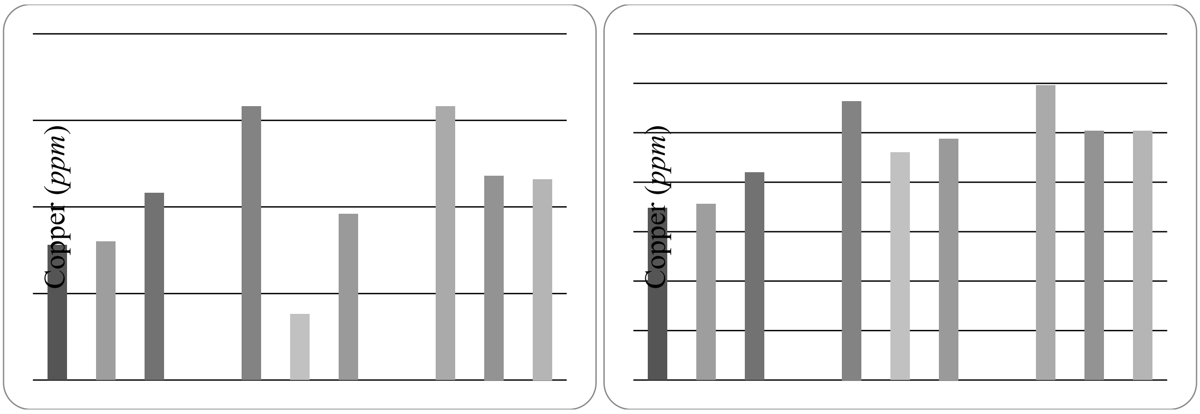
The mean copper concentration in the foliage and branches increased from dry semi-deciduous to moist evergreen deciduous. The mean foliage varied from 2.63*ppm* to 7.96*ppm* and branches ranged from 2.07*ppm* to 2.48*ppm*. There were no significant difference among the foliage and branches.

Concentration of copper at various the compartments (top, middle and base)

Apart from the mature samples which had its lowest value from the moist semi-deciduous, the rest of the mean copper concentrations of the bamboo rose from the dry semi-deciduous zone to moist evergreen zones (Figure 4.24). The shoots ranged from 1.72*ppm* (top and base) to 6.68*ppm* (base), juvenile ranged from 1.26 (base) to 7.76*ppm* (middle), mature culms ranged 0.38*ppm* from the middle portion to 1.58ppm (base) for both dry semi-deciduous and moist evergreen zones.



Shoot Juvenile



Mature Dead

Figure 4.24 Variations of copper with bamboo age groups in the three ecological zones

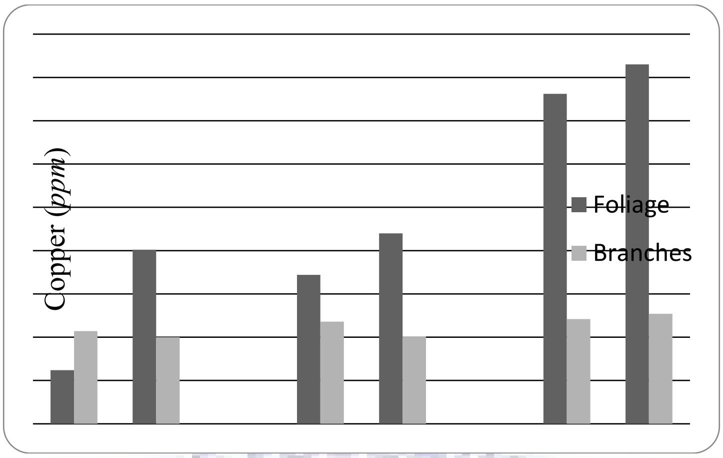


Figure 4.25 Variations of copper contents Bambusa vulgaris branches and foliage

The copper samples for both branches and the foliage increased from dry semi-deciduous zone to moist evergreen zone (Figure 4.25). The mean concentration of copper in the green branches ranged from 1.24 to 2.42*ppm* and the dead branches ranged from 2.00*ppm* to 2.54*ppm*. The green foliage or leaves from 1.24 to 7.62*ppm*. The dead foliage ranged from 4.02 to 8.30*ppm*.

The concentration of Zinc: One-way ANOVA test shows the mean concentration of zinc in *Bambusa* v. *vulgaris* at various age groups in three ecological zones in Ghana (Table 4.25). The mean zinc concentration increased from dry semi-deciduous to moist evergreen zones, with except the mature samples at moist semi-deciduous. The mean values of zinc concentration in the shoot ranged from 13.16 to 3.90*ppm*, juvenile from 3.30 to 4.87*ppm*, the mature culm from 3.25*ppm* (moist evergreen) to 2.74*ppm* (dry semi-deciduous) and dead culm had 3.44 to 3.71*ppm*.

Table 4.25

Concentration of zinc in shoot, juvenile, mature and dead culms of Bambusa v. vulgaris at different ecological zones

Item	Dry semi-deciduous	Moist semi-deciduous	Moist Evergreen	*p-value*
Shoot	3.16± 0. 648	3.41± 0.960	3.90± 1.191	0.650
Juvenile	3.30± 0.156	3.87± 0.352	4.87± 1.015	0.057
Mature	2.74± 0.847	2.36± 0.872	3.25± 0.114	0.366
Dead	3.44± 0.868	3.58± 0.642	3.71± 0.580	0.901
Foliage	2.26± 0.311	2.76± 0.707	2.95± 0.750	0.821
Branches	3.03± 1.683	3.26± 1.160	3.36± 1.188	0.751

The mean values for foliage and branches ranged from dry semi-deciduous to moist evergreen zone. The foliage obtained the mean value from 2.26 to 2.95*ppm* and that of branches ranged from 3.03 to 3.36*ppm*. There were no significant difference among both foliage and branches.

Concentration of zinc at various the compartments (top, middle and base)

The highest average concentrations of zinc from various compartments are seen from Figure 4.26. The mean shoot ranged from 2.34 (middle part) to 5.20 *ppm* (base) at moist semi-deciduous and moist evergreen zone respectively. The mean juvenile varied from 3.12*ppm* (top) to 5.82*ppm* (middle) at dry semi-deciduous and the moist evergreen zone respectively. The mean matured culms ranged from 1.36 *ppm* (top) at moist semi-deciduous to 3.70*ppm* (top) dry semi-deciduous zone. The dead samples ranged from 2.44*ppm* (middle) at the dry semi-deciduous to 4.28*ppm* (middle) at both moist semi-deciduous and moist evergreen zones.

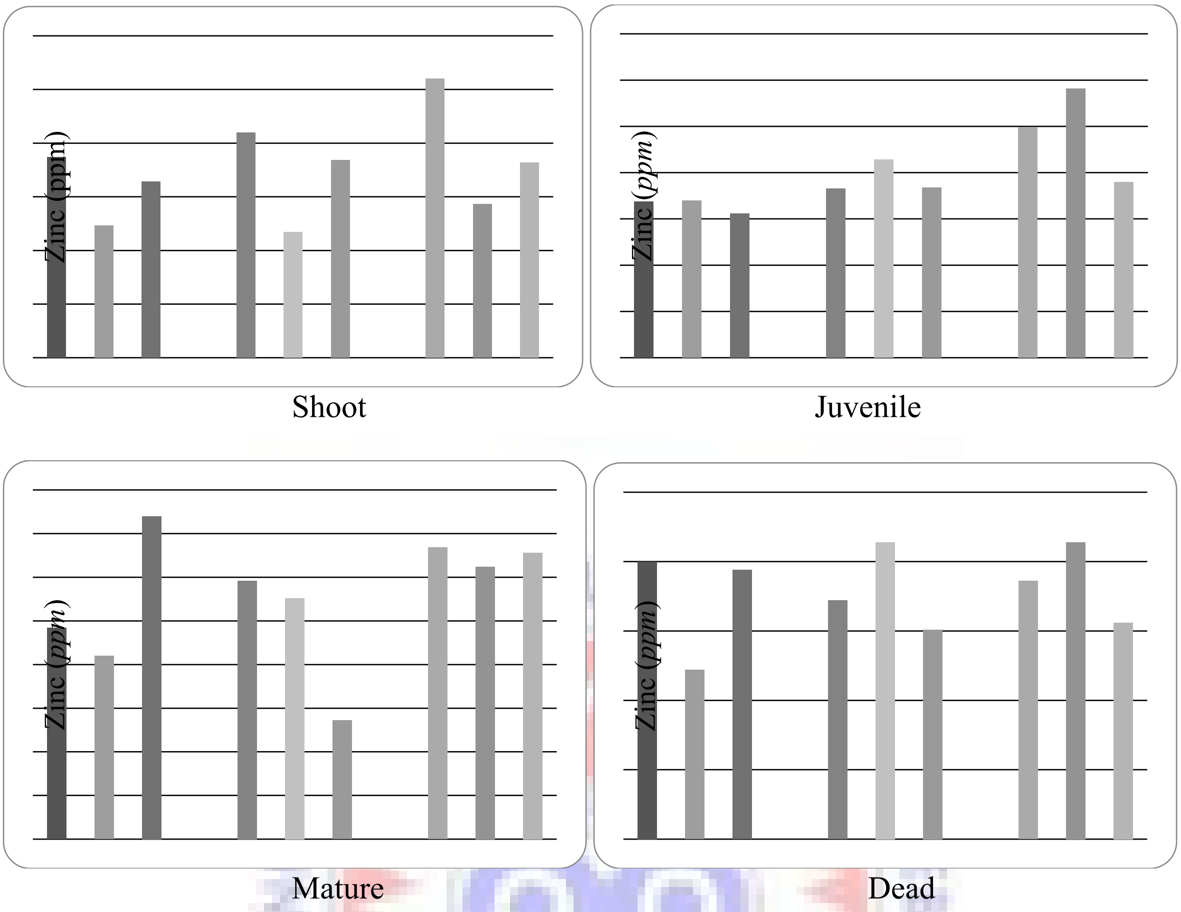


Figure 4.26 Variations of zinc with bamboo age groups in the three ecological zones

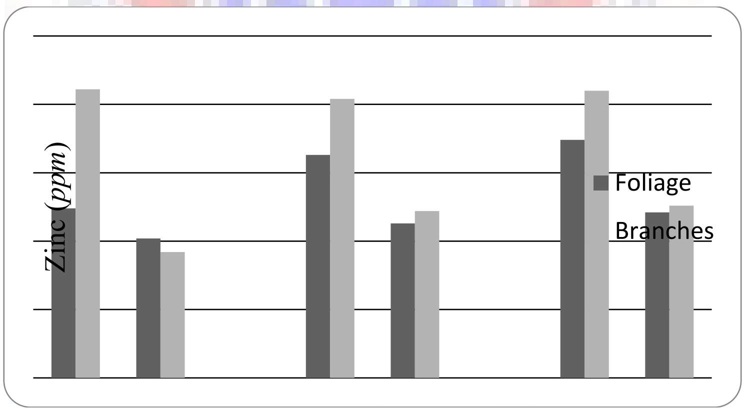


Figure 4.27 Variations of zinc contents Bambusa vulgaris branches and foliage

The green branches recorded the highest values of zinc from 4.08*ppm* at moist semi-deciduous to 4.22*ppm* in the moist semi-deciduous and dry semi-deciduous zone respectively. The dead branches varied from 1.84 *ppm* (dry semi-deciduous) to 2.52 *ppm* in the dry semi-deciduous and moist evergreen zone respectively. The mean green foliage ranged from 2.48*ppm* (dry semi-deciduous) to 3.48*ppm* (moist evergreen) and the dead ranged from 2.04*ppm* at dry semi-deciduous to 2.42*ppm* at moist evergreen zone (Figure 4.27).

The concentration of lead values increased from dry semi-deciduous zone to moist evergreen zone amongst all the bamboo age groups (Table 4.26). The lead concentration in the shoot ranged from 0.023 to 0.103 *ppm*, juvenile from 0.027 to 0.060 *ppm* and dead bamboo samples from 0.017 to 0.040 *ppm*. These rose from dry semi-deciduous to moist evergreen deciduous zone. However, the average values for mature culms recorded for both dry semi-deciduous and moist semi-deciduous were similar (0.010*ppm*). Among the bamboo types only the mature culm was statistically significant (F = 7.692, $p = 0.022$).

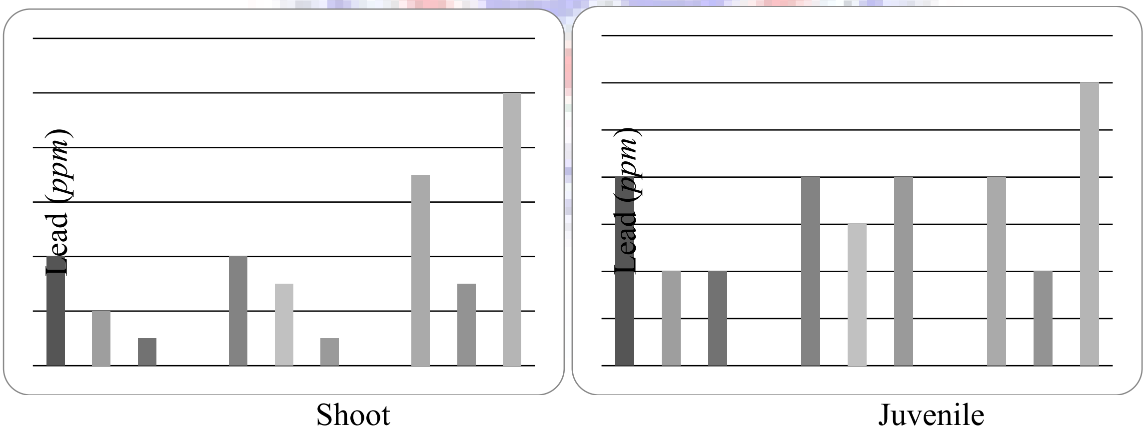
Table 4.26

Concentration of lead in shoot, juvenile, mature and dead culms of Bambusa vulgaris at different ecological zones

Item	Dry semi-deciduous	Moist semi-deciduous	Moist Evergreen	*F-value*	*p-value*
Shoot	0.023± 0. 015	0.027± 0.015	0.103± 0.094	1.961	0.221
Juvenile	0.027± 0.012	0.037± 0.006	0.060± 0.053	0.888	0.460
Mature	0.010± 0.000	0.010± 0.000	0.077± 0.042	7.692	0.022
Dead	0.017± 0.006	0.023± 0.015	0.040± 0.010	3.545	0.096
Foliage	0.02± 0.014	0.02± 0.014	0.08± 0.021	5.452	0.080
Branches	0.03± 0.007	0.02± 0.007	0.04± 0.021	0.071	0.802

The highest mean value of lead in foliage was found in moist evergreen zone (0.08*ppm*) and both dry semi-deciduous and moist semi-deciduous had similar values of 0.02*ppm*. Meanwhile, the highest average value for the branches were found in moist evergreen zone (0.04*ppm*), followed by dry semi-deciduous (0.03*ppm*) and then moist semi-deciduous (0.02*ppm*). The values were not statistically significant.

Concentration of lead at various the compartments (top, middle and base)



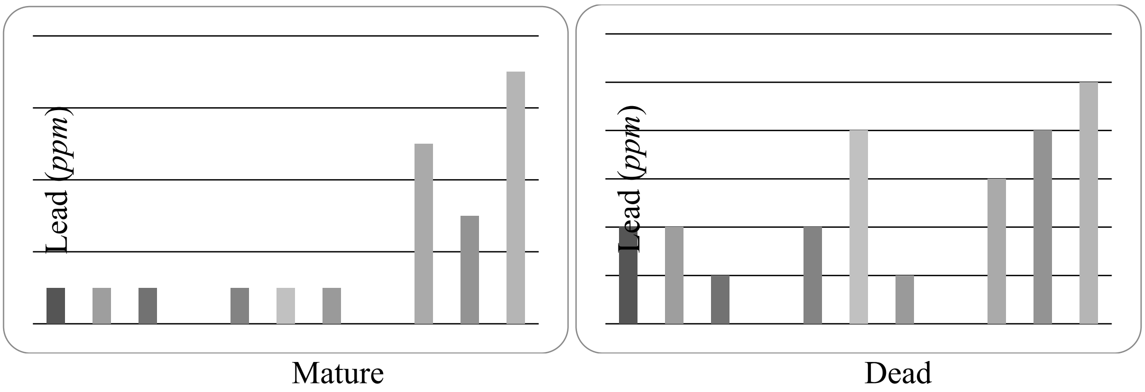


Figure 4.28 Variations of lead contents of Bambusa vulgaris against culm's age

The highest mean lead values were recorded at moist evergreen-deciduous amongst all the age groups. The shoot ranged from 0.01 (dry semi- deciduous) to 0.10 *ppm* (moist evergreen), juvenile varies from 0.02*ppm* (dry semi-deciduous) to 0.06*ppm* (moist evergreen zone).

The mature ranged from 0.01 (dry semi- deciduous) to 0.07 *ppm* (moist evergreen), dead varies from 0.01*ppm* (dry semi-deciduous) to 0.05*ppm* (moist evergreen zone).

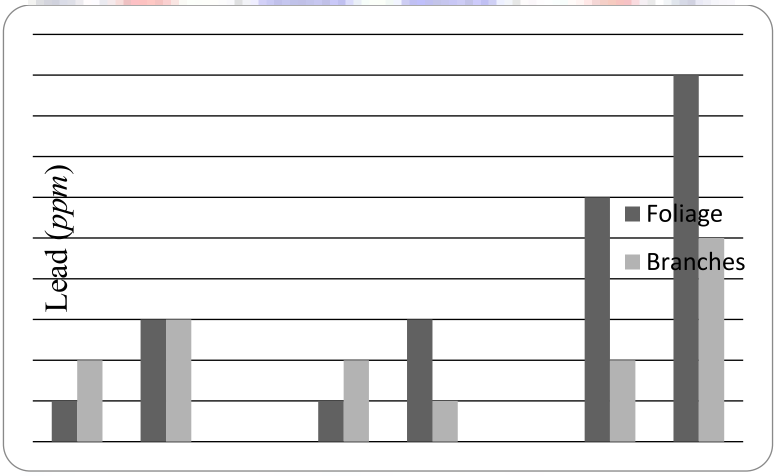


Figure 4.29 Variations of lead contents Bambusa vulgaris branches and foliage

The levels of lead in foliage range from 0.01*ppm* (green) found in both dry semi-deciduous and moist semi-deciduous zones to 0.06*ppm* at moist evergreen deciduous (Figure 4.29). The dead samples of the foliage ranged from 0.02*ppm* found at dry semi- deciduous to 0.09*ppm* at moist evergreen deciduous. All the three zones recorded 0.02ppm for the green branches, while the dead samples recorded 0.01*ppm* at moist semi-deciduous to 0.09*ppm* at moist evergreen zone.

Concentration of arsenic at various the ecological zones

The average arsenic values for both dry semi-deciduous and moist semi-deciduous for shoot, mature and the dead samples were equal. However, the shoot ranged from 0.070 to 0.072 *ppm*, juvenile varies from 0.055*ppm* (dry semi-deciduous) to 0.078*ppm* (moist evergreen zone). The mean arsenic values of the mature samples ranged from 0.070 to 0.073*ppm*. The one-way ANOVA (Table 4.27) again recorded an interesting value the dead samples, all the ecological zones got the value of 0.078*ppm*. The arsenic concentrations for the three zones were from 0.055 to 0.078*ppm*. The bamboo age groups do not differ significantly from each other.

Table 4.27

Concentration of arsenic (ppm) in shoot, juvenile, mature and dead culms of Bambusa vulgaris at different ecological zones

Item	Dry semi-deciduous	Moist semi-deciduous	Moist Evergreen deciduous	*F-value*	*p-value*
Shoot	0.072± 0.004	0.072± 0.001	0.070± 0.000	0.463	0.478
Juvenile	0.055± 0.023	0.073± 0.004	0.078± 0.002	2.579	0.155
Mature	0.073± 0.008	0.073± 0.006	0.070± 0.009	0.168	0.849
Dead	0.078± 0.003	0.078± 0.002	0.078± 0.003	0.048	0.953
Foliage	0.08± 0.007	0.11± 0.000	0.05± 0.014	0.481	0.526
Branches	0.08± 0.000	0.08± 0.000	0.08± 0.000		

The mean values of foliage in arsenic ranged from 0.05*ppm* (moist semi-deciduous) to 0.11*ppm* (moist semi-deciduous) (Table 4.28). The branches in all the three zones recorded similar mean values of 0.08*ppm*.

Concentration of arsenic at various the compartments (top, middle and base)

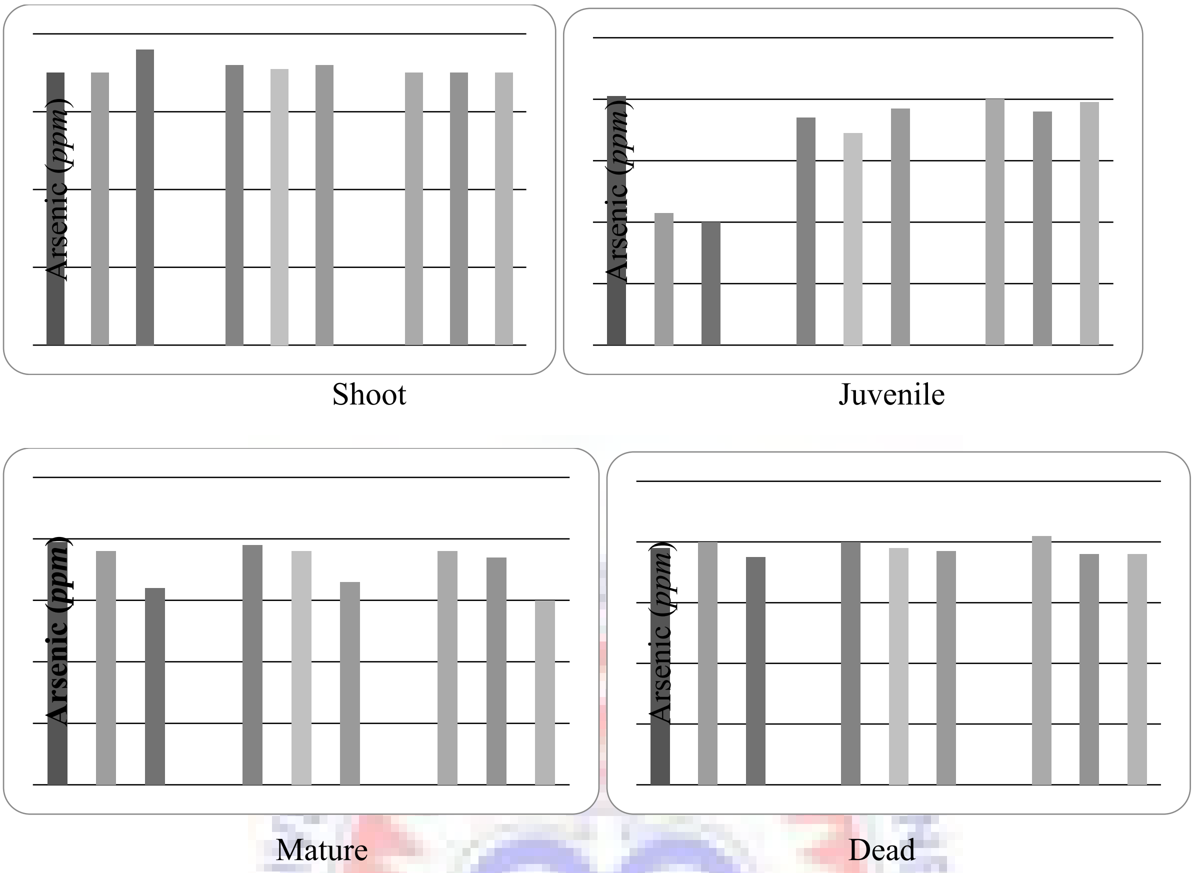


Figure 4.30 Variations of arsenic contents of Bambusa vulgaris against culm's age

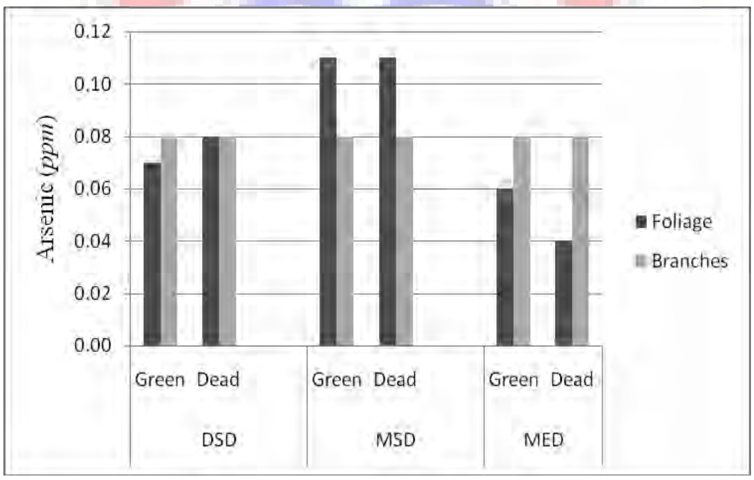


Figure 4.31 Variations of arsenic contents Bambusa vulgaris branches and foliage

The average concentrations of arsenic from various compartments are shown in Figure 4.30. Samples obtained from the shoots varied marginally in arsenic concentration from 0.07*ppm* (middle and base parts) at dry semi-deciduous and (top, middle and base) at moist evergreen to 0.076*ppm* (base) at dry semi-deciduous. The mean juvenile varied from 0.04*ppm* (top) to

0.081*ppm* (base) both located at the moist evergreen zone. The mean matured culms ranged from 0.060*ppm* (top) at moist evergreen deciduous to 0.079*ppm* (base) located at dry semi-deciduous. The dead samples ranged from 0.075*ppm* (top) at the dry semi-deciduous to 0.082*ppm* (base) at moist evergreen zones.

The arsenic contents in *Bambusa vulgaris* green foliage ranged from 0.06 to 0.11 *ppm* and the dead foliage ranged from 0.04 to 0.11 *ppm* (Figure 4.31). Both the green and the dead branches have similar values of 0.08 *ppm*. The highest value was found in both green and dead foliage at moist semi-deciduous with similar value of 0.11 *ppm*. It was followed by dead foliage (0.08 *ppm*) and green (0.07 *ppm*) at dry semi-deciduous zone. The lowest values for both green (0.06 *ppm*) and dead (0.04 *ppm*) foliage were found in moist evergreen zone. Meanwhile, all the branches both green and dead in all the zones recorded the average values of 0.08 *ppm*.

The concentration of Nickel in *Bambusa vulgaris* across the three ecological zones

There were low concentrations of nickel in the moist semi-deciduous zone and the highest concentration was found in moist evergreen. The shoot and juvenile samples of nickel have the lowest values from moist semi-deciduous zone and the highest values were found in moist evergreen zone (Table 4.28). The mean values of the mature and dead samples of nickel also increase from dry semi-deciduous to moist evergreen zones. The shoot varied between 0.40 *ppm* from moist semi-deciduous and 0.64 *ppm* located at moist evergreen zone. The juvenile ranged from 0.55*ppm* (moist semi-deciduous) to 0.77*ppm* (moist evergreen); mature recorded 0.49 (dry semi-deciduous) to 0.82 *ppm* (moist evergreen) and dead samples, 0.43 (dry semi-deciduous) to 0.85 *ppm* (moist evergreen). The average nickel concentrations ranged 0.40 to 0.85 *ppm*. It can be observed from the one-way ANOVA (Table 4.28), the bamboo age group does not differ significantly from each other in the ecological zones, but the dead culm group is significantly different from the ecological zones.

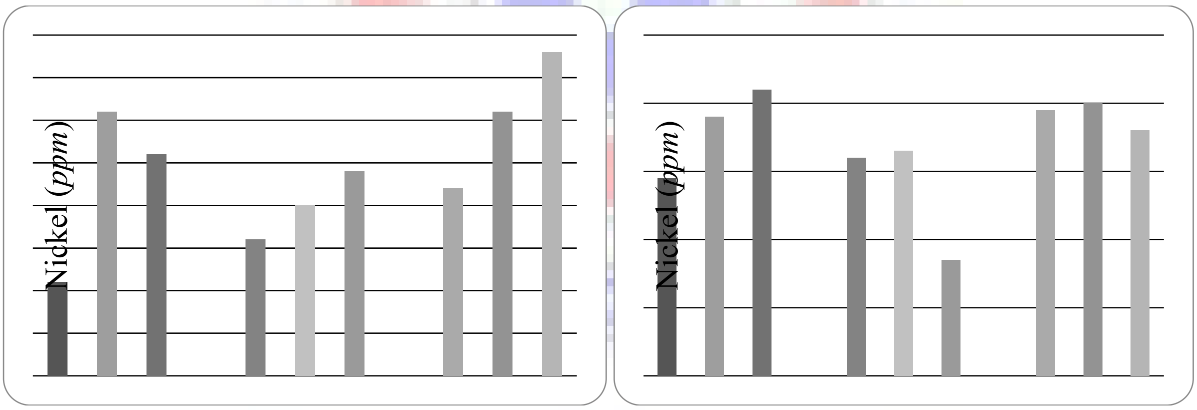
Table 4.28

Concentration of nickel in shoot, juvenile, mature and dead culms of Bambusa vulgaris at different ecological zones

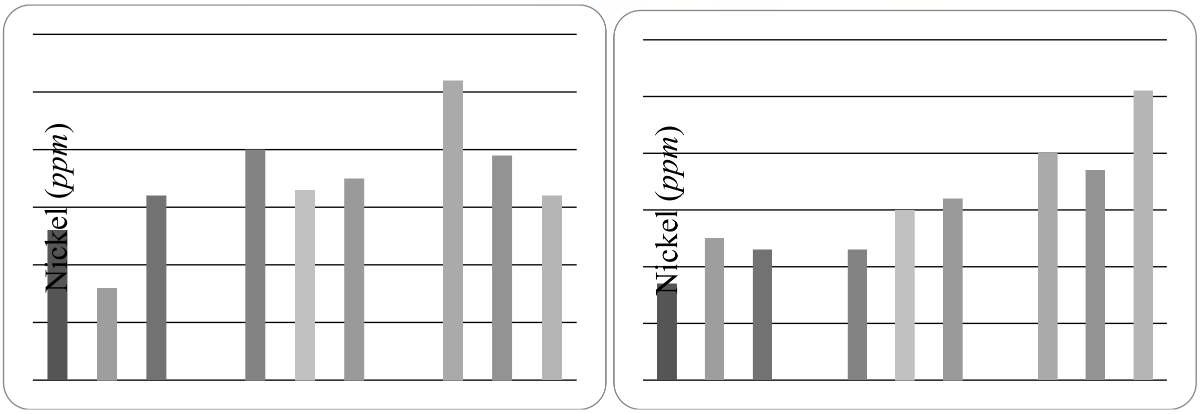
Items	Dry semi-deciduous	Moist semi-deciduous	Moist Evergreen	*F-value*	*p-value*
Shoot	0.45± 0. 208	0.40± 0.080	0.64± 0.211	1.518	0.293
Juvenile	0.73± 0.133	0.55± 0.179	0.77± 0.042	2.395	0.172
Mature	0.49± 0.162	0.72± 0.072	0.82± 0.203	3.476	0.990
Dead	0.43± 0.083	0.57± 0.094	0.85± 0.147	1.025	0.010
Foliage	0.75± 0.127	1.19± 0.297	1.33± 0.212	16.687	0.015
Branches	0.84± 0.339	1.08± 0.113	1.15± 0.269	0.521	0.510

The mean values for nickel in foliage and branches of the three zones are recorded in Table 4.29. The mean values of foliage increased from dry semi-deciduous (0.75*ppm*) to moist semi-deciduous (1.33*ppm*), similarly, the mean values of the branches rose from dry semi-deciduous (0.84*ppm*) to moist evergreen (1.15*ppm*). The significant difference among the foliage of the bamboo across the three zones by one-way ANOVA (F = 16.687, p < .05).

Concentration of nickel at various the compartments (top, middle and base)



Shoot Juvenile



Mature Dead samples

Figure 4.30 Variations of nickel contents of Bambusa vulgaris against culm's age

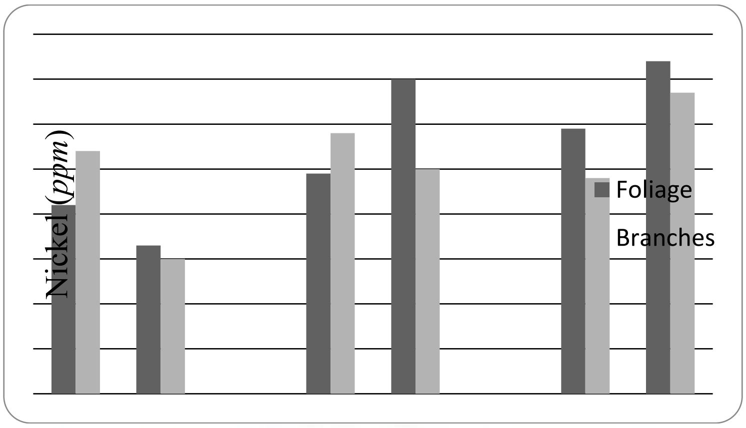


Figure 4.32 Variations of nickel contents Bambusa vulgaris branches and foliage

The average concentrations of nickel from various compartments are shown in Figure 4.31. The highest concentration of nickel was recorded ant the mature (1.04*ppm*) located at the base in moist evergreen zone whilst the lowest was recorded at base of the shoot (0.22 *ppm*) located at the base in dry semi-deciduous zone. Samples obtained from the shoots varied marginally in nickel concentration from 0.22*ppm* (base) to 0.86*ppm* (top) at dry semi-deciduous. The mean juvenile varied from 0.34*ppm* (top) found at moist semi-deciduous to 0.84*ppm* (top) both located at the dry semi-deciduous zone. The mean matured culms ranged from 0.32*ppm* (middle) at dry semi-deciduous to 1.04*ppm* (base) located at moist evergreen deciduous. The dead samples ranged from 0.34*ppm* (base) at the dry semi-deciduous to 1.02*ppm* (top) at moist evergreen zones.

The dead foliage or leaves samples exhibited both the highest (1.48 *ppm*) and lowest (0.60 *ppm*) values of nickel in the Moist evergreen and Dry semi-deciduous zones respectively (Figure 4.31). Similarly, dead branches got both the highest (1.34 *ppm*) and lowest (0.66 *ppm*) values recorded from Moist evergreen and Dry semi-deciduous respectively. The mean values of nickel recorded in the green branches ranged from 0.96*ppm* (moist evergreen deciduous) to 1.16*ppm* (moist semi-deciduous). The mean values of the dead branches varied from 0.60*ppm* (dry semi-deciduous) to 1.34*ppm* in the moist evergreen deciduous zone. The mean green foliage ranged from 0.84*ppm* (dry semi-deciduous) to 1.18*ppm* (moist evergreen) and the dead foliage ranged from 0.66*ppm* at dry semi-deciduous zone to 1.48*ppm* at moist evergreen.

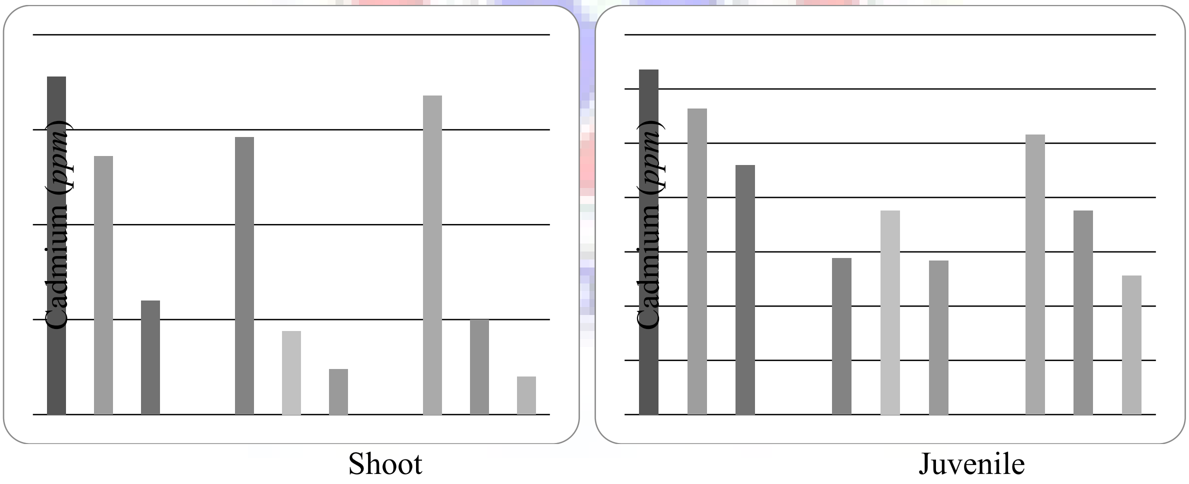
The concentration of Cadmium in *Bambusa v. vulgaris:* The mean concentrations of cadmium in the shoot, juvenile, mature and dead culms of *Bambusa vulgaris* at different ecological zones is illustrated in Table 4.29. Dry semi-deciduous zone recorded the highest values of cadmium in all the zones. The lowest values found in shoot and juvenile were located at moist semi-deciduous zone. On the contrary, the lowest concentrations for mature and dead were found in moist evergreen deciduous zone. Meanwhile, the shoot ranged from 0.71*ppm* (moist semi-deciduous) to 1.25*ppm* (dry semi-deciduous), juvenile from 1.58*ppm* (moist semi-deciduous) to 2.77*ppm* (dry semi-deciduous), mature from 0.81 (moist evergreen) to 3.66 *ppm* (dry semi-deciduous) and dead 2.15 (moist evergreen) to 4.21 *ppm* (dry semi-deciduous). The mean cadmium concentration for the three zones ranged from 0.71 to 4.21*ppm*. Nevertheless, the cadmium concentrations did not significantly differ from each other in the three ecological zones.

Table 4.29
Concentration of cadmium in shoot, juvenile, mature and dead culms of Bambusa vulgaris at different ecological zones

Item	Dry semi-deciduous	Moist semi-deciduous	Moist Evergreen deciduous	*F-value*	*p-value*
Shoot	1.25± 0.598	0.71± 0.654	0.79±0.782	0.533	0.612
Juvenile	2.77± 0.442	1.58± 0.260	1.91± 0.651	4.910	0.055
Mature	3.66± 0.200	2.27± 0.430	0.81± 0.417	0.676	0.497
Dead	4.21± 0.468	2.29± 0.335	2.15± 0.273	0.009	0.932
Foliage	2.50± 0.000	2.22± 0.283	2.26± 0.311	0.016	0.906
Branches	1.40± 0.198	2.03± 0.863	1.85± 1.457	0.021	0.893

The highest mean value of cadmium in the foliage was found in the dry semi-deciduous (2.50*ppm*) and the least in moist semi-deciduous (2.22*ppm*). Table 4.30 indicated that branches have the following values; dry semi-deciduous (1.40*ppm*), moist evergreen (1.85*ppm*) and the highest at moist semi-deciduous (2.03*ppm*). The values were not significant.

Concentration of cadmium at various the compartments (top, middle and base)



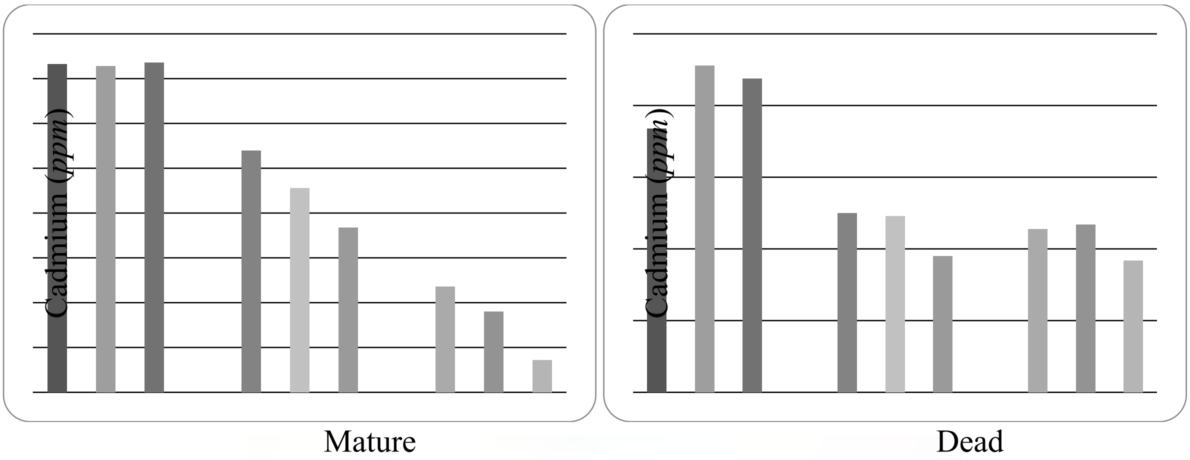


Figure 4.34 Variations of cadmium contents of Bambusa vulgaris against culm's age

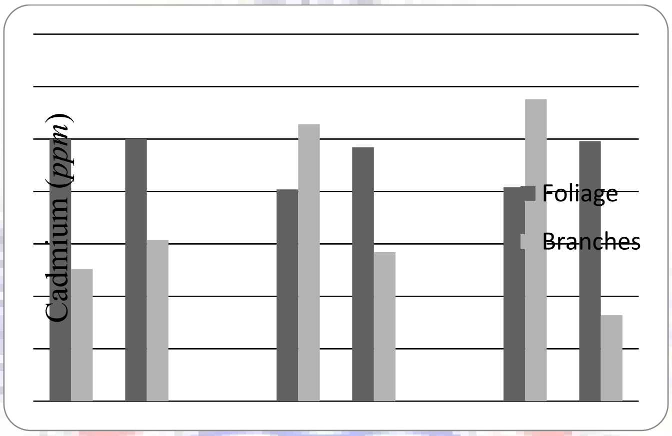


Figure 4.35 Variations of cadmium contents Bambusa vulgaris branches and foliage

The highest values were found in the dry semi-deciduous zone and the lowest at the tops of moist evergreen zone. The highest mean values of cadmium in the mature samples were found at the top whilst the highest mean values of the shoot, juvenile and the dead samples were located at the bottom of the bamboo culms. The mean concentrations of cadmium of the bamboo shoots increase from top (0.20*ppm*) to base (1.78*ppm*) at moist evergreen and dry semi-deciduous respectively. Juvenile recorded 1.28*ppm* (moist evergreen) to 3.18*ppm* (dry semi-deciduous). Mature culms recorded 0.36*ppm* (moist evergreen) to 3.68*ppm* (dry semi-deciduous). The dead samples obtained 1.84*ppm* from moist evergreen to 3.68*ppm* (Figure 4.34).

The green foliage recorded 2.02*ppm* (moist semi-deciduous) to 2.50*ppm* (dry semi-deciduous). Dead foliage had 2.42*ppm* (moist semi-deciduous) to 2.50*ppm* (dry semi-deciduous).

The green branches of the mature culm recorded 1.26*ppm* at dry semi-deciduous to 2.88*ppm* at moist evergreen deciduous zone. The dead branches obtained 0.82*ppm* at moist evergreen deciduous to 1.54*ppm* from dry semi-deciduous zone.

4.4.2. Evaluation of minor metals across the three ecological across the three ecological zones

Concentration of Calcium in *Bambusa v. vulgaris:* Apart from the mature samples which recorded the different values from dry semi-deciduous and moist semi-deciduous, the rest of the values at both dry semi-deciduous and moist semi-deciduous samples got the same values for shoot, juvenile and dead bamboos samples. Moist evergreen deciduous zone had the lowest concentration of calcium amongst all the ecological zones. The mean concentrations of calcium of the shoots were 17.67*ppm* from moist evergreen) to 28.66*ppm* for both dry semi-deciduous and moist semi-deciduous zones. Juvenile also recorded 17.20*ppm* (moist evergreen) to 26.47*ppm* (dry semi-deciduous and moist semi-deciduous). The mature culms ranged from 16.70*ppm* (moist evergreen) to 26.49*ppm* (dry semi-deciduous). The dead samples ranged from 17.48*ppm* (moist evergreen) to 26.95*ppm* (dry semi-deciduous). The mean calcium concentration in *Bambusa vulgaris* ranged from 16.70 to 28.66 *ppm* across the three ecological zones (Table 4.30).

Table 4.30

The mean concentration of calcium in shoot, juvenile, mature and dead culms of Bambusa vulgaris at different ecological zones

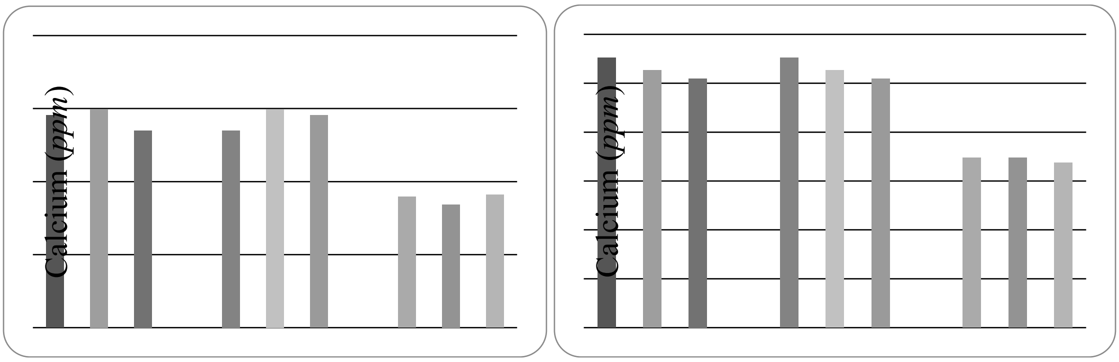
Items	Dry semi-deciduous	Moist semi-deciduous	Moist Evergreen	*F-value*	*p-value*
Shoot	28.66± 1.485	28.66± 1.485	17.67± 0.705	73.792	0.000
Juvenile	26.47± 1.068	26.47± 1.078	17.20± 0.289	107.977	0.000
Mature	26.49± 0.500	25.61± 6.717	16.70± 1.655	3.541	0.000
Dead	26.23± 0.682	26.23± 0.682	17.48± 2.014	46.132	0.000
Foliage	25.99± 0.156	25.99± 0.156	16.87± 0.000	3.809	0.123
Branches	26.19± 0.240	26.36± 0.339	18.12± 0.594	3.381	0.140

There were significant effects of calcium concentration at the three zones for all the parameters, shoot (F = 73.792, p<.05 level), juvenile (F = 107.977, p<.05 level), mature (F = 3.541, p<.05 level) and dead culm (F = 46.132, p<.05 level).

Pairwise comparisons of the means using Tukey's Honestly Significant Difference (HSD) procedure indicated dry semi-deciduous vs. moist evergreen deciduous, moist evergreen deciduous vs. dry semi-deciduous and moist evergreen vs. moist semi-deciduous were significant comparisons: Subjects in the moist semi-deciduous (*M* = 27.50, SD = 1.60) had more amount of calcium, followed by dry semi-deciduous (*M* = 26.62, SD = 1.79) and then moist evergreen (*M* = 17.36, SD = 1.11) reported that the tasks were significantly ($p < .05$), with a 95% confidence interval of the difference between means from dry semi-deciduous vs. moist evergreen deciduous and moist evergreen deciduous vs. dry semi-deciduous 7.7 to 10.8 and moist evergreen vs. moist semi-deciduous 8.6 to11.7 points on a -5 to +5 scale. The other one comparison was not significant ($p > .34$).

It can be seen from Table 4.31 that dry semi-deciduous and moist semi-deciduous zones have 25.99*ppm* of the mean score of foliage and the lowest value was recorded 16.87*ppm* (moist evergreen). The mean score of the branches ranged from 18.12*ppm* (moist evergreen) to 26.19*ppm* (dry semi-deciduous and moist semi-deciduous). None of the values was significant.

Concentration of calcium at various the compartments (top, middle and base)



Shoot

Juvenile

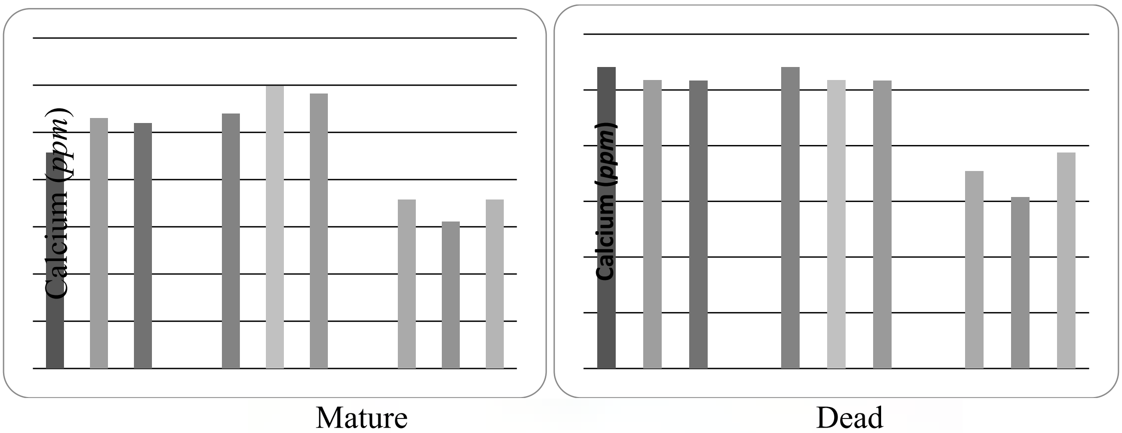


Figure 4. 36 The amount of calcium contents in Bambusa vulgaris against culm's age

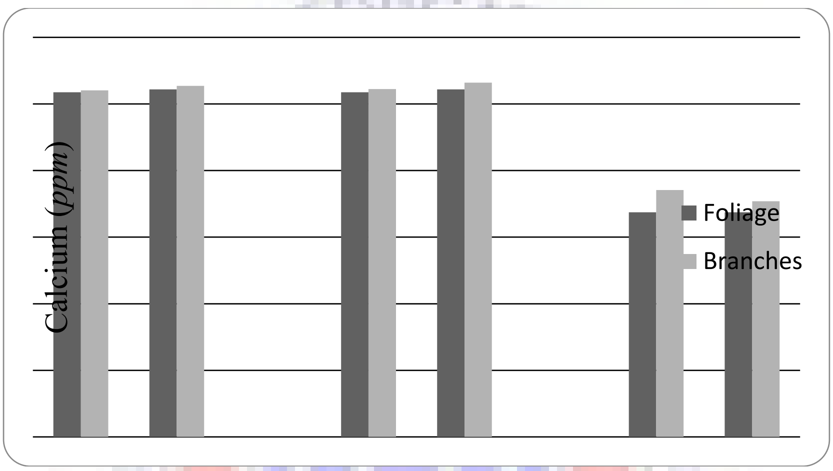


Figure 4.37: The amount of calcium contents in Bambusa vulgaris branches and foliage

The concentrations of calcium in the bamboo samples in various compartments are shown in Figure 4.36. The moist evergreen deciduous zone recorded the lowest concentration of calcium amongst the ecological zones. The mean proportion of the shoot ranged from 16.87 *ppm* at the middle portion in the moist evergreen to the middle part 29.87 *ppm* in both dry semi-deciduous and moist semi-deciduous zones. The juvenile ranged from 16.87 (top at moist evergreen) to 27.61 *ppm* (base at moist semi-deciduous). Mature samples ranged from15.53*ppm* (moist evergreen) to 29.87*ppm* (moist semi-deciduous). The dead values of the bamboo ranged 15.36 *ppm* at midddle in the moist evergreen to 27.02 *ppm* at both dry semi-deciduous and moist semi-deciduous zones.

Generally the moist evergreen deciduous zone exhibited low proportions of calcium in the branches and foliage (Figure 4.38). The following mean scores were recorded for both foliage and branches across the zones; green foliage (16.87 *ppm* (moist evergreen deciduous) to 25.88 *ppm* (for both dry semi-deciduous and moist semi-deciduous) whilst the dead foliage had 16.87 *ppm* to 26.10 *ppm* (for both dry semi-deciduous and moist semi-deciduous). The lowest value for the green branches was shown in the moist evergreen (18.54 *ppm*) and the highest values was made known at moist semi-deciduous (26.12 *ppm*). The lowest dead branches ranged from 17.70 *ppm* (moist evergreen) to 26.60 *ppm* at the moist semi-deciduous zone.

Concentration of potassium at three ecological zones in Ghana

Moist semi-deciduous zone recorded the highest amount of potassium concentrations in all the three zones (Table 4.31). Meanwhile, the lowest values were found in dry semi-deciduous zone. The mean values for potassium in the shoot ranged from 0.60*ppm* (dry semi-deciduous) to 2.44*ppm* (moist semi-deciduous), juvenile from 0.42*ppm* (dry semi-deciduous) to 1.80*ppm* (moist semi-deciduous), mature from 0.42*ppm* (dry semi-deciduous) to 2.45*ppm* (moist semi-deciduous) and dead culm from 0.12*ppm* (dry semi-deciduous) to 0.62*ppm* (moist evergreen).

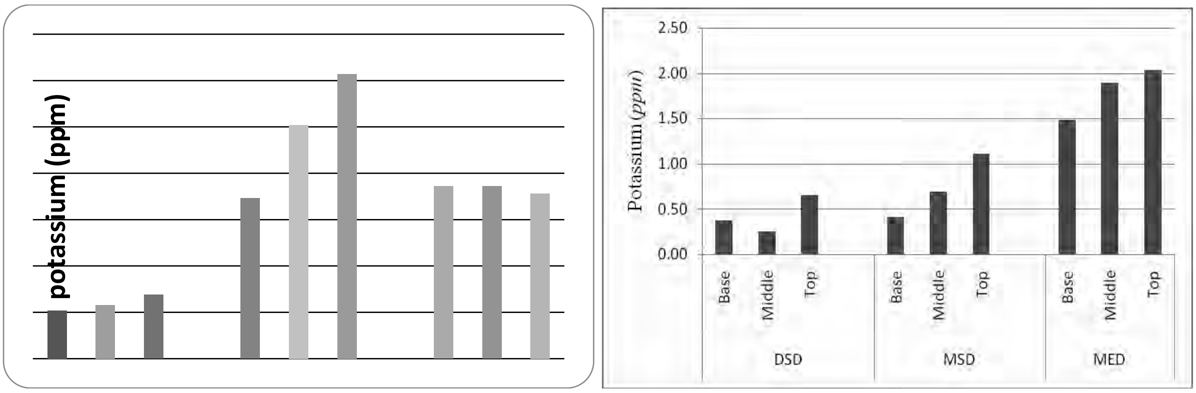
Table 4.31

Concentration of potassium in shoot, juvenile, mature and dead culms of Bambusa vulgaris at different ecological zones

Item	Dry semi-deciduous	Moist semi-deciduous	Moist Evergreen deciduous	*F-values*	*p-values*
Shoot	0.60± 0.086	2.44± 0.674	1.83±0.046	17.145	0.003
Juvenile	0.42± 0.205	0.74± 0.352	1.80± 0.286	18.898	0.003
Mature	0.42± 0.205	2.45± 0.431	1.25± 0.422	22.954	0.002
Dead	0.12± 0.035	2.57± 0.474	0.62± 0.161	59.639	0.000
Foliage	0.95± 0.969	1.00± 0.983	1.03± 0.976	0.379	0.571
Branches	0.21± 0.042	0.60± 0.516	0.64± 0.509	0.015	0.908

The mean concentration of potassium in the foliage and branches increased from dry semi-deciduous, moist semi-deciduous to moist evergreen zones. The foliage ranged from 0.95*ppm* (dry semi-deciduous) to 1.03*ppm* (moist evergreen) and branches ranged from 0.21*ppm* (dry semi-deciduous) to 0.64*ppm* (moist evergreen).

Concentration of potassium at various the compartments (top, middle and base)



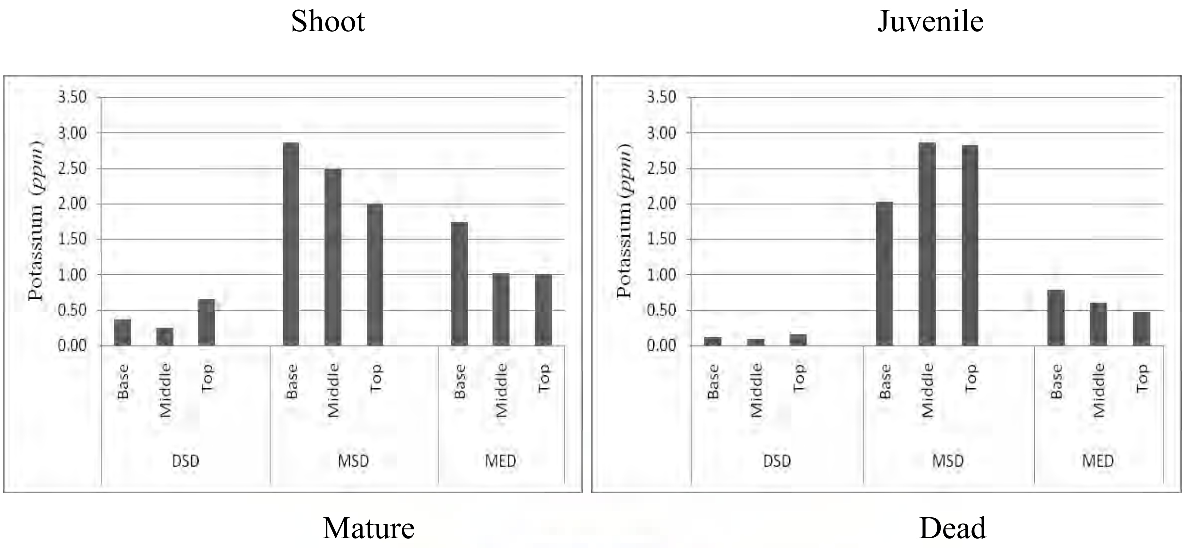


Figure 4.38: The amount of potassium contents in Bambusa vulgaris against culm's age

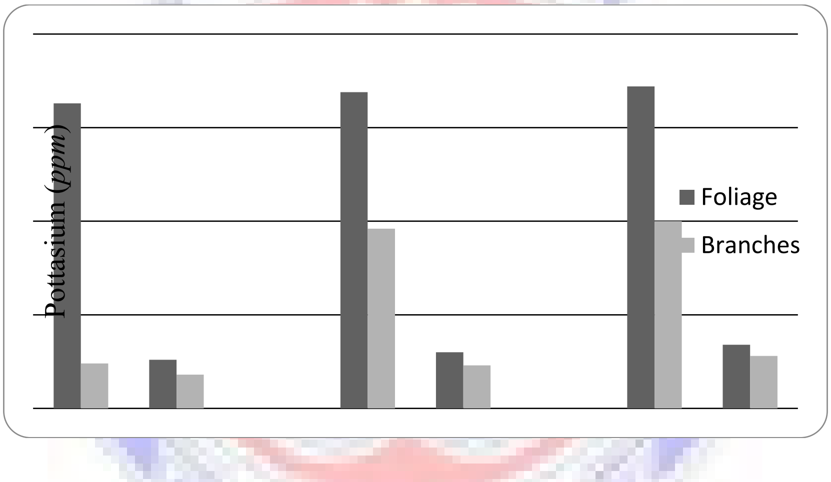


Figure 4.39: The amount of potassium contents in Bambusa vulgaris branches and foliage

The mean concentrations of potassium in *Bambusa vulgaris* are shown in figure 4.38. Amongst the bamboo aged groups the dead sample at the middle portion recorded the lowest value of 0.09*ppm* found at dry semi-deciduous zone, whilst the highest 3.07*ppm* located at top portion found in the moist semi-deciduous zone.

The shoot recorded the lowest mean value of 0.52 *ppm* (base) from dry semi-deciduous whilst the highest mean value was (3.07*ppm*) (top) in moist semi-deciduous region. The juvenile exhibited the following mean values, 0.25*ppm* (middle) from dry semi-deciduous and the highest 2.03*ppm* from moist evergreen zone. The mature samples recorded 0.25*ppm* (dry semi-deciduous) and 2.86*ppm* (moist semi-deciduous). The dead samples were 0.09*ppm* (dry semi-deciduous) to 2.86*ppm* (moist semi-deciduous).

The mean concentrations of potassium in green foliage were higher than dead foliage in all the ecological zones (Figure 4.39). The mean values for both foliage and branches rose from dry semi-deciduous to moist evergreen zone. The average green foliage scored from 1.63 to 1.72 *ppm*, dead foliage ranged from 0.26 to 0.34 *ppm*, green branches from 0.24 to 1.00 *ppm* and dead branches from 0.18 to 0.28 *ppm*.

Concentration of magnesium at various the three ecological zones

The average values of magnesium across the different ecological zones of *Bambusa vulgaris* are shown in Table 4.32. The shoot recorded the lowest value at moist semi-deciduous whilst the highest was found in moist evergreen zone. The average culm values of magnesium for all the zones decrease from dry semi-deciduous, through moist semi-deciduous to moist evergreen zones. Magnesium mean concentration obtained ran from 0.11*ppm* (moist semi-deciduous) to 0.18*ppm* (moist evergreen) for shoot, juvenile from 0.06 (moist evergreen) to 0.13*ppm* dry semi-deciduous, mature from 0.05*ppm* (moist semi-deciduous) to 0.15*ppm* (dry semi-deciduous) and dead culm rose from 0.07*ppm* (moist semi-deciduous and moist evergreen) to 0.12 (dry semi-deciduous). One-way ANOVA indicated that mature culms were statistically significant at .05 levels.

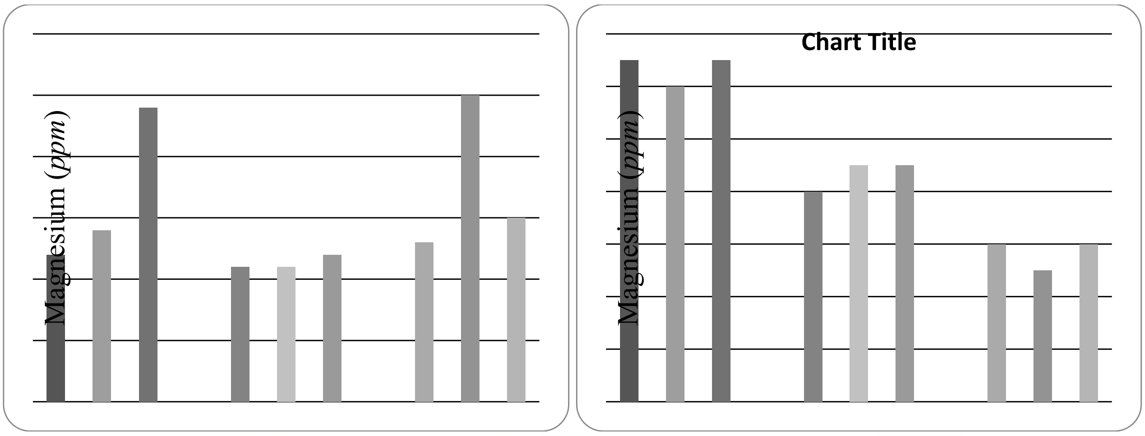
Table 4.32

Concentration of magnesium in shoot, juvenile, mature and dead culms of Bambusa vulgaris at different ecological zones

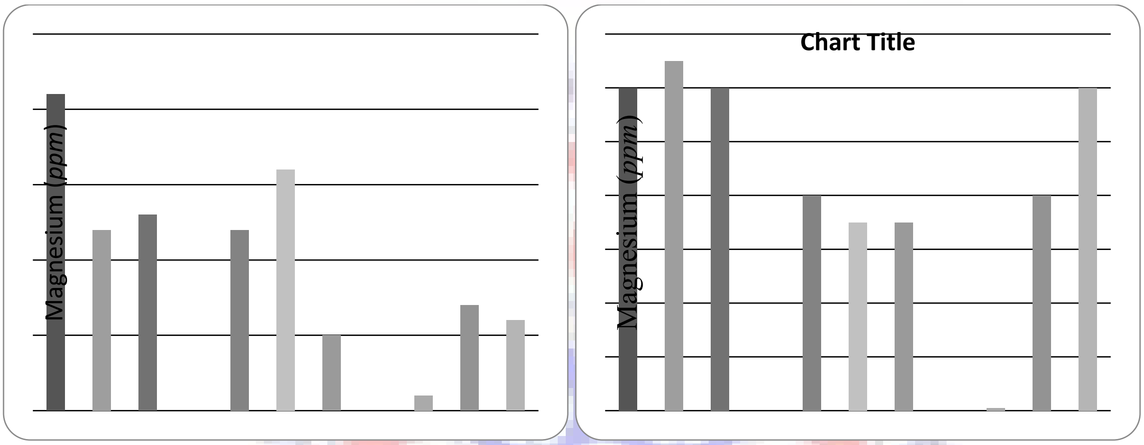
Item	Dry semi-deciduous	Moist semi-deciduous	Moist Evergreen deciduous	*F-values*	*p-values*
Shoot	0.17± 0.064	0.11± 0.006	0.18±0.064	1.257	0.350
Juvenile	0.13± 0.006	0.09± 0.006	0.06± 0.006	1.000	0.000
Mature	0.15± 0.049	0.11± 0.056	0.05± 0.032	3.944	0.081
Dead	0.12± 0.006	0.07± 0.006	0.07± 0.060	2.295	0.182
Foliage	0.14± 0.007	0.14± 0.028	0.07± 0.085	0.422	0.551
Branches	0.14± 0.007	0.07± 0.028	0.07± 0.000	1.052	0.363

The one-way ANOVA test (Table 4.32) pointed out that the mean values for the foliage varied from 0.07*ppm* (moist evergreen) to 0.14*ppm* (for both dry semi-deciduous and moist semi-deciduous). Also, the mean scores of the branches ranged from 0.07*ppm* (moist semi-deciduous and moist evergreen) to 0.14*ppm* (dry semi-deciduous).

Concentration of magnesium at various the compartments (top, middle and base)



Shoot Juvenile



Mature Dead

Figure 4.40: The amount of magnesium contents in Bambusa vulgaris against culm's age

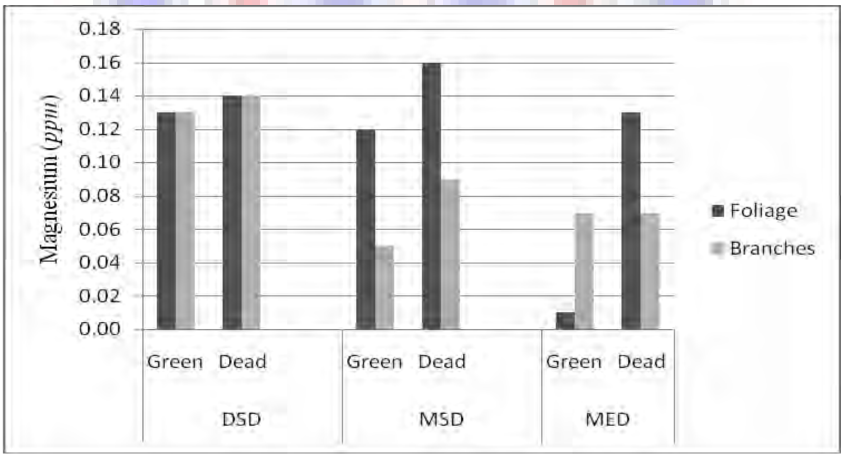


Figure 4.41: The amount of magnesium contents in Bambusa vulgaris branches and foliage

The mean concentration of magnesium in the bamboo shoot varied from 0.11*ppm* (middle and base) in moist semi-deciduous to 0.25*ppm* (middle) in moist evergreen (Figure 4.40). Juvenile average values ranged from 0.05*ppm* located in the middle portion at the moist evergreen to 0.13*ppm* located in top and base parts at the dry semi-deciduous zone. The base of the mature culms from dry semi-deciduous obtained the highest value of 0.21*ppm* of magnesium and the lowest 0.01*ppm* was found in base in moist evergreen zone. However, the dead (base) from moist evergreen recorded the lowest value 0.001*ppm* and the highest was found in the middle portion in dry semi-deciduous zone (Figure 4.40).

The mean value of magnesium of the bamboo branches and leaves did not differ among species. The dead leaves of the bamboo registered the highest as compare to the green type (Figure 4.41). The green foliage ranged from 0.01*ppm* (moist evergreen) to 0.13*ppm* (dry semi-deciduous). The dead foliage ranged from 0.13*ppm* (moist evergreen deciduous) to 0.16*ppm* found in moist semi-deciduous. The green branches obtained the following mean values 0.07*ppm* (moist evergreen) to 0.13*ppm* (dry semi-deciduous). The dead branches from dry semi-deciduous had the highest concentration of magnesium of 0.14 *ppm* while moist semi-deciduous green branches obtained the lowest of 0.05 *ppm*.

Concentration of phosphorus at various three ecological zones in Ghana

Apart from the dead bamboo samples, the rest of the parameters from moist semi-deciduous registered the highest values of phosphorus across the zones. The mean values for phosphorus were from 0.03 to 0.18*ppm*. The shoot recorded 0.07*ppm* (moist evergreen) to 0.18*ppm* (moist semi-deciduous), juvenile from 0.04*ppm* to 0.08*ppm* at dry semi-deciduous and moist semi-deciduous respectively, mature from 0.04*ppm* (dry semi-deciduous and moist evergreen) to 0.06*ppm* (moist semi-deciduous) and dead culm ranged from 0.03*ppm* (moist semi-deciduous) to 0.06*ppm* (moist evergreen). One-way ANOVA test of phosphorus in shoot, juvenile, mature and dead culms of *Bambusa vulgaris* at different ecological zones were not significant (Table 4.33).

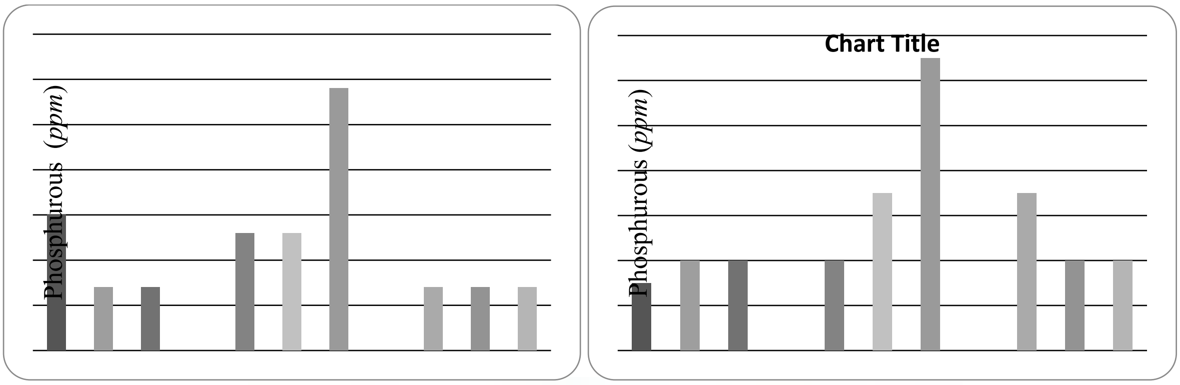
Table 4.33

Concentration of phosphorus in shoot, juvenile, mature and dead culms of Bambusa vulgaris at different ecological zones

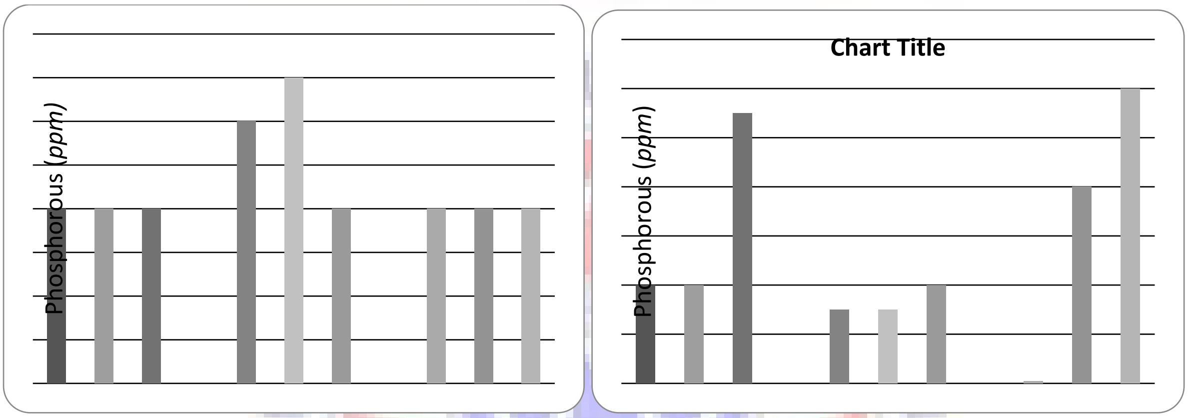
Item	Dry semi-deciduous	Moist semi-deciduous	Moist Evergreen deciduous	*F-value*	*p-value*
Shoot	0.10± 0.046	0.18± 0.092	0.07±0.000	2.963	0.127
Juvenile	0.04± 0.006	0.08± 0.046	0.05± 0.017	1.822	0.241
Mature	0.04± 0.000	0.06± 0.015	0.04± 0.000	3.571	0.095
Dead	0.06± 0.040	0.03± 0.006	0.06± 0.066	0.576	0.591
Foliage	0.13± 0.000	0.10± 0.085	0.11± 0.021	4.983	0.089
Branches	0.09± 0.021	0.06± 0.021	0.09± 0.021	0.250	0.643

One-way ANOVA test of phosphorus for foliage and branches of *Bambusa vulgaris* at three zones in Ghana are shown in Table 4.33. The highest mean value for foliage was found in dry semi-deciduous (0.13*ppm*), next was moist evergreen (0.11*ppm*) and the lowest was recorded at moist semi-deciduous (0.10*ppm*). The branches ranged from 0.06*ppm* (moist semi-deciduous) to 0.09*ppm* (dry semi-deciduous and moist evergreen).

Concentration of phosphorous at various the compartments (top, middle and base)



Shoot Juvenile



Mature Dead

Figure 4.42: The amount of phosphorus contents in Bambusa vulgaris against culm's age

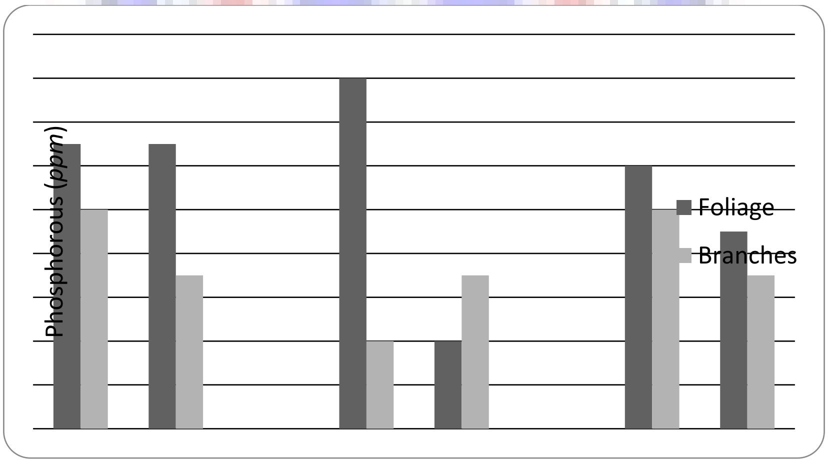


Figure 4.43: The amount of phosphorus contents in Bambusa vulgaris branches and foliage

The mean percentage of phosphorus in the bamboo samples are shown in Figure 4.42. The lowest mean values of the shoot were recorded from moist evergreen 0.07*ppm* (at all positions) and the top and middle parts in the dry semi-deciduous zone. The highest value was found at the top part of the shoot at dry semi-deciduous zone (0.29*ppm*). Juvenile average values ranged from 0.03*ppm* located in the base portion at the dry semi-deciduous zone to 0.13*ppm* located in top in moist semi-deciduous. The mature samples obtained similar average values 0.04*ppm* in all parts of the bamboo across all the ecological zones except the middle and base parts of the bamboo in moist semi-deciduous zone. Meanwhile, the highest mean value 0.07*ppm* was located at middle in moist semi-deciduous zone. The dead samples from moist evergreen recorded the lowest value 0.001*ppm* (base) and the highest was found in the top portion in moist evergreen deciduous zone.

It was observed that the phosphorus of the green branches from both dry semi-deciduous and moist evergreen have 0.10*ppm* (Figure 4.43). The dead branches exhibited similar mean values of 0.07*ppm* in all the ecological zones. The green leaves or foliage ranged from 0.12*ppm* to 0.016*ppm,* and the dead leaves obtained 0.04*ppm* to 0.13*ppm.*

Concentration of sodium at various ecological zones in Ghana

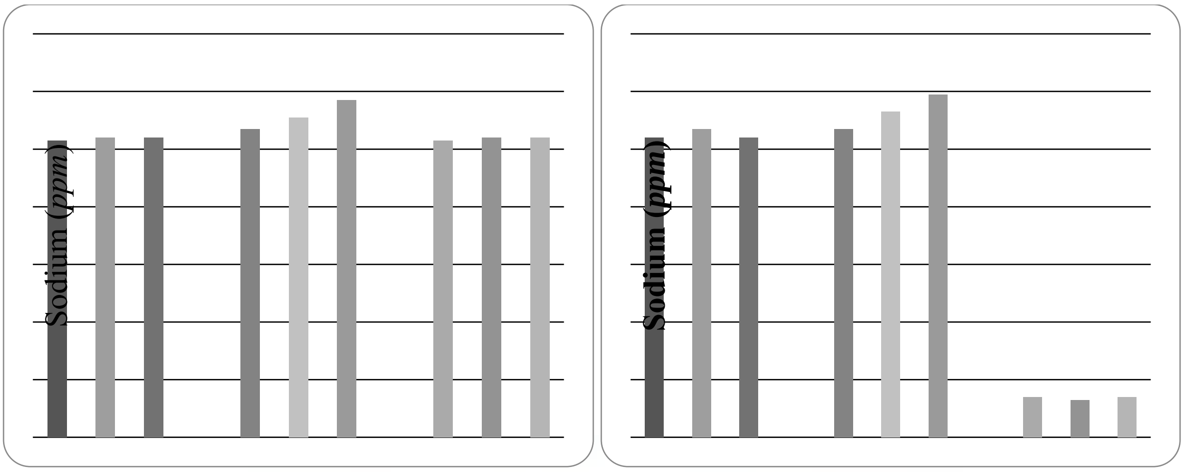
Moist semi-deciduous zone had the highest amount of sodium concentration among the three zones in Ghana (Table 4.34). The concentration of the shoot ranged from 0.13*ppm* (moist evergreen zones) to 1.05*ppm* (moist semi-deciduous), juvenile ranged from 1.06 *ppm* (moist evergreen) to 1.28*ppm* (moist semi-deciduous), mature had 0.13*ppm* (for both dry semi-deciduous and moist evergreen) to 1.06*ppm* (moist semi-deciduous) and dead samples ranged from 0.12*ppm* (for both dry semi-deciduous and moist evergreen) to 0.72*ppm* (moist semi-deciduous). There were no significant effects of amount of sodium at the $p<.05$ level for the three zones. The sodium concentration in the bamboo from shoot to dead culm ranged 0.12 to 1.28*ppm.*

Table 4.34
Concentration of sodium in shoot, juvenile, mature and dead culms of Bambusa vulgaris at different ecological zones

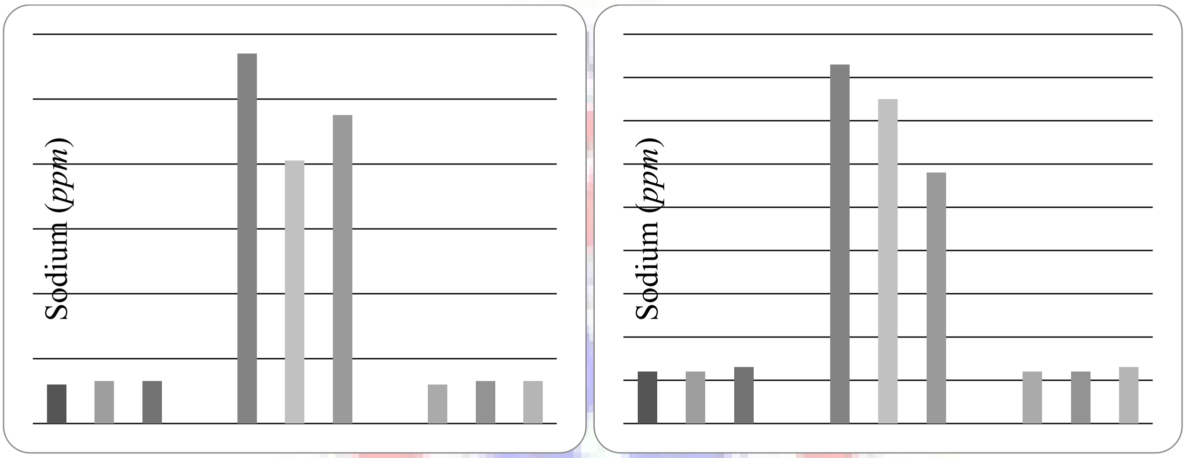
Item	Dry semi-deciduous	Moist semi-deciduous	Moist Evergreen deciduous	*F-value*	*p-value*
Shoot	0.74± 0.525	1.05± 0.017	0.13±0.006	7.180	.026
Juvenile	1.22± 0.050	1.28± 0.186	1.06± 0.314	4.921	.032
Mature	0.13± 0.006	1.06± 0.314	0.13± 0.006	26.315	.001
Dead	0.12± 0.006	0.72± 0.128	0.12± 0.006	65.257	.000
Foliage	0.15± 0.007	0.94± 0.290	0.45± 0.297	0.033	.864
Branches	0.12± 0.000	0.64± 0.205	0.41± 0.396	0.124	.742

The highest mean value of sodium was found in moist semi-deciduous, followed by moist evergreen and the least from dry semi-deciduous zone. One-way ANOVA test in Table 4.34 indicated that the mean foliage ranged from 0.15*ppm* to 0.94*ppm* and branches varied from 0.12*ppm* to 0.64*ppm*. The values were not statistically significant.

Concentration of sodium at various the compartments (top, middle and base)



Shoot Juvenile



Mature Dead

Figure 4.44: The amount of sodium contents in Bambusa vulgaris against culm's age

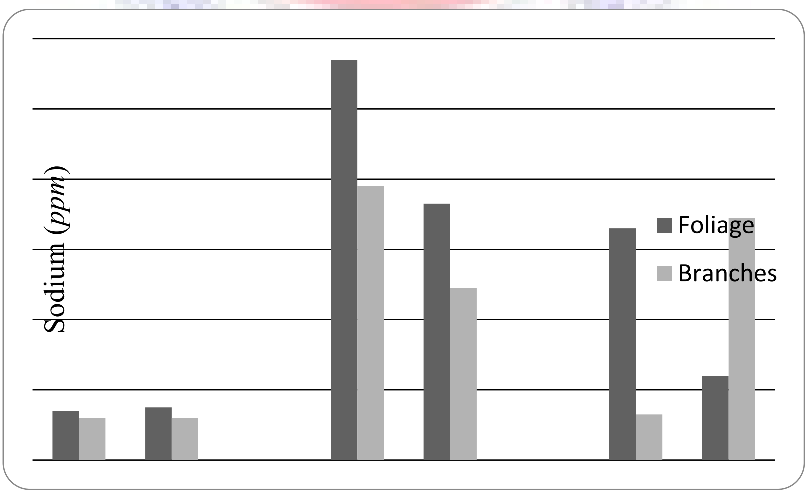


Figure 4.45: The amount of sodium contents in Bambusa vulgaris branches and foliage

The mean values for the shoots' various compartment ranged from base 1.03*ppm* (dry semi-deciduous) to top 1.27*ppm* (moist semi-deciduous). The values for the juvenile ranged from 1.04*ppm* found at top and base in dry semi-deciduous zone to 1.43*ppm* found at the top in moist semi-deciduous zone. Mature samples exhibited 0.12*ppm* located at base from dry semi-deciduous and moist evergreen zone and the highest found at the top in moist semi-deciduous. The values of the dead samples at dry semi-deciduous and moist evergreen at the top (0.12 *ppm*), middle (0.12 *ppm*) and base (0.13*ppm*) were the same.

The samples from dry semi-deciduous zones showed the lowest values of sodium concentrations in both branches and leaves with the values range from 0.12 *ppm* and 0.15 *ppm* respectively (Figure 4.44). The mean sodium concentration found in the green foliage ranged from 0.66*ppm* (moist evergreen) to 1.14*ppm* (dry semi-deciduous and moist semi-deciduous) while the dead foliage ranged from 0.15*ppm* (dry semi-deciduous) to 0.73*ppm* (moist semi-deciduous zone). The mean score of the green branches ranged from 0.12*ppm* (dry semi-deciduous) to 0.78*ppm* (moist semi-deciduous) whilst the dead branches obtained 0.12*ppm* (dry semi-deciduous) to 0.69*ppm* (moist evergreen zone).

Concentration of aluminium at three ecological zones in Ghana

Moist evergreen zone exhibited the highest values of aluminium concentration across the zones with the exemption of dead culms which highest concentration was establised in moist semi-deciduous zone (Table 4.35). There were very close increase from one bamboo type to another. The lowest scores were found in the dry semi-deciduous zone. The mean values of the shoot ranged from 0.06 to 0.15*ppm*, juvenile had 0.07 to 0.14*ppm*, mature 0.09 to 0.11*ppm* and dead samples ranged from 0.09 to 0.11*ppm*. The means of all bamboo age groups were not significant.

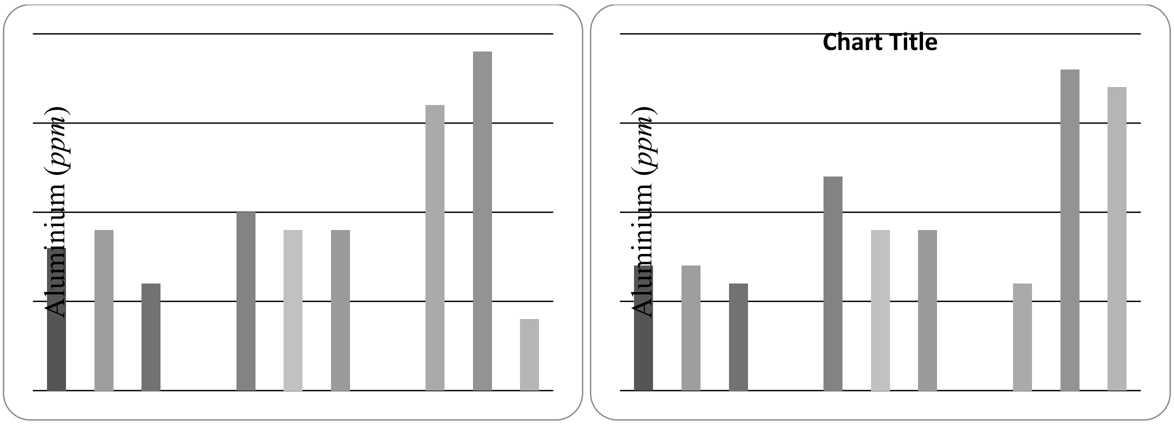
Table 4.35

Concentration of aluminium in shoot, juvenile, mature and dead culms of Bambusa vulgaris at different ecological zones

Item	Ecological zone			ANOVA	
	DSD	MSD	MED	*F-value*	*p-value*
Shoot	0.06± 0.038	0.08± 0.021	0.15±0.051	3.191	0.105
Juvenile	0.07± 0.006	0.10± 0.017	0.14± 0.067	2.315	0.180
Mature	0.09± 0.015	0.10± 0.038	0.11± 0.092	0.063	0.940
Dead	0.09± 0.017	0.11± 0.015	0.09± 0.062	0.368	0.706
Foliage	0.09± 0.021	0.16± 0.071	0.16± 0.050	7.200	0.055
Branches	0.09± 0.007	0.10± 0.021	0.21± 0.078	4.005	0.116

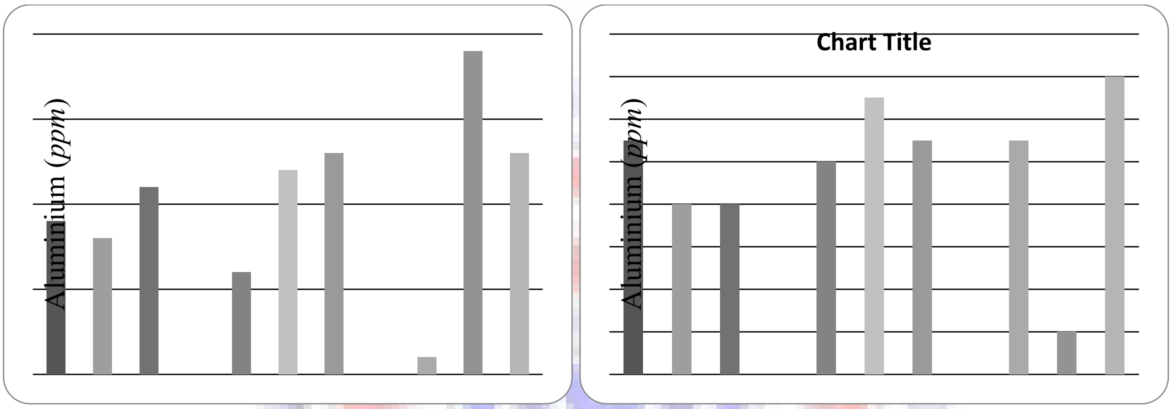
The highest foliage mean value of aluminium was recorded in moist semi-deciduous and moist evergreen zones (0.16*ppm*) and the lowest was found in the dry semi-deciduous (0.09*ppm*). The branches increased from dry semi-deciduous (0.09*ppm*) to moist evergreen (0.21*ppm*).

Concentration of aluminium at various the compartments (top, middle and base)



Shoot

Juvenile



Mature

Dead

Figure 4.46: The amount of aluminium contents in Bambusa vulgaris against culm's age

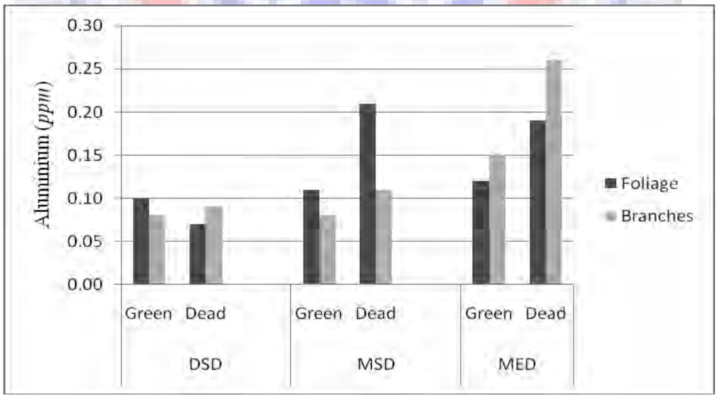


Figure 4.47: The amount of aluminium contents in Bambusa vulgaris branches and foliage

The shoot at the moist evergreen exhibited both the highest and the lowest values of aluminium concentrations. The shoot ranged from 0.04*ppm* (top) to 0.19 *ppm* (middle portion) both found in the moist evergreen zone. Juvenile obtained 0.06*ppm* (base) to 0.18*ppm* (top) both found in moist evergreen zone. Mature samples varied from 0.01*ppm* (base) to 0.19*ppm* (middle). The mean concentration of aluminium of the dead culms varied from 0.02*ppm* (middle) to 0.19 *ppm* (top) found in moist evergreen zones.

Both Dry semi-deciduous and moist semi-deciduous recorded similar values (0.08 *ppm*) of aluminium for the green branches (Figure 4.47). The green branches ranged from 0.08*ppm* located at dry semi-deciduous and moist semi-deciduous to 0.15*ppm* located at moist evergreen zone. The dead branches ranged from 0.09*ppm* (dry semi-deciduous) to 0.26*ppm* (moist evergreen). The green foliage ranged from 0.10*ppm* (dry semi-deciduous) to 0.12*ppm* (moist evergreen) whilst the dead foliage obtained 0.07*ppm* (dry semi-deciduous) to 0.21*ppm* (moist semi-deciduous).

Concentration of iron at three ecological zones in Ghana

The highest mean concentration of iron in the shoot was found at the moist semi-deciduous zone (0.20*ppm*), followed by both dry semi-deciduous and moist evergreen zone (0.14*ppm*). The least mean score of iron in the juvenile was 0.03*ppm* found in the dry semi-deciduous, to 0.07*ppm* located in moist semi-deciduous and moist evergreen zone (Table 4.36). The mature recorded average values of 0.03*ppm* (dry semi-deciduous) to 0.17*ppm* (moist semi-deciduous) and dead culms varied from 0.02*ppm* to 0.03*ppm* (dry semi-deciduous and moist evergreen zones). There was a significant effect of amount of iron on juvenile culms at the $p<.05$ level for the three zones (F = 1.778, $p = 0.006$).

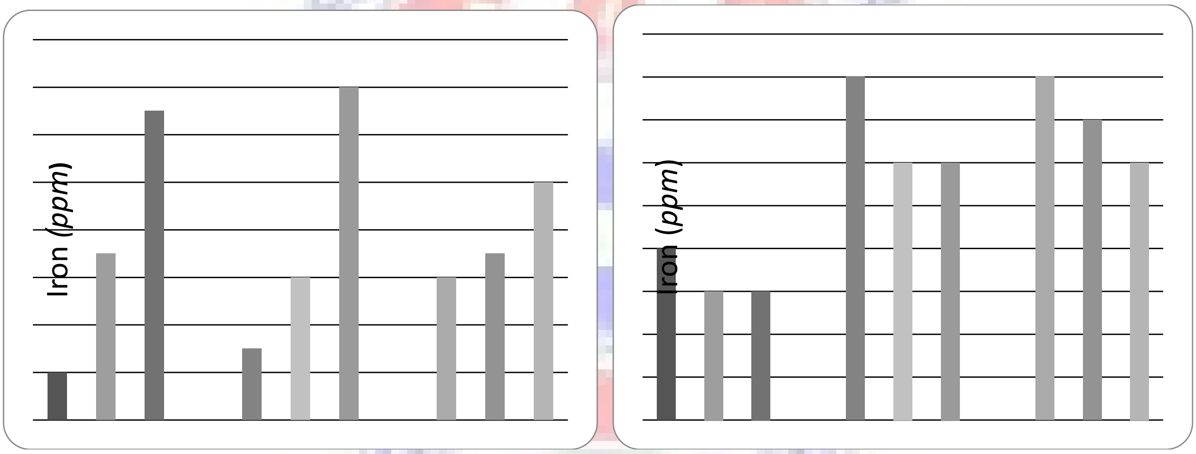
Table 4.36

Concentration of iron in shoot, juvenile, mature and dead culms of Bambusa vulgaris at different ecological zones

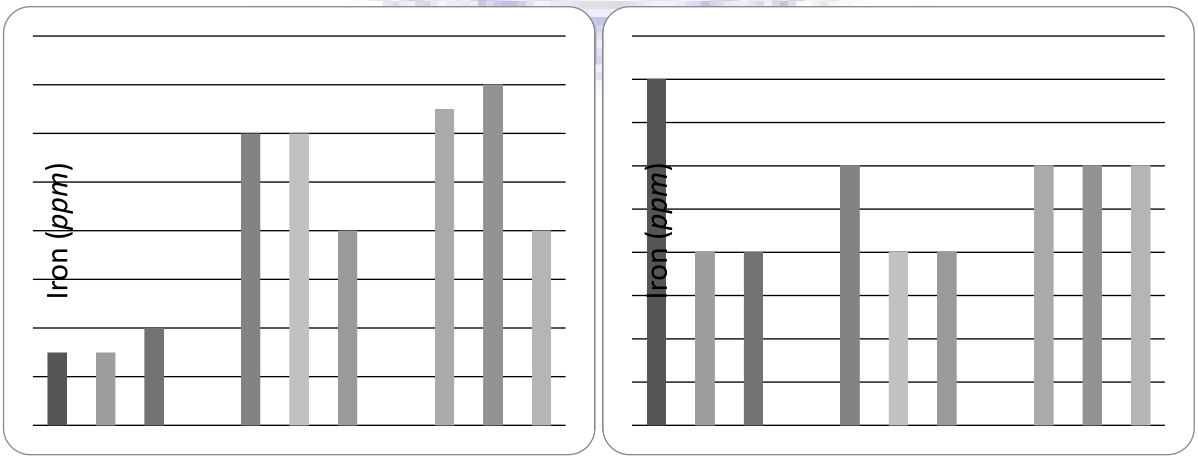
Item	Ecological zone			ANOVA	
	DSD	MSD	MED	*F-value*	*p-value*
Shoot	0.14± 0.166	0.20± 0.263	0.14±0.136	0.079	0.925
Juvenile	0.03± 0.006	0.07± 0.012	0.07± 0.012	1.778	0.006
Mature	0.03± 0.006	0.17± 0.081	0.15± 0.082	3.817	0.085
Dead	0.03± 0.012	0.02± 0.006	0.03± 0.000	0.600	0.579
Foliage	0.03± 0.000	0.20± 0.233	0.05± 0.007	1.305	0.317
Branches	0.05± 0.021	0.02± 0.000	0.03± 0.021	0.800	0.422

The foliage ranged from 0.03*ppm* (moist semi-deciduous) to 0.20*ppm* in moist semi-deciduous and the branches ranged from 0.02*ppm* in moist semi-deciduous to 0.05*ppm* in dry semi-deciduous (Table 4.37). The values were not statistically significant.

Concentration of iron at various the compartments (top, middle and base)



Shoot Juvenile



Mature Dead

Figure 4.48: The amount of iron contents in Bambusa vulgaris against culm's age

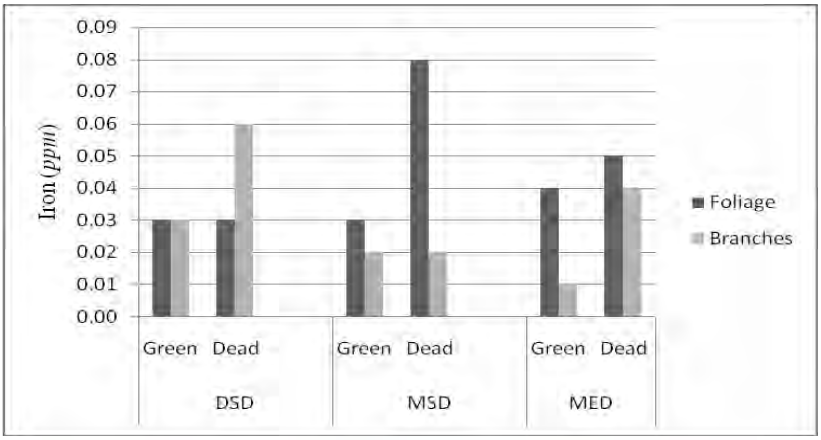


Figure 4.49: The amount of iron contents in Bambusa vulgaris branches and foliage

The top portion of the shoots recorded the highest concentration of iron 0.14*ppm* (moist semi-deciduous), 0.13*ppm* and the lowest found at the base 0.02*ppm* located at dry semi-deciduous zone (Figure 4.48). The mean iron concentrations of the juvenile culms were found in the top and middle parts (0.03*ppm*) located at the dry semi-deciduous. The highest were found in middle and base (0.08*ppm*) of the juvenile at moist evergreen zone. The least values of the mature culms were seen at the middle and the base (0.03*ppm*) at dry semi-deciduous whilst the highest (0.14*ppm*) was found at moist evergreen. The mean values of the dead samples exhibited slight increase top and middle to the base. The mean dead samples varied from 0.02 found at the top and middle located in dry semi-deciduous and moist semi-deciduous zones to the base (0.04*ppm*) located at dry semi-deciduous zone.

With the exception of dead leaves which had 0.36 *ppm* of iron concentration recorded at moist semi–deciduous zone, the rest; green and old branches and green leaves have the values around 0.01 to 0.05 *ppm* (Figure 4.49). The green branches ranged from 0.01*ppm* (moist evergreen) to 0.03*ppm* (dry semi-deciduous). The dead branches also got 0.02*ppm* (moist semi-deciduous) to 0.06*ppm* (dry semi-deciduous). The mean values of the green foliage varied from 0.03*ppm* (dry semi-deciduous and moist semi-deciduous) to 0.04*ppm* (moist evergreen) whilst the dead foliage ranged from 0.03*ppm* (dry semi-deciduous) to 0.05*ppm* (moist evergreen).

It could be observed from various figures shown above that magnesium, phosphorus, sodium, aluminium and iron had fewer concentrations in ash. It was also could be seen that the shoot recorded the highest concentration in all the micronutrients of the *Bambusa vulgaris* samples.

4.4.3. The relationships between ash content, minor and heavy metals of *Bambusa vulgaris* culms or stems, branches and leaves

The relationships of ash elemental as against the micronutrients of *Bambusa vulgaris* culms, branches and leaves are shown in Table 4.37a, b & c. The carbon content decreases significantly with increasing *ash* content ($r = -.371$ $p > 0.05$). The concentration of potassium (*K*) increases as the *ash* content increases (r is 0.819 and $p < 0.01$). The *ash* content relates strongly positive to *P* ($r = .799$, $p < 0.01$) while *Na* ($r = -.58$, $p < 0.05$). The *ash* content moderately associates indirectly with *Ni* ($r = -.664$, $p < 0.05$). There was a strong positive correlation between calcium and ash variables ($r = .75$, $p < 0.01$). Copper increases as the value of Zinc increases ($r = 0.875$ where $p = 0.01$). *Ni* relates negatively to *Ca* ($r = -.730$, $p < 0.01$) and relates positively with *P* ($r = .728$, $p = 0.01$). *Al* associates with *Cu* ($r = 662$, $p = 0.05$) and *Pb* ($r = 0.641$ $p = 0.05$).

Table 4.37a

Pearson's Correlation of Ash Content, Minor and Heavy Metals of Bambusa vulgaris Culms, Branches and Leaves

Culms/stems

	Ash	C	H	N	Cu	Zn	Pb	As	Ni	Cd	Ca	K	Mg	P	Na	Al
C	-.371*															
H	.103	.179														
N	.016	-.029	.045													
Cu	-.03	.232	.128	-.035												
Zn	0.875	.233	-.106	-.282	0.88**											
Pb	0.27	.317	.580*	-.113	.657**	.56										
As	0.05	-.408	-.243	-.094	.23	.19	-.14									
Ni	-.66*	.397	.153	-.281	-.02	-.04	.28	-.13								
Cd	.10	-.142	-.650*	-.328	-.42	-.26	-.66**	.10	-.13							
Ca	0.75**	-.635	-.128	.285	-.473	-.512	-.598*	.143	-.730**	.189						
K	.819**	-.484	.135	-.261	-.231	-.304	-.422	.206	-.097	.034	.25					
Mg	.02	-.104	.318	.494	-.127	-.372	-.042	-.280	-.397	.115	.35	-.196				
P	0.80**	-.106	.102	.407	.252	.246	-.077	.072	.728**	.333	.42	.23	.21			
Na	0-.58	-.375	.405	.332	.238	-.042	.024	.048	-.493	-.510	.56	.32	.30	.59		
Al	-.51	.024	.446	-.382	.662*	.513	.641*	.391	.296	-.423	.51	.19	-.27	-.21	.09	
Fe	0.26	-.148	.575	.598*	.244	.051	.371	-.070	-.509	-.621*	.27	-.14	.52	.75	.66	.08

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed)

Table 37b

Branches

	Ash	C	H	N	Cu	Zn	Pb	As	Ni	Cd	Ca	K	Mg	P	Na	Al
C	-.547**															
H	-.940**	.609**														
N	-0.137	.997**	0.044													
Cu	0.208	0.254	-0.171	.963**												
Zn	-0.106	.498**	0.024	.963**	.675**											
Pb	0.225	-.542**	-0.059	.935**	-0.295	-.423*										
As	0.02	0.354	-0.046	.965**	.527**	.729**	-0.193									
Ni	-0.247	.436*	.439*	.841**	0.217	0.162	0.183	0.277								
Cd	-.526**	0.181	0.297	-.914**	0.12	.616**	-0.305	0.346	-0.139							
Ca	-.667**	-0.077	.813**	.963**	0.042	0.042	.532*	0.07	.495*	.622**						
K	0.029	-.540**	0.004	.999**	-0.354	-0.149	.850**	-0.051	0.019	0.176	.663**					
Mg	.786**	-.417*	-.809**	-0.176	-0.005	-0.228	-0.163	-0.216	-.461*	-.441*	-.885**	-0.288				
P	.365*	0.144	-0.319	.866**	-0.139	0.217	-0.029	0.09	-0.089	-0.063	-.607**	0.031	.495**			
Na	-.546**	0.279	.743**	0.182	0.033	-0.298	0.285	-0.16	.539**	-0.21	.966**	0.042	-.610**	-.545**		
Al	-.444*	.521**	.629**	-0.176	-.480**	-0.352	0.12	-0.267	.397*	-0.331	0.219	-0.074	-0.268	0.236	.529**	
Fe	0.212	-0.14	-0.259	-.862**	-0.142	-.500**	-.366*	-.460*	-0.286	-.428*	-.711**	-.596**	.543**	-0.084	-0.086	0.071

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed)

Table 37c

Leaves

	Ash	C	H	N	Cu	Zn	Pb	As	Ni	Cd	Ca	K	Mg	P	Na	Al
C	-.654**															
H	-0.131	.485**														
N	-.560**	0.169	0.248													
Cu	-0.024	.537**	.940**	-0.433												
Zn	-0.039	0.083	.498**	-0.433	.532**											
Pb	.673**	-.849**	-.371*	-.956**	-0.352	0.038										
As	-0.169	-.549**	-.519**	-.987**	-.635**	0.17	.397*									
Ni	.569**	-0.158	.497**	0.515	.500**	0.169	0.137	-.393*								
Cd	0.055	0.025	-0.326	-0.294	-0.284	-.788**	-0.011	-0.337	-0.151							
Ca	.657**	-.787**	0.059	0.606	-0.003	.455*	.710**	.395*	.442*	-.460*						
K	-.388*	.490**	.456*	.999**	.451*	.788**	-.403*	0.072	-0.049	-.714**	0.021					
Mg	0.347	-.651**	-.502**	-0.336	-.583**	-.678**	.522**	0.202	0.015	.542**	0.163	-.911**				
P	-.872**	.381*	0.043	0.018	-0.071	0.301	-.441*	.499**	-.554**	-0.346	-0.3	.535**	-0.355			
Na	0.353	-.556**	0.138	0.018	0.08	.735**	.506**	.528**	0.261	-.716**	.902**	.408*	-0.182	0.061		
Al	.808**	-.402*	0.346	.761*	0.337	-0.011	.430*	-.421*	.763**	0.049	.560**	-0.329	0.323	-.776**	0.245	
Fe	.960**	-.734**	-0.355	.^{a}	-0.28	-0.189	.701**	-0.034	.421*	0.13	.601**	-.463**	.461*	-.832**	0.289	.697**

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed)

CHAPTER FIVE

DISCUSSION

5.0. OVERVIEW

This chapter primarily discusses the results obtained from the field, the various tests conducted at the laboratory and the summary of the relationships of *Bambusa vulgaris* samples collected for the morphological, proximate, ultimate, calorific value and ash elemental analyses. The main objective of the project was to investigate the fuel properties of *Bambusa v. vulgaris* and its utilisation potential to the manufacture of biofuels.

5.1: Compare the morphological properties of *Bambusa v. vulgaris* (bamboo) culms and their affects on biofuel production.

The morphological features of *B. vulgaris* in mean DBH were determined in three ecological zones in Ghana. The areas looked at include clump size, culm height, culm diameter, internode distance and culm wall thickness. This is to compare the morphological features that can provide effective and efficient source of fuel without causing problems to the fuel generating plants. Bamboo culms for production of charcoal should be based on thicker culm wall thickness and shorter internode distance. The results will show if the values of the bamboo parts are able to produce biofuels. The values of ash content should not be above the European threshold of ≥3% (EN 14775), cadmium and nitrogen ≤ 1% contents (EN 15104). Mature and dead bamboo culms in any zone can be used for the production of biofuels because of large amount of Fix Carbon, Carbon, Hydrogen, high heating values and high density (Ganesh, 2003; Bain, 2004; Choy et al, 2005).

5.1.1. Clump size of Bamboos at various ecological zones

Moist semi-deciduous zone recorded the biggest average clump size 622.33cm. It was followed by moist evergreen (584.33cm) whereas the least clump size was recorded at dry semi-deciduous zone (512.3cm). This implies there were more bamboo culms in the moist semi-deciduous zone that could be used for the production of biofuels. However, the statistical result shows that clump sizes for the three zones were almost the same. Bamboo is an alternative material to wood for the production of bioenergy (Scurlock *et al*., 2000), consequently reduces the pressure on the forest.

5.1.2. Culm Height of the bamboo culms at various Ecological zones

The culms' heights increased consistently from dry semi-deciduous, moist semi-deciduous to moist evergreen for all portions investigated. The average height of the bamboo culms among the age groups ranged from 10 to 14 metres. This findings is little higher than that reported by Tekpetey (2006) and Sarfo (2008) who concluded that the mean height of the bamboos in Ghana are between 8-10 metres. The difference in height may due to environmental factors like type of soil and canopy of the surrounding trees. The variations of culm quality do not generally differ between sites within same ecological zone but varies between ecological zones. This means that; bamboo culms selected from the same ecological zones may have the same quality provided planting stock and silvicultural management are identical (Kweku, 2006).

In conclusion, longer culms may provide good yield for fuel wood, biodiesel and charcoal production based on other factors such as calorific values.

5.1.3. Diameter of the bamboo culms at various Ecological zones

The highest average diameter of the shoot was found in moist semi-deciduous zone, followed by shoot from dry semi-deciduous and moist evergreen recorded the least. The mean diameter for juvenile, mature and dead culms ranged from 67 to 95mm. The diameter of the bamboo samples were within the ranges reported by the earlier workers 40 -100 mm with heights of 8-10m (Sarfo, 2008; Tekpetey, 2011). The average values of the culms diameter decrease from the bottom to the top in all the ecological zones. This means that the full bamboo culm is not uniform in terms of culm wall thickness. Meanwhile, grass such as bamboo with any height or diameter can be used as feedstock for anaerobic digestion (AD) to generate biogas and biomethane for use as a transport fuel (Murphy and Power, 2009; Smyth *et al*. 2009).

5.1.4. Variation of diameter at breast height (DBH), culm wall thickness and internode distance

The test results proved that the internodes distance from the moist evergreen zone was found to be the longest (43.88cm), followed by the moist semi-deciduous (39.54cm) and the shortest were recorded in dry semi-deciduous zone (39.44cm). With the exception of matured culms from moist evergreen deciduous which had insignificant longer internode at top and middle than the bottom internodes, all the other parts had their internode decreasing from bottom to top. These differences may be explained by some zonal conditions such as rainfall, temperature and the canopy of trees around the stands which may affect the properties of the bamboo species. These results were in agreement with those reported by (Tekpetey, 2011).

All the average values of the bamboo culms wall thicknesses increase from dry semi-deciduous to moist evergreen zone. The average culm wall thickness values of the various compartments decrease from the bottom or base (13mm) to the top (7.82mm) in all the ecological zones. The reason may be that there were more fibres at the base of the bamboo. Similar observations have been made in top, middle and basal (bottom) parts of *Bambusa v. vulgaris* by Tekpetey (2011).

The internode distance and culm thickness were not significantly different among the ages of the culm. This suggests that these two morphological properties of *Bambusa v. vulgaris* are not clearly affected by the age of the culm. On the other hand, mean culm DBH was found to be affected by culm age. Comparisons of mean DBH across the culm ages show the following trend: dead>mature>young.

Bamboo culms with 10 mm or more wall thickness either with short or long internode distance can be used for making solid or briquetted charcoal. Branches with about 20 mm diameter can also be used for the making charcoal. Pyrolyzing bamboo processing residues such as particle, sawdust, thread left in processing etc. can manufacture bamboo briquette charcoal (Zhang 2002; Jiang, 2004).

5.2. Determine the impact of density, bulk density and calorific value of *Bambusa v. vulgaris* for the production of biofuels.

Heat, electricity and transport fuels can be produced by modern technologies such as direct combustion of biomass, advanced liquefaction, gasification, and pyrolysis in commercial-scale (Demirbas, 1998). The physical property in a biomass either contributes or impedes the production of biofuel. The physical and fuel properties of this study include the moisture content, ash content, basic density, bulk density and calorific value.

5.2.1. Density of *Bambusa v. vulgaris* across the ecological zones

Wood with high density has high energy content and is preferred for fuel than low density (Lucas and Fuwape, 1984). The moist evergreen deciduous zone recorded the highest average basic density, followed by moist semi-deciduous and the lowest recorded at dry semi-deciduous. The mean density of the bamboo samples ranged from 394.64 to 745.06 kg/m^3. The density reduces along the height from base to the top. Marginal reduction in density was observed for dead bamboos across the three ecological zones, implicating that as *Bambusa v. vulgaris* over-matures, its density diminishes.

Some of the results obtained from this research were a bit higher than the results recorded by former authors Assouan (2002) and Tekpetey (2011) ranging from 371.35 kg/m^3 to 684.00 kg/m^3, in Ghana. Ebanyenle and Oteng-Amoako (2007) recorded the basic density of Bambusa vulgaris in Ghana in wet evergreen as 577.00 kg/m^3 and 684.00 kg/m^3 at moist semi-deciduous forest type. However, the values were in agreement with Montaño (2014). The samples were collected in the rainy season. Bamboos have higher densities as compare to wood (Lucas and Fuwape, 1984).

5.2.2. Bulk Density of *Bambusa vulgaris* across the three ecological zones

The bulk density is one of the parameters used to determine the energy density of biomass (Hakkila and Kalaja, 1983). The mean bulk density exhibited more definite pattern of variation within and between all the zones. On the whole, moist evergreen had the highest values for all the parameters – shoots, culms, branches and foliage. On the contrary the culms from dry semi-deciduous got the lowest values among the age groups. The bulk density for the bamboo culms ranged from 0.10 to 0.42 kg/m^3, foliage varied from 0.14 to 0.51 kg/m^3 and the branches varied from 0.27 to 0.54 kg/m^3.

The bulk densities recorded were in line with the research conducted by the earlier researchers' values on both bamboo and some wood samples (Toolbox (*n.d*); Qisheng *et al.* 2002). The bulk density of seasoned and dry wood are as follows; Afromosia 0.71 kg/m^3; Ash, white 0.54 kg/m^3; Ash, black 0.54 kg/m^3; Ash, European 0.71 kg/m^3; Bamboo 0.3 – 0.4 kg/m^3; African Mahogany 0.5 – 0.85 kg/m^3; Teak, Africa, 0.98; Utile 0.66; Walnut 0.65 – 0.7 kg/m^3 (Toolbox*n.d*). Qisheng *et al.* (2002) reported bulk density values from 0.40 – 0.90 g/cm^3 of *Phyllostachys pubescence.*

Bulk density helps to determine an energy density of a fuel. Energy is a unit energy contained within of fuel. This can be derived by multiplying calorific value (MJ/kg) by bulk density (kg/m^3). According to Carbon Trust (2009), energy density enables users to understand volumetric fuel consumption rates, the size of fuel storage required, the number of deliveries required and the total annual quantity of fuel required.

5.2.3. The calorific values of *Bambusa v. vulgaris* across the three ecological zones

The calorific value of a fuel is the amount of energy released during the complete combustion. This work compares the calorific or heating values of *Bambusa v. vulgaris* across the three ecological zones in Ghana. It also compares the heating values at the various bamboo parts and ages. The overall highest mean heating values were recorded at the dry semi-deciduous zone, followed moist evergreen deciduous zone and the lowest were found in moist semi-deciduous zone. The highest heating values were found at the top of bamboo age groups except the juvenile which had the highest at the base. The highest heating value was recorded at top part of the dead culm. The top part of the bamboo may contain less moisture content. The average values of the calorific values of the culms ranged from 14.23 to 18.10 MJKg^{-1}. The mean values of dead branches exhibited slightly higher heating values than the mature culm. The mean green foliage samples heating values were higher than that of the mean dead foliage. The mean values of the branches varied from 14.31 to 14.56 MJKg^{-1} and the foliage ranged from 10.54 to 14.82 MJKg^{-1}.

The calorific or heating value increases with increase wall thickness of the culm, suggesting that thicker culms would have higher heating value and may burn more slowly than thinner culms. The increase in the bamboo culm wall thickness has correspondent increase in density. It was observed that any increase in density of the culm there was its correspondent increase in calorific value, indicating that culms with more fibres would result in higher heating value.

The net calorific values of *Bambusa v. vulgaris* were comparable to tree species or lower than some agricultural residues and grasses. The higher heating value (dry) of bamboo culm is similar to that of wood which ranges from 17-20 MJKg^{-1} (Montaño, 2014), wood chips (30% MC) 12.5 MJKg^{-1}, wood pellets 17 MJKg^{-1} (Carbon Trust, 2009) wood species like spruce, eucalyptus and populars range from 18.0 - 19.7 MJKg^{-1} (Fieden, 1999) and *Terminalia glanicensus, Ficus ovate and Erythrina senegalensis* 16.02, 17.01 and 18.75 MJKg^{-1} respectively

(Amoah and Cremer, 2017). The values for cane bagasse are 18-20 MJ/kg and wheat straw is 16-19 MJ/kg (Montaño, 2014), miscanthus (bale – 25% MC) 12.1 MJKg^{-1} (Carbon Trust, 2009).

Calorific value or heating value decreases with high moisture content. This means the water in feedstocks of fuel reduces the calorific value and therefore lowers fuel efficiency. Dry bamboos may have more values than the green bamboos used. In an ideal situation, wood species should have high calorific value, high density and low ash content. A combination of three factors: calorific value, density and ash will be most appropriate in determining the suitability of a wood as fuel. On this basis out of the parameters selected from *Bambusa v. vulgaris* analysed the dead culm has the highest fuel property.

5.3. Assess the proximate and ultimate values of *Bambusa v. vulgaris* age groups across the three ecological zones in Ghana for the production of biofuels.

Ultimate analysis is useful in determining the quantity of air required for combustion, the volume and composition of the combustion gases. This information is required for the calculation of flame temperature and the flue duct design etc.

5.3.1. Moisture content in *Bambusa vulgaris* across the three ecological zones in Ghana

Moisture content affects the burning characteristics of biomass (Yang *et al*., 2005). Producing fuel from bamboo biomass requires low moisture content in order to achieve optimum fuel properties. For this study, the highest mean values of moisture content of the fresh or green bamboos were recorded in moist evergreen deciduous zone, followed by moist semi-deciduous and the lowest values were found in dry semi-deciduous zone. The average moisture content decreases as the bamboo matures and also decreases from the base portion to the top across all the ecological zones. The mean values of moisture content in the shoot were from 152 to 172%, juvenile from 138 to 169%, mature from 114 to 153% and the dead culm from 53 to 72%. From literature, the moisture content in bamboo is higher than that of wood.

The values for the green or fresh culms established in this study were similar to earlier researchers. The mean moisture content for *Bambusa v. vulgaris* recorded in Ghana was 61.12 % at the top to 83 % at the base (Assouan, 2002). Tekpetey (2011) also reported that the moisture content of *Bambusa vulgaris* for base, middle and top were 114.30 %, 103.65 % and 99.80 % respectively. The mean values for base, middle and top of *Bambusa vulgaris* ranges from 71.69 % to 145.48 % (Tekpetey et al. 2007; Tekpetey 2009). The culms of *Bambusa vulgaris* from the wet evergreen forest type in Ghana had higher mean values for moisture content than those from moist semi-deciduous forest type (Ebanyenle and Oteng-Amoako, 2007). It was observed that the moisture content values decrease from the base to the top. In addition, the moisture content increases from moist evergreen which has the highest rainfall to dry semi-deciduous zone with the lowest rainfall. Higher moisture content increases both the cost of production and transportation of biofuel (Antal and Gronli, 2003).

The values of moisture content in both branches and foliage rose from dry semi-deciduous zone to moist evergreen deciduous zone. The moisture content of the fresh or dead branches and foliage of *Bambusa vulgaris* were similar to the findings of Miles (1982) who worked on dry wood, stalks and cobs, and bagasse. Moisture content (MC) of green wood ranges from 67 - 150%; dry wood 17%; straw 17%; stalks and cobs 17%, and bagasse 2.30% (Miles, 1982). Other researchers reported the following base of some bamboo species (dry basis): 15 - 20% (Scurlock, 1999) and the top, middle and bottom as 13.7, 13.5 and 13.0% (Ganesh, 2003).

The evaporation of moisture in the bamboo during combustion may likely form undesirable products such as creosote and tars (Duku, Gu and Hagan 2011). This may prevent the combustion from reaching the most favorable temperature. This may affect the operations and efficiencies of the boiler. Also, majority of biomass gasifiers are made to operate on feedstock with low moisture contents of about 10-20% (BEC, 2006).

Higher moisture contents of the bamboo (biomass) reduce the calorific or heating values during combustion. This means the efficiency of the fuel is reduced because a large part of the energy available in the bamboo itself is used to heat up and evaporate this moisture. Heating bamboos (wood) with more moisture content produces more smoke which contains volatile materials including water vapour (Duku, Gu and Hagan 2011; Maker, 2004). More moisture in the bamboo produces less ash. One way to increase efficiency of the biomass would be to dry the material on site. Higher moisture content increases the cost of production and transportation of biofuel feedstocks. As a result, the bamboo biomass has to be dried bellow 20% before use in boilers to achieve maximum fuel yield.

5.3.2. The percentage of volatile matter in the *Bambusa v. vulgaris* samples across the three ecological zones

Generally, the samples from moist semi-deciduous zone recorded the highest values of volatile matter except the dead samples whilst dry semi-deciduous recorded the lowest values. In the various compartments, the mean values of volatile matter increases from the base to the top of the bamboo shoots and mature culms. Conversely, the dead bamboo samples decreases from base to top.

The mean values of volatile matter in the shoot were from 79.83 to 84.52%, juvenile from 82.34 to 86.80%, mature from 82.32 to 85.91% and the dead culm from 81.37 to 086.54%. Generally, the mean percentage volatile matter in the bamboo age groups and parts across the three ecological zones ranged from 79.83 to 86.80%. The values of volatile matter in green foliage ranged from 76.6 to 78.8%, dead foliage varied from 63.40 to 76.60% whilst the green branches ranged from 83.30 to 83.30% and the dead branches varied from 82.00 to 84.90%.

The values were similar to those provided by Ganesh (2003) from 79.6 – 80.6%, Van Loo, and Koppejan, (2008) from 70-86%, and nearly high up to 80% (Huang, 2014). Volatile matter in biomass fuel is vaporized during combustion. So, the volatiles have an effect on the thermal decomposition and combustion behavior of solid fuels (Van Loo, and Koppejan, 2008). The volatiles may consist of minor and heavy metals such as arsenic, lead and sulphur which are injurious to human health (Basu, 2013). Depending on the temperature and the gasifier designed for the combustion, volatiles can also turn into harmful tars which force the pyrolyzed gases to flow through the hot grate where most of the tar-forming components decompose (Basu, 2013).

5.3.3. The Percentage Fixed Carbon in *Bambusa vulgaris* across the three ecological zones

Fixed carbon of a solid fuel is the remains when all the volatile material is distilled off in the furnace. Fixed carbon consists mostly of carbon but also contains some hydrogen, oxygen, sulphur and nitrogen not driven off with the gases. Fixed carbon gives a rough estimate of heating value of biomass.

The highest mean percentage values of fixed carbon were found in moist evergreen zone, followed by moist semi-deciduous and the lowest was found in dry semi-deciduous zone. The mean values of the various compartments decrease from the base to the top across in all the zones. The mean values of fixed carbon in the shoot were from 15.01 to 15.33%, juvenile from 13.77 to 14.52%, mature from 15.45 to 15.59% and the dead culm from 15.87 to 16.15%. Generally, the mean percentage fixed carbon in the bamboo age groups and parts across the three ecological zones ranged from 13.77 to 16.15%.

The values of fixed carbon in green foliage ranged from 13.92 to 14.32%, dead foliage varied from 13.98 to 14.36% whilst the green branches ranged from 14.68 to 14.75% and the dead branches varied from 14.77 to 14.82%. Generally, the mean fixed carbon in the bamboo foliage and branches ranged from 13.92 to 14.82 % across all the three ecological zones.

This study fell within the range of earlier bamboo research conducted by Scurlock (2000) and Ganesh (2003). The results of Scurlock *et al* (1999) experiments to determine fixed carbon contents of three bamboos based on their age type were as follow; *Phyllostachys nigra* 1yr (16.78), 2 yr (16.68) and 4-5 yrs (13.7); *Phyllostachys ambusoides* 1yr (13.8), 2 yr (15.73) and 4-5 yrs (14.38); *Phyllostachys bissetti* 1yr (17.16) 2 yr (16.32) 4-5 yrs (12.14). The fixed carbon content of a bamboo culm is around from height distance top (15.6%), middle (15.6%) and bottom (14.9%). The fixed Carbon of bamboo dust at 11.1% moisture content was 15.9% (Ganesh, 2003) whereas the Huang (2014) stated 15 %.

The study of fixed carbon is very important parameter for gasification analysis as in most gasifiers; the conversion of fixed carbon into gases decides the rate of yield and gasification. Fixed carbon is considered as the slowest conversion reaction of the gasifier (Basu, 2013).

5.3.4. The Ash content in *Bambusa vulgaris* across the three ecological zones

The knowledge of ash and ash mineral compositions of different bamboo age groups may be helpful in assessing the best feedstock for the biofuel production.

The lowest mean values for the ash content amongst the bamboo age groups were recorded at moist evergreen and the highest was found in moist semi-deciduous zone with the exception of the mature samples which recorded its highest value at the dry semi-deciduous zone. The shoot recorded average ash weight of 0.48-2.20%, juvenile from 1.50-2.33%, mature from 0.81-2.04% and the dead culms ranged from 1.68-2.17%. The highest mean value of the foliage was recorded at the moist semi-deciduous, followed by moist evergreen and the lowest measured in dry semi-deciduous. The mean value of the branches descended from dry semi-deciduous to moist evergreen zone. The green foliage ranged from 2.41 to 2.62%, dead foliage varied from 3.48-5.11%, the green braches ranged from 0.69-2.07% and dead branches increased from 0.81-3.26%.

Among the various bamboo parts, the top part of the samples recorded the highest mean ash contents followed by the middle and the lowest found in the base across all the ecological zones with the exception the dead samples from moist semi-deciduous and moist evergreen deciduous zones. The results obtained are similar to that were reported by previous researchers. For example, Ota, (1976) reported that bamboo ash range from 1.7 – 5.0 %. Scurlock (2000) also reported of considerable variation of less than 1 % for three *Phyllostachys spp* of bamboo investigated. The shoot, branches and the leaves were within the range of 1.91% - 4.99% of five other bamboo species reported by (Dannenmann *et al,* 2007). Ratner, (2011) studied the proximate analysis of wood chips and compared it with that of coal. The wood ash was 2.24 wt % while coal was 10.6 wt %. Ash content from switchgrass (dry basis) ranged from 4.4 wt % to 9.2 wt % (Benson and Laumb, 2010).

The *ash* content increases with phosphorus, sodium and magnesium in the combustion process. This means more ash in the biomass the values of phosphorus, sodium and magnesium also increase. These correspond with the results obtained by Miles *et al*., 1998 and Baxter *et al*., 1998. The salts, chlorides, carbonates and sulphides in sodium and magnesium may form eutectics (Baxter *et al*., 1998). Phosphorus can increase the slagging potential of deposits (Baxter *et al*., 1998).

Ash in biomass may melt and agglomerate to produce clinker to cause slag in the gasifiers. If the slag is not removed then the operation in the gasifiers can break down. Repairing the gasifiers will increase costs of production of the biofuel. Usually slagging causes no troubles if the ash content of the fuel is lower than 5% - 6% (FAO, 1986). Bamboo contains approximately 3% - 5% of ash so slagging should not be a major problem but still the ash melting needs to be looked out for.

5.3.5. Carbon concentrations in *Bambusa v. vulgaris*

This section compares the percentage of carbon concentrations in *Bambusa v. vulgaris* age groups and parts. The mean percentage weight of carbon concentrations in the culms varied from dry semi-deciduous, moist semi-deciduous to moist evergreen zones in the ecological zones. This means that the bamboos located in moist evergreen zone contain more percentage of carbon than the other two zones. The mean percentages of carbon in the bamboo age groups agreed with Scurlock *et al.,* (1999) and Agblevor *et al*, (2000).

This section compares the percentages of carbon at various parts of the *Bambusa v. vulgaris*. The highest percentages of carbon were concentrated at the base whilst the lowest were found at the top of all the samples across all the ecological zones. In addition, the highest percentages were found in the dry semi-deciduous zone and the lowest were found in the moist semi-deciduous zone beside the top of the shoot at dry semi-deciduous. The shoot recorded 45.34 – 50.90%; juvenile from 50.13 – 53.70%; mature from 46.12 – 53.70% and the dead culm varied from 43.57 – 53.60%.

The findings of this study fell within the range of 48.5% to 50% on dry basis for bamboo (Nemestothy, 2002; Choy *et al*., 2005), 45-55% (Ganesh, 2003; Vessia, 2006) and carbon contents in three bamboos based on their age 1 year to 5 years ranges from 51.39- 51.84 (Scurlock *et al.,* 1999). Higher carbon content leads to a higher heating value (Clarke and Preto, 2011). Carbon is one of the main components of biomass which increases the heating value therefore high carbon content is needed in biofuels.

5.3.6. Hydrogen concentrations in *Bambusa v. vulgaris*

Hydrogen is desired in bamboos to increase the heating value. This part compares the percentage of hydrogen concentration in *Bambusa v. vulgaris*. The mean concentration of hydrogen increased from dry semi-deciduous zone to moist evergreen zone. The highest mean percentage (%) hydrogen values were found in the moist evergreen zone followed by moist semi-deciduous zone. The average values of the shoot varied from 6.00 (base) to 7.18% (base), juvenile from

5.81 (top) to 6.42% (middle), mature from 6.02 (top) to 6.84% (base) and the dead culm from 5.68 (top) to 6.90% (top). Generally, the mean values of hydrogen from the various age groups ranged from 5.68 to 7.18%.

These results are similar to those reported by other investigators. Hydrogen content of bamboo culms varies from 4.8 to 6.7% (Ganesh, 2003); 6% (Jenkins, 1998) and 6.0 – 6.5% (Choy *et al*., 2005). However, Scurlock *et al* (1999) recorded the hydrogen content in three bamboos based on their age as 1 year (4.90-5.21%), 2 year (5.00-5.29%) and 4-5 year (4.51-5.40%). Higher hydrogen content leads to a higher heating value (Clarke and Preto, 2011). Higher hydrogen content is desired in bamboos to increase the heating value.

The percentage of hydrogen in green foliage increases from the dry semi-deciduous, across the Moist semi-deciduous to moist evergreen zones. The dead foliage exhibited high hydrogen content than the green foliage. Similarly, the dead branches from moist evergreen got greater mean values than the green branches from the other zones. The mean values for the green foliage ranged from 6.20 to 6.73%, dead foliage from 5.90 to 6.98%, the branches varied from 5.90 to 6.84% and dead branches ranged from 6.10 to 6.95%.

The results were in line with earlier work done for energy content on wheat straw 6.00%, rape straw, 5.80% and switch grass, 6.15% (Greenhalf *et al*., 2012), giant reed (Di Candilo *et al*., (2005) and Ghetti *et al*., (1995); Miscanthus *spp*. by Di Candilo *et al*., (2005) and Venturi and Venturi, (2003). It was observed that as the value of hydrogen increases the heating or calorific value increases. This suggests that the higher the hydrogen concentration in the fuel the higher the heating value (Clarke and Preto, 2011). Hydrogen is a reducing gas therefore the cracking of biomass in the presence of hydrogen can reduce the oxygen content in bio-oil (Zhou *et al.,* 2013).

5.3.7. Nitrogen concentrations in *Bambusa v. vulgaris* across the three ecological zones

High nitrogen content in the biomass may lead to environmental pollution. This section examines the nitrogen contents in the various parts of the bamboo age groups across the three ecological zones in Ghana. The lowest mean value of the nitrogen was recorded at the base of the dead culm sample from moist semi-deciduous zone whilst the highest mean value was found at the top of the shoot from dry semi-deciduous zone. The mean values decreases from the shoot to the dead culm among the age groups.

The mean values of nitrogen in the shoot were from 0.46 to 3.20%, juvenile from 0.49 to 0.83%, mature from 0.25 to 0.92% and the dead culm from 0.27 to 0.69%. Generally, the mean percentage nitrogen in the bamboo age groups and parts across the three ecological zones ranged from 0.25 to 3.20%. The mean percentage of nitrogen in both the dead branches and foliage samples were low as compared with the green branches and foliage. This implies that branches and foliage should be dried to reduce the nitrogen content when using them for biofuels. The values of green foliage ranged from 2.26 to 2.99%, dead foliage varied from 1.14 to 1.54% whilst the green branches ranged from 0.38 to 0.60% and the dead branches varied from 0.22 to 0.44%.

The Nitrogen content of biomass ranges from 0.2% to more than 1% (Jenkins, 1998). Ganesh (2003) reported that the Nitrogen content of bamboo culms varies from 0.4 to 1.3%. The results of Scurlock *et al* (1999) experiments show that the nitrogen contents in three bamboos based on their age were *Phyllostachys nigra* 1yr (0.4), 2 yr (0.29) and 4-5 yrs (0.21); *Phyllostachys ambusoides* 1yr (0.59), 2 yr (0.6) and 4-5 yrs (0.38); *Phyllostachys bissetti* 1yr (0.55) 2 yr (0.3) 4-5 yrs (0.32).

Oxides of nitrogen (NOx) cause ozone, smog, and respiratory problems. Wood and fuel oil combustion have similar levels of NOx emissions (Maker, 2004). Nitrogen in fuel feedstock is responsible for most nitrogen oxide (NOx) emissions produced from biomass combustion. Lower nitrogen content in the fuel should lead to lower NOx emissions (Clarke and Preto, 2011). The higher percentage values of nitrogen contents in the *Bambusa vulgaris* were recorded in the shoot and green foliage, however, they the values are low therefore cannot affect the environment. Nitrous oxides are said to have almost the same climate warming effect as carbon dioxide. The concentration of Nitrogen in bamboo branches and the leaves fell within the limit set. The limit set by the German national standard for fuel pellet, Germany DIN 51731 should not be higher than (≤ 0.6%). Bamboo branches, shoots and roots can be used to make charcoal by pyrolysis (carburising) under high temperatures (about 1000°C) (Kittinaovarat and Suthamnoi, 2009).

5.4: Evaluate the concentrations of heavy and minor metals found in the *Bambusa v. vulgaris* age groups and how they can affect human health and fuel conversion technology plants.

The ash mineral elements consist of minor metals such as calcium, potassium, and magnesium; and heavy metals like copper, lead, arsenic and nickel. Most plants absorb heavy and minor metals accumulated in the soil by human activities such as burning fossil fuel, mining, spreading of lime, fertilizer and waste products (Hüttermann *et al*., 1999). The concentration of minor and heavy metals in the *Bambusa vulgaris* culms, branches and foliage or leaves were discussed in this section.

5.4.1. The concentrations of heavy metals in *Bambusa vulgaris*

The mean concentration of copper: The copper concentration in the samples increased consistently from dry semi-deciduous to moist evergreen deciduous zone. The mean values of copper in the shoot were from 1.72 to 6.68*ppm*, juvenile from 1.26 to 7.76*ppm*, mature from 0.38 to 1.58*ppm* and the dead culm from 1.74 to 2.98*ppm*. The mean percentage copper in the bamboo age groups across the three ecological zones ranged from 0.38 to 7.76*ppm*. The mean values of copper in green foliage ranged from 1.24 to 7.62*ppm*, dead foliage varied from 3.44 to 8.32*ppm* whilst the green branches ranged from 2.14 to 2.42*ppm* and the dead branches varied from 2.00 to 2.54*ppm*.

The results of copper concentrations were similar to the studies conducted on wood ash by Kopecky *et al*. (1995). The relationship between copper and calcium was negative. This implies that the more the copper concentration in the bamboo would lower the values of calcium and *vice versa*. Higher concentration of Copper in the biomass can contribute to slagging and fouling in boiler during combustion of biomass for biofuels.

The mean concentration of zinc: Moist evergreen deciduous zone had the highest concentration of zinc, followed by moist semi-deciduous while dry semi-deciduous had the lowest. The juvenile bamboo samples recorded the highest average *Zn* concentration of 5.82 *ppm* whilst the *Zn* concentration at the matured stage was the least (1.36*ppm*). There was more *Zn* concentration at the middle of the samples than all other parts. The mean values of zinc in the shoot were from 2.34 to 5.20*ppm*, juvenile from 3.12 to 5.82*ppm*, mature from 1.36 to 3.70*ppm* and the dead culm from 2.44 to 4.28*ppm*. The mean percentage zinc in the bamboo age groups across the three ecological zones ranged from 1.36 to 5.82*ppm*. The mean values of zinc in green foliage ranged from 2.48 to 3.48*ppm*, dead foliage varied from 2.04 to 2.42*ppm* whilst the green branches ranged from 4.08 to 4.22*ppm* and the dead branches varied from 1.84 to 2.52*ppm*.

Kopecky *et al*. (1995) reported similar values of zinc in wood ash. Zinc also has negative association with calcium. Calcium helps in plant growth; however, the heavy presence of zinc reduces the amount of calcium in the plant (Kawasaki and Moritsugu, 1987; Saleh *et al*.1999).

The mean concentration of lead: The mean concentration of lead in the bamboo culm samples increased from dry semi-deciduous to moist evergreen deciduous zone. Among the culms, the mean lead concentration regardless of position varied insignificantly. The concentration of lead (*Pb*) at all stages of bamboo in all the three zones was very low. The mature culm from moist semi-deciduous and moist evergreen recorded the same values of 0.01 *ppm*. The mean values of lead in the shoot were from 0.01 to 0.21*ppm*, juvenile from 0.02 to 0.12*ppm*, mature from 0.01 to 0.11*ppm* and the dead culm from 0.01 to 0.05*ppm*. The mean percentage of lead in the bamboo age groups across the three ecological zones ranged from 0.01 to 0.21*ppm* (located at the top of the shoot).

The mean values of lead in green foliage ranged from 0.01 to 0.06*ppm*, dead foliage varied from 0.03 to 0.09*ppm* whilst the green branches ranged from 0.02*ppm* (all the zones) and the dead branches varied from 0.01 to 0.05*ppm*. The values of lead concentration observed in the bamboo conform to the findings of Kopecky *et al*. (1995) in wood ash.

The mean concentration of arsenic in the bamboo samples: The mean values for arsenic in both dry semi-deciduous and moist semi-deciduous for shoot, mature and the dead samples were the same. The green and dead branches recorded similar values in all the zones. The highest variation of arsenic was found in the dead sample at the base of the bamboo in the moist evergreen zone whilst the lowest was located at the top in the dry semi-deciduous zone.

The mean values of arsenic in the shoot were from 0.070 to 0.076*ppm*, juvenile from 0.040 to 0.081*ppm*, mature from 0.060 to 0.079*ppm* and the dead culm from 0.075 to 0.082*ppm*. The mean percentage arsenic in the bamboo age groups across the three ecological zones ranged from 0.040 to 0.082*ppm*. The mean values of arsenic in green foliage ranged from 0.06 to 0.11*ppm*, dead foliage varied from 0.04 to 0.11*ppm* whilst both the green and dead branches recorded 0.08*ppm.*

The mean concentration of nickel in the bamboo samples: The shoot and juvenile samples of nickel obtained the lowest values from moist semi-deciduous zone and the highest values from moist evergreen zone. Mature and dead samples also increase from dry semi-deciduous to moist evergreen zones.

The mean values of nickel in the shoot were from 0.22 to 0.86*ppm*, juvenile from 0.34 to 0.84*ppm*, mature from 0.32 to 1.04*ppm* and the dead culm from 0.34 to 1.02*ppm*. The mean values of nickel in green foliage ranged from 0.84 to 1.18*ppm*, dead foliage varied from 0.66 to 1.48*ppm* whilst the green branches ranged from 0.98 to 1.16*ppm* and the dead branches varied from 0.60 to 1.34*ppm*. The mean percentage nickel in the bamboo age groups and parts across the three ecological zones ranged from 0.22 to 1.34*ppm*. The Nickel (*Ni*) concentration in the bamboo samples were similar to that of wood ash investigated by Kopecky *et al.* (1995). The *ash* content moderately associates indirectly with *Ni*.

The mean concentration of cadmium in the bamboo samples: Dry semi-deciduous zone recorded the highest values of cadmium in all the zones. The lowest values found in shoot and juvenile were located at moist semi-deciduous zone. On the contrary, the lowest concentrations for mature and dead were found in moist evergreen deciduous zone.

The mean values of cadmium in the shoot were from 0.20 to 1.78*ppm*, juvenile from 1.28 to 3.18*ppm*, mature from 0.36 to 3.68*ppm* and the dead culm from 1.84 to 3.68*ppm*. The mean values of cadmium in green foliage ranged from 2.02 to 2.50*ppm*, dead foliage varied from 2.42 to 2.50*ppm* whilst the green branches ranged from 1.26 to 2.88*ppm* and the dead branches varied from 0.82 to 1.54*ppm*. Generally, the mean percentage nitrogen in the bamboo age groups and parts across the three ecological zones ranged from 0.20 to 2.88*ppm*. The values obtained for cadmium were within that observed by Kopecky and colleagues (1995). Cadmium has been found to decrease the amount of calcium in plants (Gussarsson, 1994; Arduini *et al*., 1998).

This work highlights the distribution of heavy metals in some selected part of *Bambusa vulgaris*. Generally, it was observed that small quantities of heavy metals were found in bamboo in the three ecological zones in Ghana. Moist evergreen deciduous zone had the highest amount of heavy metals such as copper, zinc, lead, arsenic, nickel and cadmium. The lowest concentrations of heavy metals were found in the dry semi-deciduous with the exception of cadmium. In the various portions, foliage recorded the highest amount of heavy metals (copper, lead, arsenic, nickel and zinc). This was followed by the branches and the least concentrations of the heavy metals were found in mature culms. The elements in the ash are considered necessary to decide which conversion plant should be used for a given biofuel. The ash elementals or the inorganic elements produced during combustion may cause the conversion plant not to work effectively by causing slagging, fouling and corrosion. According to Monti, Di Virgilio and Venturi (2008) slagging is connected to the low melting point of deposits, which creates a glassy layer that must be removed. Fouling is the accumulation of unwanted materials on the surfaces of processing equipment leading a decrease on the exchanger efficiency. Corrosion is caused by the interaction between deposits and metal surface of the exchanger, which involves extra costs in maintenance. The lower concentration of the ash content and the elementals will increase the plant life-span (Reumerman and Berg, 2002).

5.4.2. The concentration of minor metals in *Bambusa vulgaris* in the three ecological zones

The mean concentration of calcium in the bamboo samples: Calcium has positive influence on the growth of plants (Marschner, 1995; Hagemeyer, 1999). Research has shown that wood ash application can increase the concentration of calcium as well as heavy metals, like cadmium, copper and zinc, in the forest soil solution (Bramryd and Fransman, 1995; Arvidsson and Lundkvist, 2003). The lowest concentration of calcium was found in moist evergreen deciduous zone. Apart from the mature samples which recorded different values from dry semi-deciduous and moist semi-deciduous, the rest of the values at both dry semi-deciduous and moist semi-deciduous samples for shoot, juvenile and dead bamboos were equal. The mean calcium concentration in *Bambusa vulgaris* ranged from 15.36 to 29.87*ppm* both located at the middle at the bamboo. The results obtained were in the agreement with that of wood ash by Kopecky *et al*., (1995). Calcium has negative correlation with heavy metals such as cadmium, copper, magnesium and zinc. Equally, heavy metals, such as cadmium and copper, have been found to reduce the Calcium, magnesium and zinc contents. This suggests that calcium decrease the contents of cadmium, copper, magnesium and zinc.

The mean concentration of potassium in the bamboo samples: Moist semi-deciduous zone recorded the highest amount of potassium concentrations in all the three zones. Meanwhile, the lowest were found in dry semi-deciduous zone. The mean values for potassium obtained in all the zones ranged from 0.12 to 2.57 *ppm*. The green foliage recorded the highest mean values among all the parameters for potassium in all the ecological zones. The mean values for both foliage and branches rose from dry semi-deciduous to moist evergreen zone. The average green and dead foliage scored from 0.26 to 1.72 *ppm* and both green and dead branches ranged from 0.18 to 1.00 *ppm*. The results were in the range as compared with that of wood ash by Kopecky *et al*., (1995). The results showed that potassium (K) has a significant effect on the ash content. If the amount of potassium increases, the participant ash content also increases. This implies that more percentage potassium salts in the biomass lowers the temperature during combustion. It also increases the rate of degradation of chemical and yield of char during pyrolysis (Agblevor, 1996; Zhou *et al*., 2013). Consequently, reduces the melting point of the ashes, helping the formation of slags at the entrance of the gasifier causing substantial problem to the combustion process.

The mean concentration of magnesium in the bamboo samples: The average culm values of magnesium for all the zones decrease from dry semi-deciduous, through moist semi-deciduous to moist evergreen zones. Magnesium concentration obtained ran from 0.05 to 0.15*ppm*. Magnesium relates negatively with ash in the bamboo. Similar results were obtained by Miles *et al*., 1998 and Baxter *et al*., 1998. This means more ash in the biomass the values of phosphorus, sodium and magnesium also increase. Magnesium can easily melt to combine with other minerals in the ash to form salts, chlorides, carbonates and sulphides which may increase slagging.

The mean concentration of phosphorus in the bamboo samples: Apart from the dead bamboo samples, the rest of the parameters from moist semi-deciduous registered the highest values of phosphorus across the zones. The mean values for phosphorus were from 0.03 to 0.18*ppm*.

The mean concentration of sodium in the bamboo samples: Moist semi-deciduous zone had the highest amount of sodium concentration among the three zones in Ghana. This study site was near to former headworks of Ghana Water and Sewege. The concentration of sodium in the shoot ranged from 0.13*ppm* to 1.05*ppm* whilst juvenile, mature and dead culms ranged from 0.12 to1.28*ppm*. The samples from dry semi-deciduous zones showed the lowest values of sodium concentrations in both branches and leaves. The values of sodium in both branches and foliage range from 0.12*ppm* to 0.78*ppm*. There was negative relations with sodium and ash content. This suggests that more ash in the biomass increases the sodium which is a potential in forming slagging during gasification.

The mean concentration of aluminium in the bamboo samples: Moist evergreen zone exhibited the highest values of aluminium concentration across the zones with the exemption of dead samples which highest concentration was establised in moist semi-deciduous zone. There were very close increase from one bamboo type to another. The mean values of aluminium ranged from 0.06 to 0.15*ppm.*

The mean concentration of iron in the bamboo samples: The highest concentrations of iron were found in the shoots across the three ecological zones ranging from 0.14*ppm* to 0.20*ppm*. The culms recorded the values ranging from 0.02 to 0.17*ppm*. Among the various compartments, the top of the shoots have the highest values.

Conclusion

The ash content and the mineral elements of *Bambusa v. vulgaris* discovered in this study were comparable to some wood type while that of the bamboo branches and leaves were lower than most wood type but similar to some herbaceous energy crops. The ash in the foliage ranged from 0.48 to 5.11%. These inorganic materials cannot cause any serious slagging, fouling and corrosion to the conversion plant during combustion, according to the guiding values for ashes related to the solid biofuels ISO 1171 (1997). However, 5.11% is slightly higher than 5% provided by ONORM standard (ONORM M 7135, 2003). This implies that *Bambusa v. vulgaris* may be a good feedstock for the production of bioenergy in terms of heat, charcoal, biogas, biopower and transportation fuel.

However, the latest draft of product standard for wood pellets prEN 14961-2 (July 2009) shows that the threshold for ash content was ≥3% (EN 14775). This implies that the ash content in the foliage was more than what was mentioned in the standard. The ash content and mineral in the leaves may cause fouling, slagging and corrosion in the boiler as well as can cause problems to human health. The leaves of the studied bamboo specie had higher ash, nitrogen and cadmium contents than the culms. Removal of the leaves therefore is necessary when using bamboo biofuels.

CHAPTER SIX

SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

6.0. OVERVIEW

The four groups of bamboo culms studied include almost the entire age range of growth stages (shoot, juvenile, mature and dead) and some parts (branches and leaves) of mature and dead culms of *Bambusa v. vulgaris* available for the production of biofuels in Ghana and elsewhere.

6.1. SUMMARY OF FINDINGS

The findings drawn from the study cover the morphological properties; physical and fuel properties; proximate analysis, ultimate analysis; and minor and heavy metals (ash elementals) in the *Bambusa v. vulgaris* in three ecological zones in Ghana.

6.1.1. Compare the morphological properties of *Bambusa v. vulgaris* (bamboo) culms and their affects biofuel production.

The clumps size: The results of the clump sizes showed that moist semi-deciduous zone has more bamboo culms for the production of biofuels. However, the findings show that clump sizes for the three zones were almost the same since there were marginal increase from the lowest mean value of 512cm (dry semi-deciduous) to the biggest 622cm (moist semi-deciduous). Differences in morphological properties of culms were observed across the ecological zones. These differences might be due to differences in climatic and soil conditions.

The height of the bamboo culms: The study addressed the culms in the zones that will provide more bamboo fuel based on the height. The average height of the bamboo culms among the age groups ranged from 10 to 14 metres. The mature culm increases in height consistently downstream from the dry semi-deciduous, moist semi-deciduous to moist evergreen zones. There were marginal differences among the heights of juvenile, mature and dead culms found in the three zones. The culms tapered from the base to the top, however, some samples tapered from the middle to the top. The average height of the bamboo shoots increases from dry semi-deciduous (35.72 cm), moist semi-deciduous (36.44 cm) to moist evergreen (36.82 cm) among the ecological zones.

The culms diameter: The average values of the culms diameter decrease from the bottom to the top in all the ecological zones. The mean diameter of the shoot ranged from 9.43cm to 10.28cm. The highest mean diameter was recorded at moist semi-deciduous and the least at moist evergreen zones. The mean diameter for other culms ranged from 6.67cm to 9.51cm.

The internodes distance: The findings showed that there was a significant difference of the internode distance across the three zones. The internodes distance from the moist evergreen zone has the longest and the shortest found in dry semi-deciduous zone. Generally the internode distance decrease marginally from the bottom to the top of the bamboo culm. The mean internode distance among the culms ranged from 33.98cm to 41.13cm. It was also counted that the average internodes distance of the bamboo ages – juvenile, mature and dead/over-mature of the various ecological zones were different but within each zone they are almost same.

The culm wall thickness: All the average bamboo culm wall thickness increases from dry semi-deciduous to moist evergreen zone. The mean mature culm wall thickness also rose from 10.65mm top to 11.79mm at the bottom. The bamboo culm wall thickness decreases along the culm. The mean values at DBH and thickness of the culms suggest that the morphological properties of *Bambusa vulgaris* are not affected by the geographical locations.

In conclusion, the results obtained from the morphological properties indicated that the full bamboo culm is not uniform in terms of culm wall thickness. Bamboo culms with 10 mm or more and bamboo branches with about 20mm wall thickness either with short or long internode distance can be used for making solid or briquetted charcoal. Shorter internode distance and thicker culm wall thickness produced denser biomass feedstock with higher heating values.

Meanwhile, from literature grass such as bamboo with any height or diameter can be used as feedstock for anaerobic digestion (AD) to generate biogas and biomethane for use as a transport fuel. Finally, bamboo culms found in the moist evergreen deciduous were better-quality morphological properties (if they are well dried) followed by those in moist semi-deciduous then dry semi-deciduous zones.

6.1.2. Physical and fuel properties of *Bambusa v. vulgaris*

The increase in the bamboo culm wall thickness has its correspondent increase in **density**. It was observed that any increase in density of the culm has its correspondent increase in calorific value, indicating that culms with more fibres would result in higher heating value. The moist evergreen deciduous zone recorded the highest average basic density, followed by moist semi-deciduous and the lowest recorded at dry semi-deciduous. The density reduces along the height from base to the top. The average basic density of shoot of *Bambusa vulgaris* decreased from 413kgm^{-3} to 401kgm^{-3}. The average basic density of other culms ranged from 664 to 715kgm^{-3}. The green branches recorded the density of 279 kgm^{3} and dried branches 208 kgm^{-3}.

Bulk density helps to determine an energy density of a fuel. The energy density enables users to be aware of volumetric fuel utilisation rates, the size of fuel storage required, the number of deliveries required and the total annual quantity of fuel required. The average bulk density decreased from moist evergreen zone to dry semi-deciduous. The juvenile from the moist evergreen zone recorded the highest bulk density. The bulk density the culms ranged from 0.12 to 0.54kgm^{-3}. The bulk density of shoot was from 0.13 to 0.17kgm^{-3}, foliage varies from 0.40 to 0.51kgm^{-3} and the mean branches ranged from 0.27 to 0.52kgm^{-3}.

The overall mean highest **heating/calorific values** were recorded at the dry semi-deciduous zone, followed moist evergreen deciduous zone and the lowest were found in moist semi-deciduous zone. The calorific or heating value of bamboo fuel decreases with increasing of its moisture content. The water in feedstocks of fuel reduces the calorific value and therefore lowers fuel efficiency. The calorific value also increases with increase wall thickness of the culm, suggesting that thicker culms would have higher heating value and may burn more slowly than thinner culms. The average calorific value of the shoot ranged from 15.21 MJKg^{-1} to 17.02 MJKg^{-1}. The culms mean values ranged from 15.20 to 17.74 MJKg^{-1}. The average calorific values of foliage vary between 12.13 MJ/kg and 13.93 MJ/kg. The value of branches ranged from 13.58 MJ/kg to 15.98 MJ/kg.

6.1.3 The Proximate and ultimate analyses of *Bambusa v. vulgaris*

Proximate analysis specifies the percentage by weight of the moisture content, volatiles, fixed carbon and ash in biomass. Ultimate analysis consists of carbon, hydrogen and nitrogen.

The results proved the mean **moisture content** from the moist evergreen deciduous zone exhibited high values, followed by moist semi-deciduous and then dry semi-deciduous zones in Ghana. The average moisture content decreases with age from the base portion to the top along the height culm across all the ecological zones. The fresh shoot rose from 154% to 169%, juvenile ranged from 147% to 158%, mature samples also ranged from 121% to 148% and the dead samples ranged from 53% to 68%. The moisture content of the *Bambusa vulgaris* ranged from 76 to 103% for green bamboo mature branches, 11 to 19% in dead branches, 36 to 38% green leaves and 9 to 16% for dead leaves.

Generally, the samples from moist semi-deciduous zone recorded the highest values of volatile matter except the dead samples whilst dry semi-deciduous recorded the lowest values. The mean volatile matter in the bamboo age groups ranged from 79.83 (foliage) to 86.80 % (juvenile). In the various compartments, the mean values of volatile matter increases from the base to the top of the bamboo shoots and mature culms. Conversely, the dead bamboo samples decreases from base to top. This was a significant difference among the foliage of the bamboo across the three zones. The mean values of the volatile matter in the foliage ranged from 63.40 to 78.80% and branches vary between 82.00 and 84.90%. Depending on the temperature and the gasifier designed for the combustion, volatiles can also turn into harmful tars which force the pyrolyzed gases to flow through the hot grate where most of the tar-forming components decompose.

The highest mean **fixed carbon** of the culms was observed at the base portion of the dead bamboo in moist evergreen deciduous zones. The culms from the top of dead at dry semi-deciduous recorded the least value. The mean values of the various bamboo compartments decrease from the base to the top across all the zones. The results of percentage weight of **fixed**

carbon across the three ecological zones ranged from 13.77 to 16.15%. The mean values of the fixed carbon in the foliage ranged from 13.92 to 14.36% and branches vary between 14.68 and 14.82%.

The results pointed out that higher ash content have more phosphorus, sodium and magnesium content which can increase the slagging potential of deposits in the combustion plant. The mean **ash content** in the shoot ranged from 0.51% to 1.72%, juvenile samples was from 1.71% to 2.01%, mature samples ranged from 0.93% to 1.83% and the dead bamboo samples recorded 1.32 to 2.17%%. Among the various portions, the top part of the samples recorded the highest mean ash content followed by the middle and the lowest found in the base across all the ecological zones with the exception the dead samples from moist semi-deciduous and moist evergreen deciduous zones. The average ash content of the green bamboo foliage recorded 2.41% to 2.62% and the mean dead values ranged from 3.48% to 5.11. The mean dead branches vary from 0.81% to 3.26% whilst the average green branches recorded 0.69% to 2.07%.

The finding showed that **carbon** in the bamboo biomass increases the heating value; this suggests that high carbon content is needed in biofuels. The higher the percentage of carbon contents in the fuel the lower the ash content. The average percentage of carbon in the bamboo increases from dry semi-deciduous zones moist semi-deciduous zone. The juvenile recorded the highest percentage of carbon, followed by the dead samples. The average percentage weights of carbon in the bamboo culms ranged from 48.58 to 53.31%, foliage ranged from 38.46 to 52.16% and branches also ranged from 36.56 to 52.68%.

The results of percentage weight of **hydrogen** across the three ecological zones ranged from 5.68 to 7.18%. The percentage of hydrogen in the foliage ranged from 5.90 to 6.73%. The branches ranged from 5.90% to 6.95%. The correlation between the heating or calorific value and hydrogen was very strong and positive. This suggests that the higher the hydrogen concentration in the fuel, the higher the heating value. Hydrogen is desired in bamboos to increase the heating value.

The **nitrogen** concentration in juvenile was higher than that of the rest of the culms. The results of percentage weight of nitrogen across the three ecological zones ranged from 0.25 to 3.20%. The values of nitrogen for foliage and branches at different ecological zones ranged from 1.14 to 2.99% in foliage and branches vary between 0.22 and 0.60%. The relationships between the percentage of nitrogen, heating value and ash content were not significant. The percentage of nitrogen content in the *Bambusa vulgaris* was low as a result cannot affect the environment. Nitrogen in fuel feedstock is responsible for most nitrogen oxide (NOx) emissions produced from biomass combustion. Nitrous oxides are said to have almost the same climate warming effect as carbon dioxide.

In conclusion, it was observed that high moisture content reduces the ash content in the bamboo and dried bamboo produces more ashes. It was also found out that the higher the density of the bamboo culm the lower the ash content. Calorific value or heating value decreases with high moisture content. This suggests that high moisture content in the bamboo feedstock reduces the calorific value and therefore lowers fuel efficiency. The calorific values established in this work were slightly lower than some wood species like beach, sprue and eucalyptus. However, the calorific values of bamboo samples were higher than most Agricultural residues, grasses and straws used to manufacture biofuels. Meanwhile, the foliage and branches were similar to some of Agricultural residues, grasses and straws.

6.1.4. Evaluate the concentrations of heavy and minor metals found in the *Bambusa v. vulgaris* age groups and how they affect fuel conversion technology plants

The elements of ash minerals in *Bambusa vulgaris* consist of heavy metals like copper, zinc, lead, arsenic, nickel and cadmium.

The results of percentage weight of **copper** across the three ecological zones ranged from 0.38 to 7.76 *ppm*. The mean values of the copper in the foliage ranged from 1.24 to 8.32*ppm* and branches vary between 2.00 and 2.54 *ppm*. The copper concentration in the samples increased consistently from dry semi-deciduous to moist evergreen deciduous zone. There was negative correlation between copper and calcium. This puts forward that the more the copper concentration in the bamboo would lower the values of calcium and *vice versa*. Copper contributes to slagging and fouling in boiler during combustion of biomass for biofuels.

Moist evergreen deciduous zone had most of the concentration of **zinc**, moist semi-deciduous was medium while dry semi-deciduous had the lowest. Zinc also has negative association with calcium. Calcium helps in plant growth; however, the heavy presence of zinc reduces the amount of calcium in the plant.

The **lead** concentrations in the bamboo culm samples rose from dry semi-deciduous to moist evergreen deciduous zone. The results of percentage weight of lead across the three ecological zones ranged from 0.01 to 0.06*ppm*. The mean values of the lead in the foliage ranged from 0.01 to 0.09*ppm* and branches vary between 0.01 and 0.09*ppm*.

The **arsenic** concentrations were equal in both dry semi-deciduous and moist semi-deciduous for shoot, mature and the dead samples. However, the juvenile recorded variations from dry semi-deciduous to moist evergreen zone. The results of percentage weight of arsenic across the three ecological zones ranged from 0.040 to 0.082*ppm*. The mean values of the arsenic in the foliage ranged from 0.04 to 0.11*ppm* and branches vary between 0.04 and 0.11*ppm*.

The shoot and juvenile samples of **nickel** obtained the lowest values from moist semi-deciduous zone and the highest values from moist evergreen zone. Mature and dead samples also increase from dry semi-deciduous to moist evergreen zones. The *ash* content moderately associates indirectly with *Ni*. The results of percentage weight of nickel across the three ecological zones ranged from 0.22 to 1.34*ppm*.

Dry semi-deciduous zone recorded the highest values of **cadmium** in all the zones. The lowest values found in shoot and juvenile were located at moist semi-deciduous zone. On the contrary, the lowest concentrations for mature and dead were found in moist evergreen deciduous zone. The results of percentage weight of cadmium across the three ecological zones ranged from 0.20 to 2.88*ppm*. Cadmium has been found to decrease the amount of calcium in plants.

6.1.5. The concentrations of minor metals in *Bambusa vulgaris*

The minor metals include as calcium, potassium, magnesium, phosphorus, sodium, aluminium and iron.

Moist evergreen deciduous zone had the lowest concentration of **calcium** in all the ecological zones. The mean calcium concentration in *Bambusa vulgaris* culms ranged from 15.36 to 29.87 *ppm*.

The mean values for **potassium** obtained in all the zones ranged from 0.12 to 2.57 *ppm*. Magnesium concentration obtained ran from 0.05 to 0.15*ppm*. The mean values for phosphorus were from 0.03 to 0.18*ppm*. The values of sodium in both branches and foliage range from 0.12*ppm* to 1.28*ppm*. The mean values of aluminium ranged from 0.06 to 0.15*ppm*. The mean concentration of iron ranged from 0.02*ppm* to 0.20*ppm*.

The average culm values of **magnesium** for all the zones decrease from dry semi-deciduous, through moist semi-deciduous to moist evergreen zones. Magnesium, phosphorus and sodium relate negatively with ash in the bamboo. This means if the ash content in the biomass increases the magnesium, phosphorus and sodium contents increase.

Apart from the dead bamboo samples, the rest of the parameters from moist semi-deciduous registered the highest values of **phosphorus** across the zones. Moist semi-deciduous zone had the highest amount of **sodium** concentration among the three zones in Ghana. The samples from dry semi-deciduous zones showed the lowest values of sodium concentrations in both branches and leaves. There was negative relations with sodium and ash content. This suggests that more ash in the biomass increases the sodium which is a potential in forming slagging during gasification.

Moist evergreen zone exhibited the highest values of **aluminium** concentration across the zones with the exemption of dead samples which highest concentration was establised in moist semi-deciduous zone. There were very close increase from one bamboo type to another.

The highest concentrations of **iron** were found in the shoots across the three ecological zones. In conclusion, it was observed that magnesium, phosphorus, sodium, aluminium and iron had fewer concentrations in ash. It was also clear that the shoot recorded the highest concentration of all the micronutrients.

The relationship among the heavy and minor metals: Calcium has negative correlation with heavy metals such as cadmium, copper, magnesium and zinc. Equally, heavy metals, like cadmium and copper, have been found to reduce the Calcium, magnesium and zinc contents. This suggests that calcium decrease the contents of cadmium, copper, magnesium and zinc. Moist semi-deciduous zone recorded the highest amount of potassium concentrations in all the three zones. Meanwhile, the lowest were found in dry semi-deciduous zone. The green foliage recorded the highest mean values among all the parameters for potassium in all the ecological zones. The mean values for both foliage and branches rose from dry semi-deciduous to moist evergreen zone. The results showed that potassium (K) has a significant effect on the ash content. If the amount of potassium increases, the participant ash content also increases.

In conclusion, the concentrations of minor and heavy metals were below the standard set by EN 1496 1-2 and therefore may not cause problems to human health. However, the values of *Cadium* were above the standard. Calcium and Magnesium contents increase the melting point of ash. Potassium content lowers the melting point of ash which can cause slagging (Kopecky *et al,* 1995).

6.2. CONCLUSIONS

6.2. 1. Compare the morphological properties of *Bambusa v. vulgaris* (bamboo) culms and their affects on biofuel production

The study was to investigate the fuel properties of *Bambusa vulgaris* for the production of biofuels.

Moist semi deciduous zone (MSD) recorded the biggest clump size (622.33cm), 584cm (MED) and 512cm (DSD). However, the result shows that the number of bamboo culms in the clumps found in the three zones were almost the same to produce biofuels. Differences in morphological properties of culms were observed across the ecological zones. These differences might be due to differences in climatic and soil conditions.

Bamboo culms with shorter internode distance (35-38mm) and thicker walls (9-11mm), high density has high heating values. These culms can produce quality solid charcoal and other biofuels to reduce the emissions of greenhouse gases. Bamboo branches with diameter less than 10mm, culms with longer internode distance and thinner walls less than 10mm can be used for briquette charcoal to avoid waste of materials. Bamboo with shorter internode distance and thicker culm wall thickness produced denser biomass feedstock with higher heating values.

6.2.2. Determine the physical and fuel properties of *Bambusa v. vulgaris* (bamboo) age groups' culms

The mean values for density range from (395-743kg/m^3), bulk density (0.12-0.52g/m^3) and calorific value (12-18.0 MJKg^{-1}).

Density increased along the culm this may be due to the increment of vascular bundles from bottom to the top. The dead bamboo culm might go through trends involving consistent increases in culm volume density.

A biomass with higher bulk density has more mass of fuel in a given volume. The bulk density reduces the cost of production, transportation, conversion and distribution of the biomass.

The mean calorific value of the bamboo is higher than most Agricultural residues, grasses and straws. Meanwhile, it is lower than many woody biomasses.

Density, bulk density and calorific value have enough values for energy needs to generate electricity, heat homes, fuel vehicles and heat for industrial facilities. This will reduce the emission of greenhouse gasses.

6.2.3. Assess the ultimate and proximate values of *Bambusa v. vulgaris* age groups across the three ecological zones in Ghana for the production of biofuels.

The values for volatile matter ranged from 76 – 84%, fixed carbon from 14-16%, carbon from 46-52%, hydrogen from 6.4-6.6%, nitrogen from 0.12-1.3% and oxygen 40-44%.

The volatiles consist of permanent gases like methane, carbon dioxide, carbon monoxide and vapours, which can be condensed to form bio-oil.

Volatile matter and fixed carbon contents are significant in biofuels because they increase flame length and help easier ignition and subsequent gasification of biomass. Mature and dead bamboo culms in all the zones have large amount of FC, C, H, high heating values and high density to produce quality biogas. Volatile matter increases as Ash content decreases ($r= -0.830$, $p= 0.01$).

The mean value of nitrogen in the shoot and foliage were more than the ≤ 1% according to European standard EN 15104. Nitrogen in the shoot and foliage can be released to atmosphere to combine with oxygen to form oxide. Nitrous oxide is one of the agents of greenhouse gasses which can cause global warming.

6.2.4. Evaluate the concentrations of minor and heavy metals found in the *Bambusa v. vulgaris* age groups and how they affect human health and fuel conversion technology plants.

Ash is the non-combustible component (formed from mineral matter bound in the carbon structure) of biomass and the higher the fuel's ash content, the lower its calorific value.

The study show that minor and heavy metals vary across the age groups of culms and also across the ecological zones. This suggests that mobility of minor and heavy metals are age-dependant and also dependant on the level of soil contamination across the ecological zones.

The leaves of the studied bamboo specie had higher ash, nitrogen and cadmium contents than the culms. They were above the standard set by the Europeans. The ash content and mineral in the leaves may cause fouling, slagging and corrosion in the boiler as well as cause problems to human health.

6.3. RECOMMENDATIONS

The following recommendations have been made to ensure sustainability bamboo resource as feedstock for the development of bioenergy sector. I recommend that;

6.3.1. Production of biofuels: Selection of bamboo culms for production of charcoal should be based on thicker culm wall thickness and shorter internode distance. Bamboo branches with diameter less than 10mm, culms with longer internode distance and thinner walls less than 10mm can be used for briquette charcoal.

Mature and dead bamboo culms from any ecological zones have large amount of fixed carbon, carbon, hydrogen, high heating values and high density that can be used to produce quality biofuel such as charcoal, bioethanol, synthetic gasses and biodiesel.

Mature and dead bamboo culms in any zone can be used for the production of biofuels. Shoots and juvenile should not be used to produce biofuels but allowed to grow in order to help to maintain and sustain the clumps.

6.3.2. Cost of bamboo fuel production: An investigation into the cost of harvesting and processing of bamboo plants as a raw material for biofuel should be carried out in order to understand the potential use.

6.3.3. Research and Development (R&D): The Government of the Republic of Ghana, Forestry Research Institute of Ghana, Ministry of Land and Forestry, and Ministry of Energy should help research, take the inventory of bamboos in terms of quantity, quality and location and develop a data bank and resource documentation centre. Then establish standards and operational procedures for bamboo producers and operators.

6.3.4. Identification and importation of small or large scale technologies: The Government of Ghana and the Ministry of Energy should import technologies that can convert bamboos and other lignocellulose materials for sustainable and commercial production of transport fuels, heat, power and gas. The products should be used for local consumption and for exports. Fiscal incentives and favourable pricing mechanisms should be introduced to those who manufacture and use the products.

6.3.5. Creating awareness to increase the knowledge base of biofuels from bamboo: The Ministry of Energy should create awareness and liaise with relevant institutions to provide range of training for the unemployed youth to design and make simple technologies to produce bamboo briquetted charcoals. These briquetted charcoals could be used in both small and large scale industries. In addition, simple technologies could be made to produce alcohol or syngas from lignocellulose materials such as bamboo to produce transport fuel and electricity. There is the need to train farmers and organisations which will manage the technologies and conduct environmental impact and risk assessments.

6.3.6. Educating farmers to cultivate more bamboos: The farmers and other stakeholders must be well informed on how to cultivate bamboos through training, seminars, workshops and related activities to enable them function more effectively in respect of good yield and environmental concerns.

6.3.7. Releasing land for the cultivation of bamboos: To ensure sound management and expansion of bamboos for the production of biofuels, local authorities and traditional rulers who are custodians of the farmlands should release lands for the cultivation of different bamboo species. In addition, there should be equitable contract agreement for the lease of land for bamboo plantations and fair compensations should be paid to those who have their properties on such lands.

6.3.8. Further research and funding: Further research should be carried out by local scientists and technologists. They should study new and innovative ways of producing charcoal and other biofuels which are less expensive but more efficient. Collective and individuals from both public and private sectors should assist scientists, technologists and farmers by funding and promoting bamboos as resource for the production of solid, liquid or gas biofuels.

6.4. CONTRIBUTION TO KNOWLEDGE

Few researchers worldwide have studied the fuel properties in varieties of bamboo for the production of biofuels.

- None of them reported on the size of the bamboo clumps sizes and their contribution to production of biofuels.
- Past studies that covered different portions of bamboos such as age groups did not mention the fuel properties of the branches and the leaves.
- Commercial uses of bamboos are lacking in most African countries. Most African countries use bamboo as firewood which is a source of respiratory problems like asthma, bronchitis and

pneumonia. Using solid and briquette charcoal and other bamboo biofuels may reduce the emissions of greenhouse gases and respiratory problems.

6.5. AREAS OF SUBSEQUENT RESEARCH

Areas of subsequent research work include the following:

1. Assess the biochemical and biomaterial properties of *Bambusa v. vulgaris* bamboo in Ghana.
2. Compare the heavy metal contents in *Bambusa v. vulgaris* bamboo to that of its surrounding soils in the three ecological zones in Ghana.
3. Investigate the chemical and fuel properties of *Bambusa vulgaris v.* (yellow-green variety); *Bambusa arundinacea; Dendrocalamus strictus; Oxytenanthera abyssinica; Bambusa multiplex and Bambusa pervariabilis* bamboo species in Ghana.
4. Assess the best technologies that can support the production of solid, liquid and gas biofuels from bamboos in Ghana.
5. Promote the cultivation of varieties of bamboo species in Ghana.

This work, when applied, in fact will provide biofuels to run transports; heat for homes and industries; reduce carbon dioxide emissions from fossil fuel; improve national energy security by reliance on foreign sources of energy and reduce threat of price instability; and alleviate poverty especially in the rural communities in the developing countries.

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APPENDICES

FIELD RAW DATA OF *BAMBUSA V. VULGARIS* BAMBOO FROM THREE ECOLOGICAL ZONES IN GHANA

1. PROXIMATE ANALYSIS

Calorific values

S/N	Parameter	Position	Dry Semi-Deciduous DSD	Moist Semi-Deciduous MSD	Moist Evergreen MED
1	Shoot	Top			
2		Middle			
3		Bottom			
4	Juvenile	top			
5		Middle			
6		Bottom			
7	Mature	Top			
8		Middle			

9		Bottom			
10	Dead	Top			
11		Middle			
12		Bottom			
13	Branches	Green			
14		Dead			
15	Leaves	Green			
16		Dead			

Density as received

S/N	Parameter	Position	Dry Semi-Deciduous	Moist Semi-Deciduous	Moist Evergreen
1	Shoot	Top			
2		Middle			
3		Bottom			
4	Juvenile	top			
5		Middle			
6		Bottom			
7	Mature	Top			
8		Middle			
9		Bottom			
10	Dead	Top			
11		Middle			
12		Bottom			
13	Branches	Green			
14		Dead			
15	Leaves	Green			
16		Dead			

Bulk density

S/N	Parameter	Position	Dry Semi-Deciduous	Moist Semi-Deciduous	Moist Evergreen
1	Shoot	Top			
2		Middle			
3		Bottom			
4	Juvenile	top			
5		Middle			
6		Bottom			
7	Mature	Top			
8		Middle			
9		Bottom			
10	Dead	Top			
11		Middle			
12		Bottom			
13	Branches	Green			
14		Dead			
15	Leaves	Green			
16		Dead			

MOISTURE CONTENT AS RECEIVED

		Dry Semi-Deciduous				Moist Semi-Deciduous				Moist Evergreen			
		Shoot	Juvenile	Matured	Dead	Shoot	Juvenile	Matured	Dead	Shoot	Juvenile	Matured	Dead
Top	1												
	1												
	1												
	1												
	1												
Middle	2												
	2												
	2												
	2												
	2												
Bottom	3												
	3												
	3												
	3												

	3												

MOISTURE CONTENT AS RECEIVED

		DSD		**MSD**		**WED**	
Parameter		**Branches**	**Leaves**	**Branches**	**Leaves**	**Branches**	**Leaves**
Green	1						
	1						
	1						
	1						
	1						
Dead	2						
	2						
	2						
	2						
	2						

VOLATILE MATTER (wt%)

		DSD				**MSD**				**MED**			
		Shoot	**Juvenile**	**Matured**	**Dead**	**Shoot**	**Juvenile**	**Matured**	**Dead**	**Shoot**	**Juvenile**	**Matured**	**Dead**
Top	1												
	1												
	1												
	1												
	1												
Middle	2												
	2												
	2												
	2												
	2												
Base	3												
	3												
	3												
	3												
	3												

VOLATILE MATTER (wt%)

		DSD		**MSD**		**WED**	
Parameter		**Branches**	**Leaves**	**Branches**	**Leaves**	**Branches**	**Leaves**
Green	1						
	1						
	1						
	1						
	1						
Dead	2						
	2						
	2						
	2						
	2						

FIXED CARBON wt% (dry)

DSD **MSD** **MED**

		Shoot	Juvenile	Matured	Dead	Shoot	Juvenile	Matured	Dead	Shoot	Juvenile	Matured	Dead
Top	1												
	1												
	1												
	1												
	1												
Middle	2												
	2												
	2												
	2												
	2												
Bottom	3												
	3												
	3												
	3												
	3												

		DSD		MSD		WED	
Parameter		**Branches**	**Leaves**	**Branches**	**Leaves**	**Branches**	**Leaves**
Green	1						
	1						
	1						
	1						
	1						
Dead	2						
	2						
	2						
	2						
	2						

ASH CONTENT (wt% (dry)%)

		DSD				MSD				MED			
		Shoot	**Juvenile**	**Matured**	**Dead**	**Shoot**	**Juvenile**	**Matured**	**Dead**	**Shoot**	**Juvenile**	**Matured**	**Dead**
Top	1												
	1												
	1												
	1												
	1												
Middle	2												
	2												
	2												
	2												
	2												
Bottom	3												
	3												
	3												
	3												

	3												

ASH CONTENT (wt%)

		DSD		MSD		WED	
Parameter		**Branches**	**Leaves**	**Branches**	**Leaves**	**Branches**	**Leaves**
Green	1						
	1						
	1						
	1						
	1						
Dead	2						
	2						
	2						
	2						
	2						

2. ULTIMATE ANALYSIS

CARBON (wt% in dry basis)

		DSD				MSD				MED			
		Shoot	**Juvenile**	**Matured**	**Dead**	**Shoot**	**Juvenile**	**Matured**	**Dead**	**Shoot**	**Juvenile**	**Matured**	**Dead**
Top	1												
	1												
	1												
	1												
	1												
Middle	2												
	2												
	2												
	2												
	2												
Bottom	3												
	3												
	3												
	3												
	3												

CARBON (wt% in dry basis)

		DSD		MSD		WED	
Parameter		**Branches**	**Leaves**	**Branches**	**Leaves**	**Branches**	**Leaves**
Green	1						
	1						
	1						
	1						
	1						
Dead	2						
	2						
	2						
	2						
	2						

HYDROGEN (wt.% in dry basis)

		DSD				MSD				MED			
		Shoot	Juvenile	Matured	Dead	Shoot	Juvenile	Matured	Dead	Shoot	Juvenile	Matured	Dead
Top	1												
	1												
	1												
	1												
	1												
Middle	2												
	2												
	2												
	2												
	2												
Bottom	3												
	3												
	3												
	3												
	3												

HYDROGEN (wt.% in dry basis)

		DSD		MSD		WED	
Parameter		Branches	Leaves	Branches	Leaves	Branches	Leaves
Green	1						
	1						
	1						
	1						
	1						
Dead	2						
	2						
	2						
	2						
	2						

NITROGEN (wt% in dry basis)

		DSD				MSD				MED			
		Shoot	Juvenile	Matured	Dead	Shoot	Juvenile	Matured	Dead	Shoot	Juvenile	Matured	Dead
Top	1												
	1												
	1												
	1												
	1												
Middle	2												
	2												
	2												
	2												
	2												
Bottom	3												

	3												
	3												
	3												
	3												

NITROGEN (wt% in dry basis)

		DSD		**MSD**		**WED**	
Parameter		**Branches**	**Leaves**	**Branches**	**Leaves**	**Branches**	**Leaves**
Green	1						
	1						
	1						
	1						
	1						
Dead	2						
	2						
	2						
	2						
	2						

3. ASH ELEMENTAL ANALYSIS (HEAVY METALS IN *BAMBUSA V. VULGARIS*)

IRON (Fe)

		DSD				**MSD**				**MED**			
		Shoot	**Juvenile**	**Matured**	**Dead**	**Shoot**	**Juvenile**	**Matured**	**Dead**	**Shoot**	**Juvenile**	**Matured**	**Dead**
Top	1												
0.027	1												
	1												
	1												
	1												
Middle	2												
	2												
	2												
	2												
	2												
Bottom	3												
	3												
	3												
	3												
	3												

IRON (Fe)

		DSD		**MSD**		**WED**	
Parameter		**Branches**	**Leaves**	**Branches**	**Leaves**	**Branches**	**Leaves**
Green	1						
	1						
	1						
	1						
	1						
Dead	2						
	2						
	2						
	2						
	2						

LEAD (Pb) ppm

		DSD				MSD				MED			
		Shoot	**Juvenile**	**Matured**	**Dead**	**Shoot**	**Juvenile**	**Matured**	**Dead**	**Shoot**	**Juvenile**	**Matured**	**Dead**
Top	1												
	1												
	1												
	1												
	1												
Middle	2												
	2												
	2												
	2												
	2												
Bottom	3												
	3												
	3												
	3												
	3												

Lead (Pb) ppm

		DSD		MSD		WED	
Parameter		**Branches**	**Leaves**	**Branches**	**Leaves**	**Branches**	**Leaves**
Green	1						
	1						
	1						
	1						
	1						
Dead	2						
	2						
	2						
	2						
	2						

ARSENIC (*As*) ppm

		DSD				MSD				MED			
		Shoot	**Juvenile**	**Matured**	**Dead**	**Shoot**	**Juvenile**	**Matured**	**Dead**	**Shoot**	**Juvenile**	**Matured**	**Dead**
Top	1												
	1												
	1												
	1												
	1												
Middle	2												
	2												
	2												
	2												
	2												

Bottom	3												
	3												
	3												
	3												
	3												

ARSENIC (*As*) ppm

		DSD		MSD		WED	
Parameter		**Branches**	**Leaves**	**Branches**	**Leaves**	**Branches**	**Leaves**
Green	1						
	1						
	1						
	1						
	1						
Dead	2						
	2						
	2						
	2						
	2						

COPPER (Cu) ppm

		DSD				MSD				MED			
		Shoot	**Juvenile**	**Matured**	**Dead**	**Shoot**	**Juvenile**	**Matured**	**Dead**	**Shoot**	**Juvenile**	**Matured**	**Dead**
Top	1												
	1												
	1												
	1												
	1												
Middle	2												
	2												
	2												
	2												
	2												
Bottom	3												
	3												
	3												
	3												
	3												

Copper (Cu) ppm

		DSD		MSD		MED	
Parameter		**Branches**	**Leaves**	**Branches**	**Leaves**	**Branches**	**Leaves**
Green	1						
	1						
	1						
	1						
	1						
Dead	2						
	2						
	2						

	2						
	2						

ZINC (Zn) ppm

		DSD				MSD				MED			
		Shoot	**Juvenile**	**Matured**	**Dead**	**Shoot**	**Juvenile**	**Matured**	**Dead**	**Shoot**	**Juvenile**	**Matured**	**Dead**
Top	1												
	1												
	1												
	1												
	1												
Middle	2												
	2												
	2												
	2												
	2												
Bottom	3												
	3												
	3												
	3												
	3												

Zinc (*Zn*) ppm

		DSD		**MSD**		**WED**	
Parameter		**Branches**	**Leaves**	**Branches**	**Leaves**	**Branches**	**Leaves**
Green	1						
	1						
	1						
	1						
	1						
Dead	2						
	2						
	2						
	2						
	2						

NICKEL (*Ni*) ppm

		DSD				MSD				MED			
		Shoot	**Juvenile**	**Matured**	**Dead**	**Shoot**	**Juvenile**	**Matured**	**Dead**	**Shoot**	**Juvenile**	**Matured**	**Dead**
Top													
Middle													

Bottom													

Nickel (*Ni*) ppm

		DSD		**MSD**		**WED**	
Parameter		**Branches**	**Leaves**	**Branches**	**Leaves**	**Branches**	**Leaves**
Green							
Dead							

CADMIUM (Cd) ppm

		DSD				**MSD**				**MED**			
		Shoot	**Juvenile**	**Matured**	**Dead**	**Shoot**	**Juvenile**	**Matured**	**Dead**	**Shoot**	**Juvenile**	**Matured**	**Dead**
Top													
Middle													
Bottom													

CADMIUM (*Cd*) ppm

		DSD		**MSD**		**WED**	
Parameter		**Branches**	**Leaves**	**Branches**	**Leaves**	**Branches**	**Leaves**
Green							
Dead							
