ASSESSMENT OF VOLUME, BIOMASS AND CARBON STOCK OF CASHEWNUTS TREES IN LIWALE DISTRICT, TANZANIA

HUMPHREY EDWARD MLAGALILA

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ABSTRACT

Estimation of individual tree volume and biomass is important for assessing removal of green house gases potential of the cashew trees and therefore provide a useful tool for the emerging carbon credit market mechanisms. The aim of this study was to estimate volume and biomass stocks of *Anacardiumoccidentale L.* grown in Coast Regions, Tanzania. Woodlots inventory data were collected from Liwale and Kisarawe districsts in Lindi and Coast regions respectively. A total of 45 cashew trees of varying dimensions were sampled for the study, covering a Dbh range between 2 and 89 cm. Non-linear models were used to regress observed biomass of stems, branches, twigs, total aboveground and below ground against Dbh or a combination of Dbh and total tree height, similar approach was applied to estimate cashew tree volume. Farm area was measured with the aid of GPS, and in the established plot of 0.008ha, tallest tree, medium and shortest tree heights were measured, for other trees only Dbh was measured. Four model forms (MFs) were fitted using data from 45 trees. MF 1 and 2 with one parameter variable (Dbh and Dbh^2) were recommended. Biomass stocks for aboveground was estimated using equation $AGB = Exp(-0.1684+0.8873lnDbh^2)$ where R^2, RMSE, RSE was 82.68%, 359.2 and 0.4738 respectively. Below ground, $BBG=Exp(-2.3765 + 0.9394lnDbh^2)$ where R^2, RMSE and RSE was 85.53%, 54.7319, 0.4675 respectively; and total tree volume was estimated using equation $V= Exp(-9.4111 + 2.6044lnDbh)$ where R^2, RMSE and RSE was 84.35%, 3.593, and 0.6477 respectively. Biomass stocks from these tree components were converted to C stocks assuming 47% of biomass is C. Carbon stock was 34.41±4.96tC/ha, and the stand volume was found to be 48.88 ±11.67m^3/ha. Developed models are recommended for use in similar site, conditions and species.

DECLARATION

I, Humphrey Edward Mlagalila, do hereby declare to the Senate of Sokoine University of Agriculture that, this dissertation is my own work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution.

Humphrey E. Mlagalila Date

(MSc. Candidate)

The above declaration is confirmed by;

Prof. E. Zahabu Date

(Supervisor)

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DEDICATION

This work is dedicated to my Almighty God, my beloved parents my uncle Dick Konga and his wife, Ms Mbatia Elisha Sambula for their love and paving the way for me to recognize the value of education; also to my wife: Leticia Kweyamba and my children.

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a.s.l	Above sea level
AGB	Above Ground Biomass
AIC	Akaike's Information Criterion
BBG	Below Ground Biomass
BD	Basic wood density
BEF	Biomass expansion factor
BOT	Bank of Tanzania
C	Carbon
CBD	Convention on Biological Diversity
CCAIM	Climate Change Impact Adaptation and Mitigation
CDM	Clean Development Mechanisms
CF	Correction Factor
CI	Confidence Interval
Cm	Centimetres
CNSL	Cashewnut Shell Liquid Oil
CO	Carbon monoxide
CO_2	Carbon dioxide
D	Diameter
Dbh	Diameter at breast height
EXP	Exponential
FAO	Food and Agriculture Organisation of the United Nations
gcm^{-3}	Grams per cubic centimeter
GHGs	Green House Gases

Ha	Hectare
IPCC	International Panel on Climate Change
M	Metres
m^3 ha^{-1}	Cubic meter per hectare
MFs	Four general model forms
MgC/ha	Megagram Carbon per hectare
Mm	Milimetres
MNRT	Ministry of Natural Resources and Tourism
NARI	National Agricultural Research Institute
^{O}C	Degrees centigrade
P	Probability
R^2	Coefficient of determination
RCD	Root colar diameter
$REDD^+$	Reduced Emissions from Deforestation and forest Degradation
RMSE	Root mean square error
RSE	Residual Standard Error
$tCha^{-1}$	Tons of Carbon per hectare
tha^{-1}	Tons per hectare
TOF	Trees Outside the Forest
UNCCD	United Nation Convention to Combat Desertification
UNFCCC	United Nation Framework Convention and Climate Change
UNIDO	United Nations Industrial Develipment Organization
URT	United Republic of Tanzania

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Cashew tree (*Anacardium occidentale L.,*) is a tropical nut crop that belongs to the family Anacardiaceae, which is known for having resinous bark and often, caustic oils in leaves, barks and fruits. Cashew is a native of South America, very likely the centre of origin is Brazil (Mitchell and Mori, 1987). It is thought to have been brought to East Africa and India by the Portuguese in the sixteenth century (Johnson, 1973; Ohler, 1979; Behrens, 1998). It consists of about 73 genera and 600 species (Nakosone and Paull, 1998). The tree is evergreen, fast growing and it reaches a height of 10-15m tall, often irregularly shaped trunk (UNIDO, 2011). Cashew trees are planted in plantations of around 70 trees per hectare at a spacing of 12m X 12m (NARI, 2009; UNIDO, 2011). Cashew tree has a preference for deep, well drained, light textured soils which facilitates extensive lateral root extension (Martin *et al*., 1997; Mitchel, 2004). It grows well from sea level up to 1200 m above sea level (a.s.l) where the temperature does not fall below 20^{o}C. The optimum monthly temperature for cashew growth is 24^{0}C to 28^{o}C. Cashew is grown in areas with rainfall ranging from 800 – 1600 mm per annum, and the soil pH ranging from 4.5 to 6.5. The crop is best adopted to the Southern region of Tanzania (Mtwara, Lindi and Ruvuma,) Coast Dar es salaam, and Tanga regions (Shomari, 2000; NARI, 2009; Orwa *et al.,* 2009, Masawe *et al*., 2013).

Cashew trees are well adapted to Tanzania and planted by majority smallholder farmers. It has ability to grow on poor soils and can be intercropped with food crops (maize, cassava, groundnuts etc. Cashew farm management practices consists of weeding, pruning and spraying pesticides and fungicides (NARI, 2009; UNIDO, 2011).

Cashewnuts are processed as well as marketed for export. The cashew kernels are used as confectionery and dessert. The shells contain high quality oil known as cashewnut shell liquid (CNSL) which has got wide industrial uses. (Mitchell, 2004; Martin *et al*., 1997; UNIDO, 2011).

Cashew trees like many other Trees outside Forests (TOF) have important economic, social and environmental values, at local, national and international scales. The products from cashew trees that are traded on international market and give foreign earnings to the nation economy as well as to the farmers are raw nuts, cashew kernel and Cashew nut shell liquid oil (CNSL) while cashew apple are consumed locally in Tanzania (World Bank, 1989; UNIDO, 2011). In developing countries like Brazil Cashew apples are processed into juice, fresh and dried fruit, jams, wines, candies and animal feed made out of waste products of cashew apple (UNIDO, 2011; Masawe *et al*., 2013; Pinho *et al*., 210).

Trees outside the forest including cashew trees, provide many goods and services to the society. This resulted for cashew volume model development for understanding the available volume and sutainable use wood resources in cashew trees (Muriga *et al.,* 2012).

Cashew trees can be used in C sequestration schemes such as the Clean Development Mechanisms (CDM), therefore; better information is required about above and belowground C stocks, soil C, and thus, there was a strong need to develop allometric models that will be used to predict the available biomass. This will help in the whole process of Reduced emission from deforestation and degradation mechanism when will be in place for cashew farmers compensation (Jose and Bardhan, 2012; Elverfeldt *et al.,* 2008).

At the international scale, agreements such as the United Nations Framework Convention on Climate Change (UNFCCC, 2008) and its Kyoto protocol there is a demand of information about all tree resources, not only trees in natural forests. In the current context of climate change, their importance will increase dramatically for people's livelihoods and national economies, and also for various international processes that address global environmental and economic challenges in carbon sequestration, biodiversity loss, desertification and poverty alleviation (Foresta *et al.*, 2013; Elverfeldt *et al.*, 2008). The reason most often cited is that, TOF have not been appropriately assessed and therefore; localization, extent, forms, natures, economic and ecological roles of the TOF resources are not well known beyond the local level (Foresta *et al.*, 2013, Kumar and Nair, 2011).

Assessing TOF poses different challenges than assessing forests, especially the variability and heterogeneity of TOF systems, their sparse distribution, complex ownership and institutional arrangements (Foresta *et al.*, 2013; Muriga *et al.*, 2012; Kumar and Nair, 2011; Schnell, 2015). However assessment of Trees outside the forest today need attention compared to the situation for natural forests when FAO began its first assessments in 1945 (FAO, 1948). Growing recognition of the potential economic importance of TOF, and recent political interest in their environmental services, could help improve the situation in the same way that forests gained attention (Foresta *et al.*, 2013; Schnell, 2015).

1.2 Allometric Equations and Biomass

the proportions between height and diameter, between crown height and diameter, between biomass and diameter follow rules that are the same for all trees, big or small, as long as they are growing under the same conditions (Picard, 2012) This is the basic principle of allometry and can be used to predict a tree variable typically its biomass from another dimension like its diameter. An allometric equation is a formula that quantitatively formalizes this relationship (Picard, 2012). It is important that accurate allometric equations are available to estimate, volume, biomass and carbon stocks from on-farm cashew tree data.

1.3 Academic and Practical matters Relevant for Volume, Biomass models and Carbon Stocks

Volume and biomass estimation models are useful tools in assessing forest and TOF structure and conditions. They can provide valuable information on supply of both industrial wood available and biomass for domestic energy, and they are elements in attempts to identifying sustainable management of forests, TOF and woodland ecosystems (Chamber *et al*., 2001 in Mugasha *et al.,* 2012). In addition, biomass and C stocks estimation models are needed to describe changes over time for carbon stocks from local to national levels and are useful for remote sensing and for all field inventories related to conventional management planning (Mugasha *et al.,* 2012).

Estimating carbon stocked in cashew trees is important for assessment of mitigation effect of cashew trees on global change and to predict the potential impact of mechanisms to reduce carbon emission.

Global carbon trading is growing rapidly. Emissions trading systems are already operating or planned in over 35 countries in the developed world. In 2008, the estimated value of the carbon market doubled to $126 billion. By 2020 the carbon market could be worth up to $2-3 trillion per year (Lazarowicz, 2009).

There are two types of carbon markets, compliance markets and voluntary markets. A compliance market is a market created by a regulatory act by national or subnational governments (e.g. under the Kyoto Protocol or through regional schemes); thus participants shape their economic behaviour to comply with the regulations. In contrast, participants in voluntary markets buy emission reductions for reasons such as public relations, personal commitments or corporate social responsibility. Carbon credits are the currency of both the compliance and voluntary carbon markets in which policymakers set a cap on total emissions and the market sets a price. Emitters above the cap purchase carbon credits in international markets from those which are below the cap.In addition, carbon credits, operating as offsets, can be generated under the Kyoto Protocol's Clean Development Mechanism (CDM). This enables developed countries to offset their emissions by investing in projects that are meant to reduce emissions in developing countries where costs are lower (Jackson, 2010; Lazarowicz, 2009). This study is aims at developing species and site-specific allometric models using destructive sampling for estimating volume and carbon stocks in cashew farms.

1.4 Problem Statement and Justification

1.4.1 Problem statement

Currently, the majority of cashew production in Tanzania is carried out by by small scale farmers in monoculture or mixed production systems, an estimated 300 000 households farming an area of 400 000ha (Anon, 2008). Three main cashew products that are traded on the international market are raw nuts, cashew kernels and cashew nut shell liquid (CNSL). A fourth product, the cashew apple that is generally processed and consumed locally (UNIDO, 2011). While other importances of cashewnut are widely documented, information about carbon storage potential is scant or not available at all in Tanzania. Little or no have been done to develop allometric equations to estimate biomass of cashewnuts. Quite few studies have been carried out elsewhere using vegetation photosynthetic model (Arulselvi *et al.,* 2011). Many studies were focused on natural forests and plantations of timber trees (Mugasha *et al.,* 2013; Alvarez *et al.,* 2012; Abbot *et al.,* 1997). For example carbon storage potential of agroforestry systems has been carried out in Tanzania (e.g. Kimaro *et al*., 2011; Kumar *et al*., 2011), but none has presented carbon sequestration potential of agrosystems with cashewnuts.

1.4.2 Problem justifications

Terrestrial carbon sequestration is an important pathway of minimizing CO_2 concentration in the atmosphere. However, to be able to quantify carbon require a number of infrastructure. First, is cashew inventory to enumerate number and size of trees and second, applying allometric equations to derive tree biomass and volume. Understanding the carbon storage potential of cashew trees, will likely provide additional value to farmers' livelihood in poverty alleviation in carbon market schemes like REDD+. This is practical since the government of Tanzania for the last two decades has been actively supporting farmers in upgrading their farming systems and practices in order to improve the conditions of the cashew trees and maximizes agronomic potential (Masawe *et al*., 2013; Lazarowicz, 2009; Jackson, 2010).

1.5 Oveall Objective

Assessment of volume, biomass and carbon stock of cashewnut trees in Liwale District.

1.5.1 Specific objectives

i. To develop allometric models for estimating volume of *Anacardium occidentale.*
ii. To develop allometric models for estimating above and below ground biomass for *Anacardium occidentale.*
iii. To determine the stand structure (Farms) of *Anacardium occidentale* in terms of tree density.

1.5.2 Research questions

(a) What are regression equations that can best estimate volume and biomass for both Belowground and aboveground in cashew tree components?

(b) What are biomass and C stocks for cashew trees grown in Liwale Distric?

(c) What is the performance of developed allometric equations on biomass and volume?

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Countries Planting Cashew Trees

Cashew is an important commercial crop in many tropical countries especially in Brazil, India, Vietnam, Eastern, Southern and Western Africa. Of the total world production 37% comes from India, 14% from Nigeria, 13% from Brazil and 11% from Tanzania (FAO, 2001). About 70% of the total national production of cashewnuts is produced in the Southern regions of Tanzania (Mtwara, Lindi and Ruvuma) (Northwood., 1962; Topper *et al.*, 1997) and 30% is produced from Coast region and Tanga.

The area under Cashew cultivation has been estimated to be about 400 000 hectares either in mono or mixed crop production systems, large private plantations in Lindi and Mtwara regions occupy only 2000 hectares while the rest 398 000 ha is occupied by small scale farmers (Masawe, 2006; Ngatunga *et al.*, 2003; Topper *et al.*, 1998; Shomari,1990).

2.2 Importance of Trees outside the Forest

The United Nation Framework Convention and Climate Change (UNFCCC), the Convention on Biological Diversity (CBD), the United Nation Convention to Combat Desertification (UNCCD), and FAO, all need much better quality data on TOF including cashew trees than they currently have, and this can only be done through carefully implemented national TOF assessments (Foresta *et al.*, 2013; Chamalindi *et al.,* 2014).

Global warming is amongst the most dreaded problems of the new millennium. Green house gas (GHGs) is supposedly the strongest casual factor for global warming. One of the options for reducing the rise of green house gas concentration in the atmosphere and thus possible climate change is to increase the amount of carbon removed by and stored in plants. In tropical countries like India, forest carbon sinks are believed to offset a significant portion of carbon emission associated with fossil fuel combustion. But due to large scale industrialization and increased population, the forest area is slowly declining. Perennial fruit trees like Cashew, Mango and Guava have similar potential like forest trees to sink atmospheric carbon (Arulselvi *et al*., 2011). Most of cashew trees are multstemic, and have ability to coppice after harverst.

2.3 Global Biomass and C Stock Estimates

It is believed that agricultural and forestry practices can partially mitigate increasing CO_2 concentrationby sequestering carbon (C). Similarly, alternative agricultural practices where biomass cropsare cultivated can impact CO_2 levels not only by sequestering C, but also by replacing fossil fuel withthe biomass produced (Jose, 2012).

Agroforestry has gained increased attention as a strategy to sequester C from both developed and developing nations. The available estimates of C stored in agroforestry ranges from 0.29 to 15.21 Mg C/ha/year above ground, and 30–300 Mg C/ha up to 1 m depth in the soil (Nair *et al*., 2010). Nowak (2002) found that average carbon stocks ranged between 4.4 Mg ha−1 and 36.1 Mg ha−1 for ten cities in the USA.

FAO (2010) world report shows that the world's forests store more than 650 billion tons of C, 44% in the biomass, 11% in dead wood and litter, and 45% in the soil. This corresponds to about 149 tons of biomass per hectare. The highest biomass stock per hectare was found in regions with tropical forests, such as South America, and Western and Central Africa, where biomass stocks are over 200 tha^{-1}.

Despite the general acceptance of the importance of TOF and advances in monitoring, data that would be needed for an integrated management of landscapes for climate change mitigation and adaptation (Plieninger, 2011) is, in general, still missing at the global scale and only partly available at the national scale (Foresta *et al.*, 2013). One reason for this is that not all kinds of TOF are included in the monitoring. For example, in Sweden TOF is generally included in the National Forest Inventory but with the exception of trees growing in human settlements, thus only allowing conclusions to be drawn about a specific subset of TOF. Another reason is that even though assessments are done in many countries, results for TOF are hardly ever reported publicly and are difficult to access.

2.4 Site and Species Specific Biomass Estimation Equations

It has been established that site and species specific biomass estimates, obtained from locally developed equations provide estimates of C with greater certainty (IPCC, 2006); that is why biomass equations for specific species and sites need to be developed.

Studies for development of site and species specific equations for estimation of biomass have been done elsewhere (Bargali and Singh, 1997; Litton *et al.,* 2003; Saint-Andre *et al.,* 2005). Equations for estimation of biomass and C stocks need to be developed for TOF. However, these equations must meet specific requirements in order to be used for biomass and Cstock estimation. According to Repola (2008), specific requirements needed are: first, the equations have to be widely applicable in giving reliable biomass estimates of the total tree and the tree components: stem wood, stem bark, living and dead branches, foliage, stump, and roots; and second, the biomass equations should be based on the variables that are normally measured in forest inventories, or which can be estimated easily and reliably from inventory data.

2.5 Relationship Between Below and Aboveground Biomass

According to Niklas (2005), the relationship between above and below ground biomass is frequently used to assess growth responses to ambient ecological conditions, or to evaluate the responses of individual trees to experimental manipulation. However, Canadell *et al.* (1996); Jackson *et al*. (1996); Schulze *et al*. (1996) and Levang-BrilzBiondini (2002) report that, there is no current model for predicting below ground biomass based on measurements of above ground biomass across diverse species including trees outside the forest. This requires accurate estimation of biomass and volume in different vegetation types including trees outside the forest in which cashew trees (*Anacardium occidentale*) is among them.

Estimation of biomass and C stocks from volume has been done by various researchers (Brown *et al.,* 1989; Brown and Lugo, 1992). In a study by Brown *et al.* (1989), biomass estimation models were developed using destructive method. The study recommends use of developed equations where species and site specific models do not exist. Their study regard estimation of biomass using general models and volume equations as less accurate, therefore, they caution their use.

2.6 Tree Biomass and Volume Estimation

Macauley *et al.* (2009) pointed out that forest biomass and C stocks estimation equations provide estimates of scientific importance to improve understanding of quantitative role of forest C sequestration in Earth's climate system. Forest C and TOF estimates are also of interest to policy makers in shaping climate policy. For example, REDD was a prominent section of the Bali Road Map established in 2007 and continues as a leading topic in international climate negotiations.

2.7 Allometric Models for Estimating Volume and Carbon Stock

Volume and carbon stocks in different vegetation types can be determined by using direct or indirect methods. The direct measurement of volume and carbon stocks on a large scale is destructive, tedious, time consuming and costful but it has high precision (Samalca, 2007; Ebuy *et al.,* 2011). Indirect method for volume and carbon stock estimation involves development of relationship that entails the use of easily accessible and measurable tree parameter such as diameter and height. The scaling relationships, by which the ratios between different aspects of tree sizes change when small and large trees of the same species are compared are generally known as allometric relations (Hairiah *et al*., 2001).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Location of Study Area

Liwale District lies between $9^{o}\ 47^{'}$ S, $37^{o}\ 55^{'}$ E. It is bordered by the Rufiji District in the Northeast, Ruangwa and Kilwa in the East, Nachingwea and Tunduru in the South and Ulanga in the Nortwest (Mugasha *et al*., 2013; URT, 1997). The district covers an area of 3 838 000 hectares out of which 2 558 600 hectares is occupied by Selous Game Reserve and the remaining area of 1 279 400 hectares is village land area.

3.2 Sample Plots and Inventory Design

Inventory was done based on tree sizes (Dbh) to cover a wide range of diameter class. The area of the farm and map of each farm was determined by the aid of GPS and Q GIS software respectively. From the map produced, sample plots were laid on the map after calculating plot distance as a square root of an area divided by number of plots, (Fig. 1). Temporary rectangular sample plots measuring 0.08ha were established systematically along the transect lines that run parallel to each other (Chave *et al*., 2003). The first plot was established randomly at half inter plots distance from the cashew farm boundary followed by systematic layout of other plots within the study site. Spacing in the cashew plantions was 12m by 12m.

The following detailed procedure was adopted during the inventory measurements:

(i) Within 0.08ha plot all trees were measured for Dbh.

(ii) Three trees (Small, medium, and large size) cashew trees, were selected in each plot and measured for height by using Suunto hypsometer. Those trees were used to develop a diameter – height relationship for estimating the height of other cashew trees.

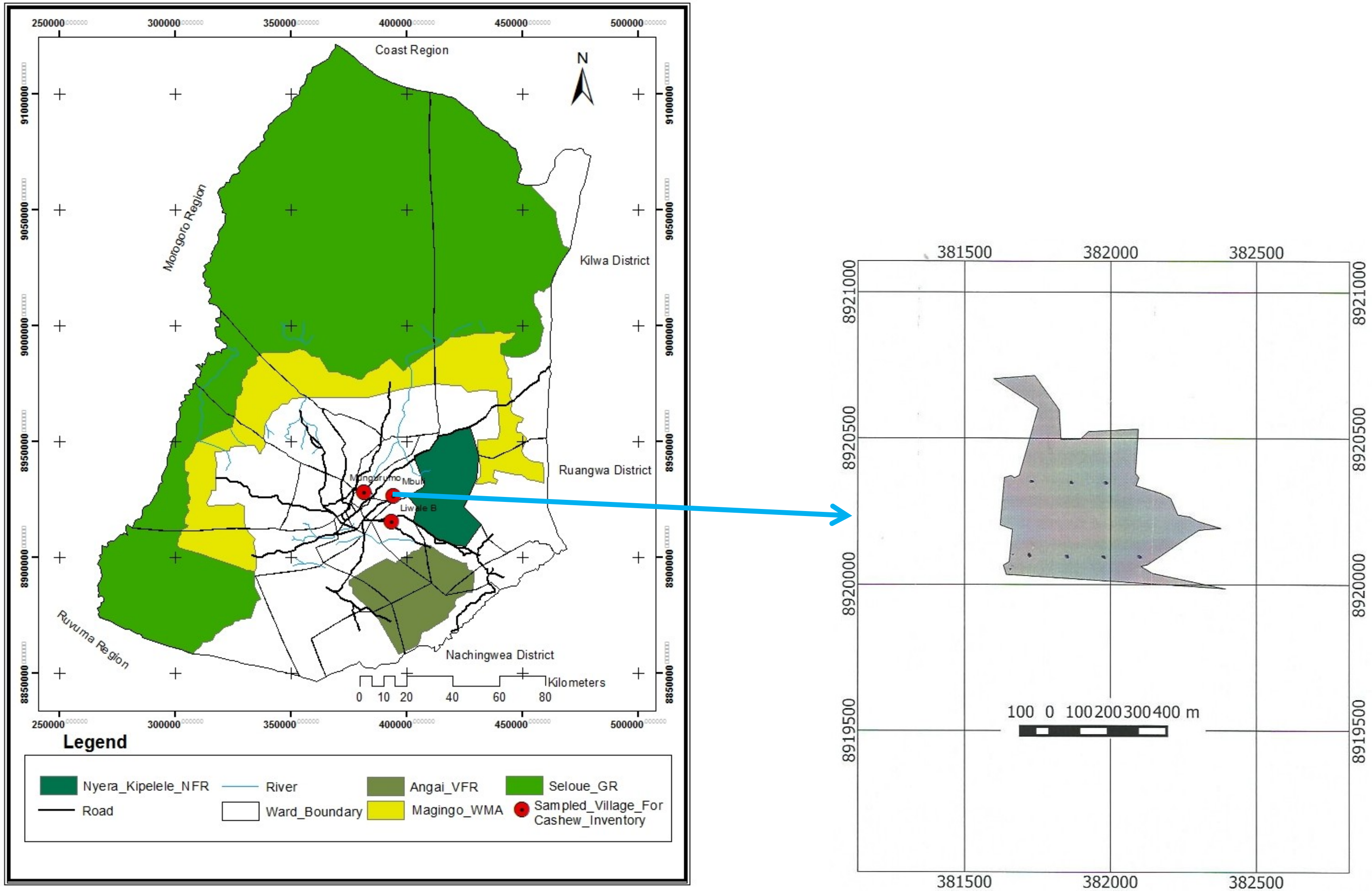

Figure 1: A map of Liwale District showing sampled villages for cashew tree inventory

Inventory was conducted in 50 sample plots from different cashew farms (Fig. 1). Many Cashew trees were mult stem, therefore; mult stems trees that were branched at Dbh below 1.3m were treated as different trees, and those branched at Dbh above 1.3m were treated as single tree. Cashew trees have broad flat canopy, but the spacing applied favour tree height measurement.

3.3 Selection of Sample Trees for Destructive Sampling

Trees for the study were selected in such a way that a wide range of tree diameter is presented to mimic forest inventory data. Similar approach has been carried out by other scholars (Mugasha *et al*., 2013; Mauya *et al*., 2014; Masota *et al*., 2015).

Selected sample trees were measured for Dbh, tree height and root collar diameter (at 15 cm above ground level) before felling. Trees were felled and stems trimmed and cross cut into billets (0.5m to 1.5m) that were convenient to weigh. Each stem billet was measured for length, mid diameter for volume model development and green weight was converted to biomass by calculating the ratio of oven dry weigth of the sample to the green weight of the sample multiplied by green weight of respective part of the cashew tree for biomass allometric model development (Plate 1 and 2). Stem tops and branches top with Dbh ≤ 5 cm diameter were considered as twigs. Each branch billet was measured for length, mid diameter and green weight. Leaves were piled into bundles and measured together for green weight. All 45 trees selected for destructive sampling were excavated for belowground tree component analysis (Plate 2). Once excavated, the main tree components were treated as by Mugasha *et al*. (2013) as follows:

(a) Root crown was cleaned to remove soil and weighed for green weight.

(b) All broken roots (roots not excavated) were measured for top diameter at breakage point on the root crown.Tap root was followed to the point where its diameter was nearly equal to the top diameter of the largest side root, and its weight was included to the weight of root crown.

(c) From each sample tree, 3 main roots (small, medium and big) were selected and traced to minimum diameter of 1 cm. The top diameter and weight of each sample root were measured and recorded (Plate 2). When main roots enter obstacles (stone or another tree) the end point diameter was measured.

For each tree component, at least 3 wood samples (cut from bark to pith) of about 2 cm thick was cut, and measured for green weight (Plate 3) put into a paper envelope, labelled and then taken for oven dry weight in the laboratory. The oven dry weight was applied to calculate dry to green weight ratio. Dry to green ratio was multiplied by respective tree component to get biomass as shown below;

$$Bm = \frac{\mathrm{ODw}}{\mathrm{Gw}} X\ Gc \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(1)$$

Where;

Bm - Biomass

ODw - Oven dry weight of a sample

Gw - Green weight of a sample

Gc - Green weight of tree component

Eventually, root to shoot ratio was calculated as ratio of below ground biomass to above ground biomass.

$$R{:}\,S = \frac{BG}{\mathrm{AG}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(2)$$

Where;

R: S – Root to shoot ratio

BG – Below ground biomass

AG – Above ground biomass

Plate 1: Tree Dbh measurements

Plate 2: Measurements of billets dendrometric parameters


Plate 3: Billet weight measurement


Plate 4: Three excavated roots weight measurements

Plate 5: Sample collection and green weight measurements

3.4 Laboratory Analysis

Samples from stem, branches, twigs, leaves roots, and root crown were soaked in water for seven days until the entire samples were fully saturated and attained a constant weight. Sample green volume was obtained by means of water displacement technique (Pyo *et al*., 2012). Disk samples were taken to laboratory for oven drying at 105^0C for 72 hours (Plate 4) and its weight determined until constant weight was attained. For leaves and twigs, sample was oven dried at 80^0C for the determination of the dry mass (Anderson *et al.,* 2012).

Plate 6: Sample oven drying to obtain constant oven dry weight

3.5 Data Analysis

3.5.1 Determination of tree biomass

3.5.1.1 Above ground biomass

The biomass of each tree component, stem, branches, leaves and twigs were computed by multiplying the green weight of individual tree component with its respective dry to green ratio. This ratio was calculated as a ratio of oven dry weight to green weight of the sample. Total above ground biomass was calculated as a summation of all above ground tree componet (Mugasha *et al.,* 2013; Ryan *et al.*, 2010).

3.5.1.2 Below ground biomass

Main roots and other roots biomass models

Green weight and top diameter of main roots (main, medium and small) were measured in order to get equations for estimating green weight of unexcavated roots. Therefore, green weight and top diameter of main roots were regressed using regression analysis tool-pack in MS Excel software. Relationship model established was used to estimate the green weight for unexcavated roots.

Below ground biomass was calculated using the same procedure as for above ground, but in this case the ratio of oven dry weight to green weight was multiplied by the respective green weights of main root, side roots and root crown (Mugasha *et al.,* 2013; Ryan *et al.*, 2010).

3.5.2 Wood basic density

Volume and weight were measured for each sample in the green and oven-dry conditions respectively in the laboratory. From these values, basic wood density (kg/m3) were calculated for each sample from different part of cashew tree, (stem and branches) and averaged for each tree component (Frederick *et al.,* 1982). In this study wood basic density is defined as the mass of oven-dry wood per unit volume measured in the green condition given by the formular below

$$\text{Basic density} = \frac{\text{Oven dry weight}}{\text{Green volume}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

3.5.3 Determination of a single tree volume

Huber's formula was employed to determine volume of billets (stem and branches) in which mid diameter of a billet was multiplied by its length and cross sectional area (Pearson *et al.*, 2005). Total tree volume was calculated as the summation of individual stems and branches billet volume.

The volume of main stem and branches greater than 5 cmdiameter was computed by using Huber's formular (Abbot *et al.*, 1997).

$$Volume\ m^3 = \frac{\pi D^2}{4} \times l \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where;

D, is a mid diameter of the log (m); L, is the length of the log (m); and π, Pie

3.6 Volume Allometric Models

In developing single tree volume estimation models, the same procedures used in developing single tree biomass estimation models were employed. Models were developed by using the relationship between tree's section volume and the predictor variable Dbh, Dbh^2 and Dbh^2*Ht.

3.7 Model Development and Fitting

Fitting of regression equations for biomass estimation

To understand the relationship between Dbh and trees' different section's biomass, graphical plots were used for each tree component. The graphs indicates that the relationship between Dbh and tree biomass were not linear (Fig. 2-6), (Fayolle *et al.,* 2014; Mugasha *et al.,* 2013; Zianis, 2008). To assume linearity, tree data were log transformed (Chave *et al*., 2005) and then logtransformed data were used to develop bimass models.

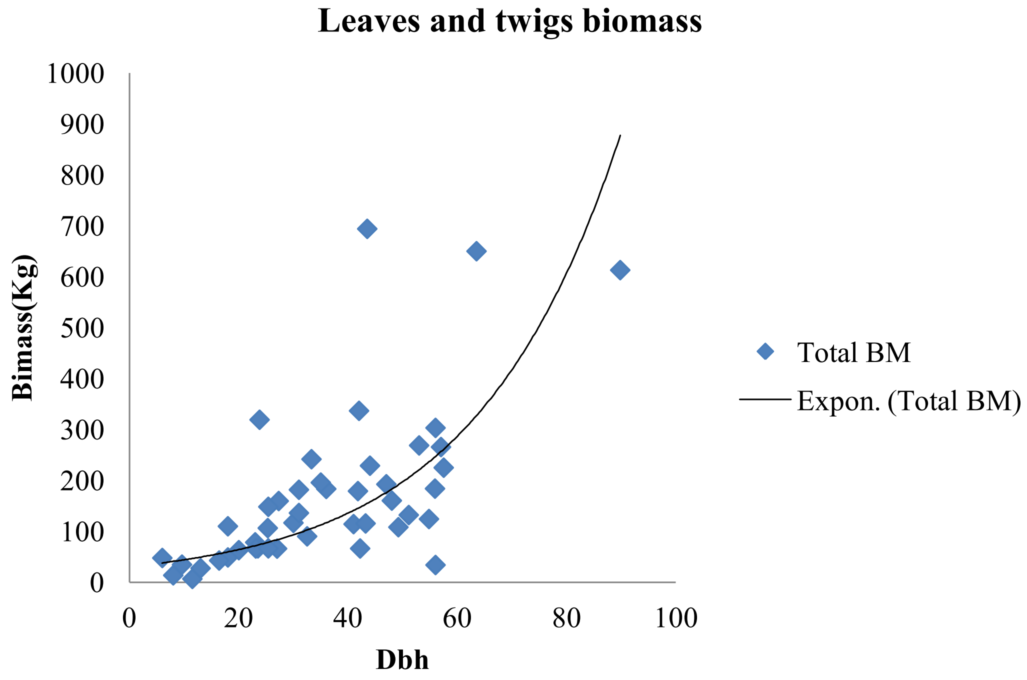

Figure 2: Relationship between Dbh and (leaves and twigs) biomass

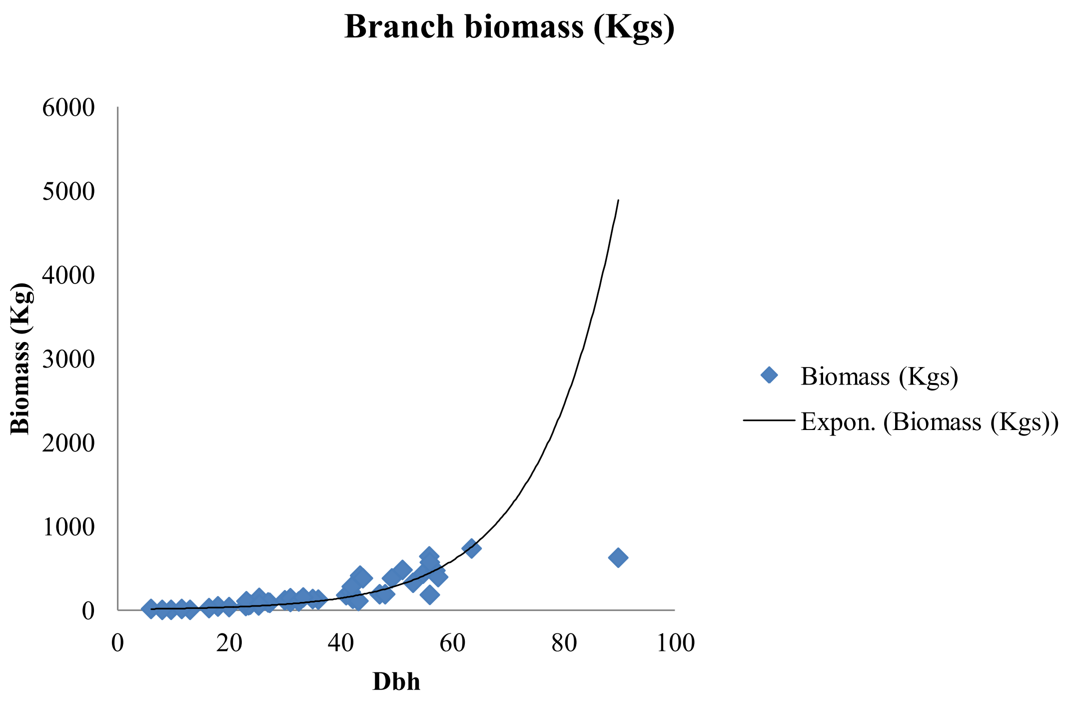

Figure 3: Relationship between Dbh and branch biomass

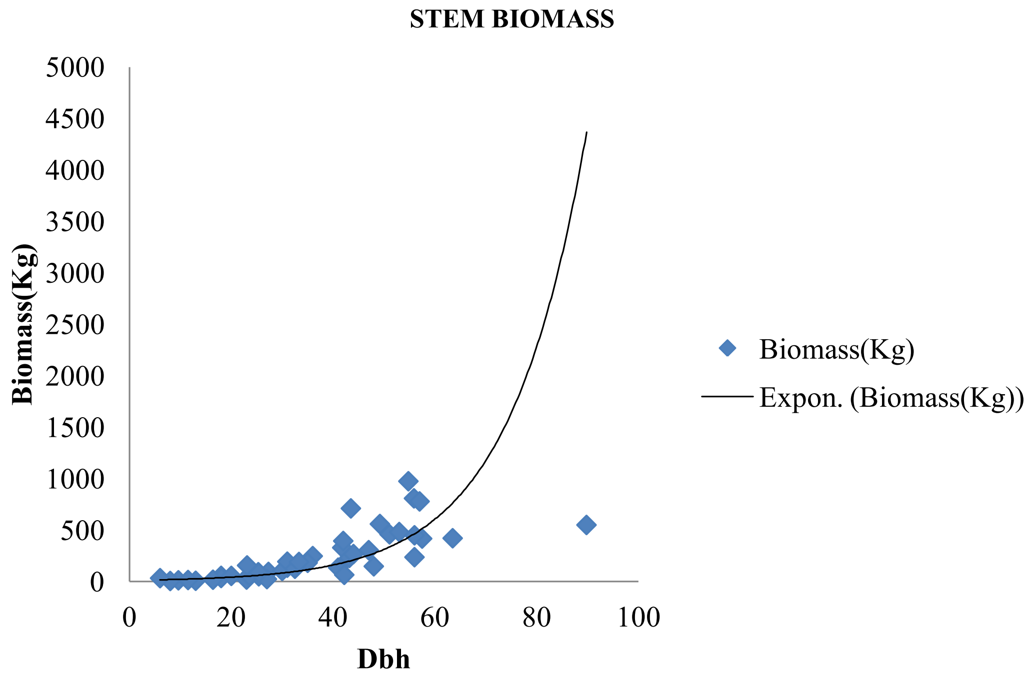

Figure 4: Relationship between Dbh and stem biomass

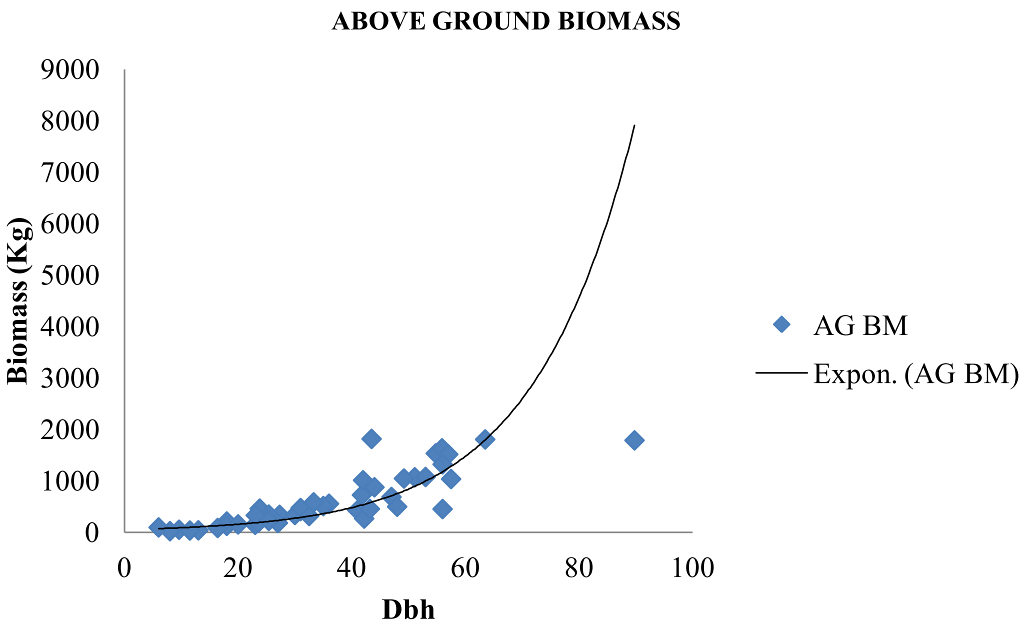

Figure 5: Relationship between Dbh and Aboveg round biomass

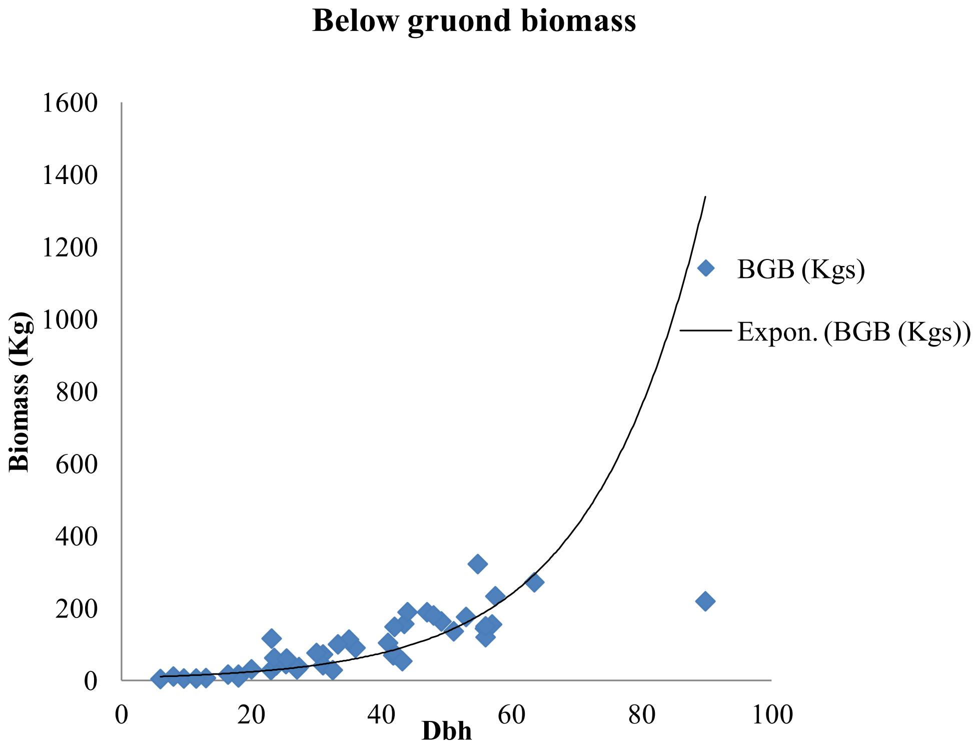

Figure 6: Relationship between Dbh and below ground biomas

Moreover, Volume estimation models and graphical plots indicated that relationship between different trees section and Dbh was also non linear (Fig. 7-9). To assume linearity data were also logtransformed.

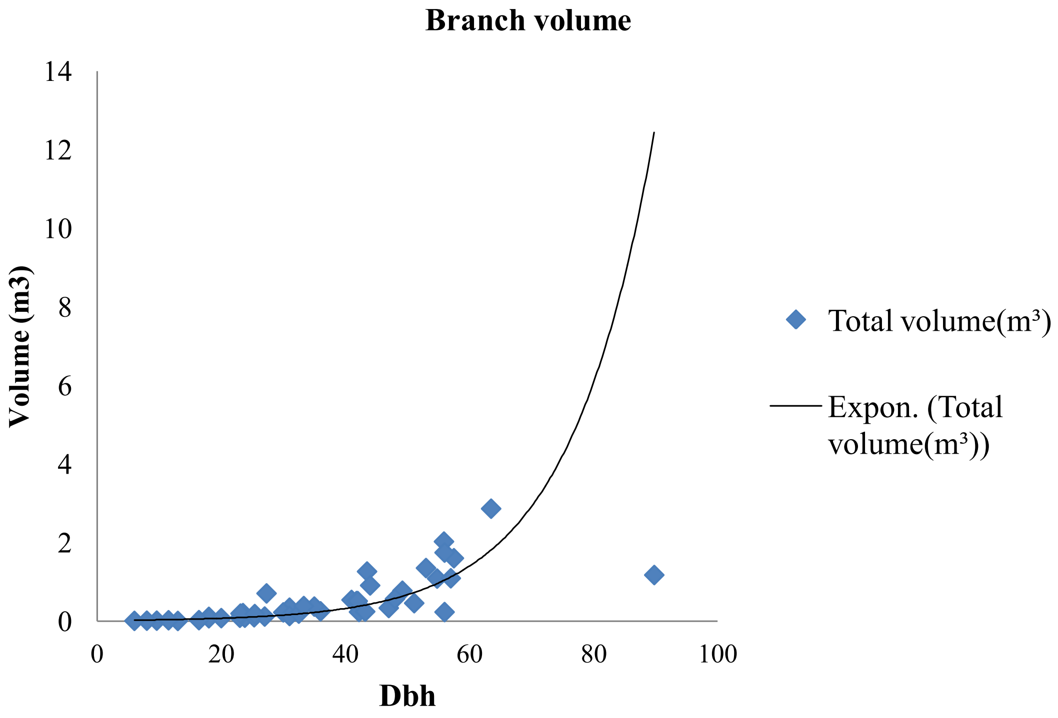

Figure 7: Relationship between Dbh and branch volume

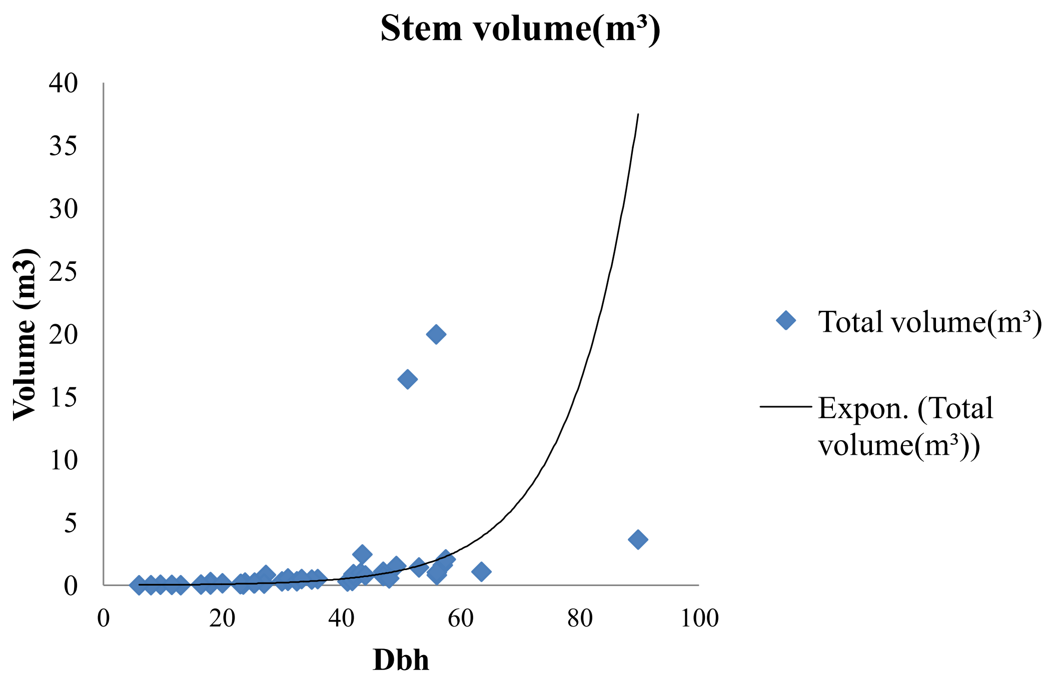

Figure 8: Relationship between Dbh and stem volume

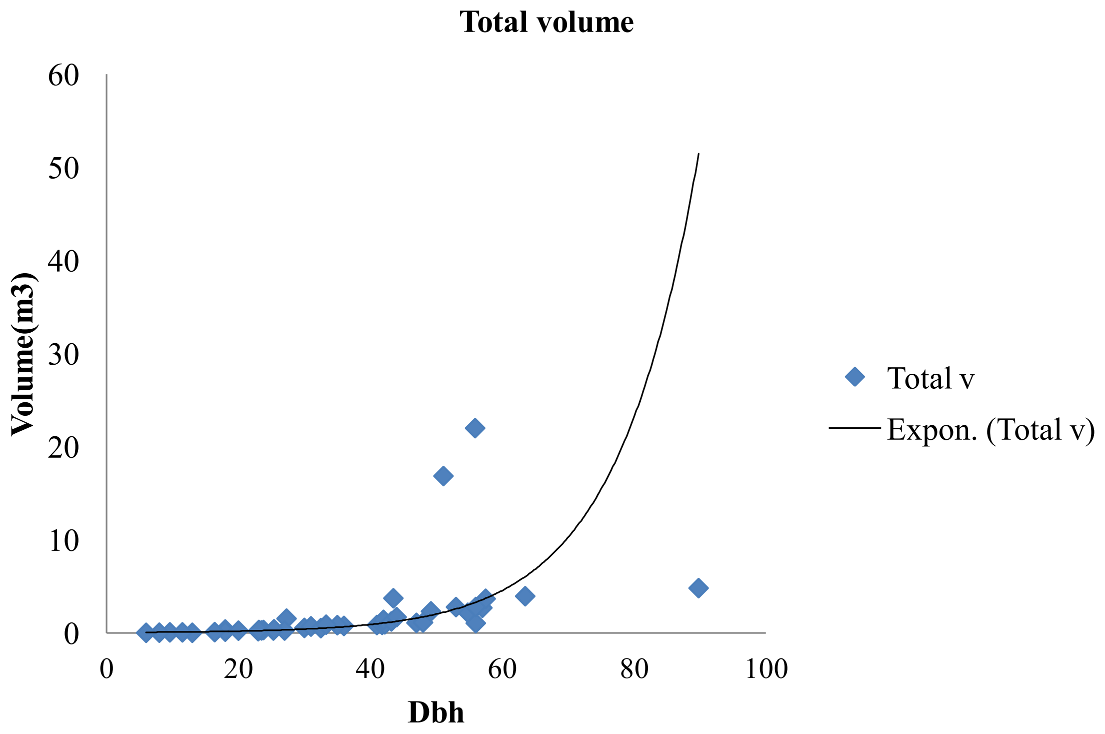

Figure 9: Relationship between Dbh and Total tree volume

Biomass equations for above ground tree components (stem, branches, twigs and leaves), were fitted to the collected data which involved 45 destructively sampled trees using Microsoft Excel. In addition, equations for below ground components (root crown, main roots and other roots) and total tree biomass were also fitted. The following general model forms (MFs) of biomass estimation were fitted:

$$\mathrm{Ln}Y = a + b \times \ln(\mathrm{Dbh}) \quad \text{.......(5)}$$

$$\mathrm{Ln}Y = a + b \times \ln(\mathrm{Dbh}^2) \quad \text{.......(6)}$$

$$\mathrm{Ln}Y = a + b \times \ln(\mathrm{Dbh}) + c \times \ln(\mathrm{Ht}) \quad \text{.......(7)}$$

$$\mathrm{Ln}Y = a + b \times \ln(\mathrm{Dbh}^2 \times \mathrm{Ht}) \quad \text{.......(8)}$$

Where;

Y = biomass (kg/tree component); Dbh = Diameter at breast height (cm); Ht = total tree height (m); a, b and c = regression coefficients and Ln = natural logarithm.

3.8 Model Selection and Evaluation

After biomass estimation models were fitted, those equations which performed better were selected for future use. Since there were no independent data for equation validation, equation selection was based on some criteria. Several selection criteria exist (Picard *et al.,* 2012). In this study, low Residual standard error (RSE), low Akaike's Information Criterion (AIC), were used (Chave *et al.,* 2005; Mugasha *et al.,* 2013; Alvarez *et al.*, 2012). Coefficient of determination (R^2) and calculation of root mean square error (RMSE) were also reported but was not used as the basis for model selection since AIC and RSE reported provide sufficient information on the quality of model fit (Fayolle *et al.,* 2014; Chave *et al.*, 2005; Alvarez *et al.,* 2012).

Correction Factor (CF) was employed to all models for biomass and volume estimation. Theoretically, log transformation of data causes biasness in the final biomass or volume predicted values, and uncorrected values are expected to underestimate biomass values (Chave *et al.,* 2005; Alvarez *et al.,* 2012). A correction factor is required for back transformation when applied to generate biomass prediction (Baskerville, 1972; in Mugasha *et al*., 2013).

$$CF = Exp\left(\frac{RSE^2}{2}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(9)}$$

Where:

CF: Correction factor, RSE: Residual Standard Error

3.9 Carbon Stock Estimation

Single tree biomass was estimated using the developed and selected best biomass models for above ground, Biomass= Exp (-0.1884 + 0.9927DBH^2, CF included). Total biomass was estimated as a result of sum of single tree biomass expressed in tonnes per hectare. Furthermore, biomass was coverted to carbon using biomass expansion factor whereby, a single tree biomass was multiplied by a factor of 0.47. Total tree biomass stocks for all trees in a plot were added to get biomass stocks per plot. Biomass per ha was obtained by converting total biomass of all trees in a plot by dividing it by plot area in ha (kg/ha). Biomass (kg/ha) was further divided by 1000 to get tons of biomass per ha (tha^{-1}). Biomass was converted to C by assuming 47% of biomass is C (MNRT., 2015; Ravindranath *et al*., 1997; Schroeder, 1992 in Baishya *et al*., 2009). C (kg/ha) was divided by 1000 to get tons of C per ha (tCha^{-1}).

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

The study aimed to assess volume, biomass and carbon stock of cashew trees in Liwale District. To capture the study, allometric models for estimating volume, above and below biomass were developed. Further more, the cashew farm structure in terms of tree density was also assessed.

4.1 Volume Models

Three volume models were developed, these models were branch, stem and total cashew tree volume models. These models were developed in relation between Dbh and volume that will help to understand the available wood volume resource for utilization. Moreover it has been observed that, as wood volume increases with increase in cashew tree Dbh.

4.1.1 Branch volume models

Model form 4 was selected to be the best candidate model as it gave low AIC and RSE% compared to other model (Table 1). In addition, it meets other criteria like low RMSE, also the model indicates that; there is a strong relationship between branch volume and both DBH^2 and Ht ($R^2 > 84\%$), ($p < 0.05$).

4.1.2 Stem volume models

Model form 2, (Table 1) gave low AIC and RSE and was selected to be the best models for stem volume measurements. About 80.13% of the variation in the stem volume was explained by predictor variable Dbh and Dbh^2. Parameter estimate for the height variable (Model 3) was not significant at the chosen level of probability and was discarded for estimating stem volume. Model 4 was also eliminated in stem volume estimation as it gave very high AIC and RSE compared to other models. That can cause overestimation or underestimation of predicted volume.

4.1.3 Total tree volume models

Braindeis *et al.* (2006); found that, including tree height variable improves the model fit by increasing the value of R^2 from 97.08 to 99.16 in estimating total volume in Puetro Rican subtropical dry forests. These findings are contrary to cashew trees. In this study model 1 has been selected to be the competent model, however model form 2 can also be used depending on the users' preference (Table 1) for total tree volume estimation above ground, the models used Dbh and Dbh^2 as predictor variables that explains 84% of the variation in total volume was explained by Dbh and Dbh^2. Model 1 and 2 gave very low AIC and RSE and very high R^2 compared to other models.

Table 1: Selection and performance of model forms to estimate cashew tree component volume

	Model	**Regression coefficients**			**RSE**	**RMSE**	**R^2**	**AIC**	**CF**
		a	**b**	**c**					
Branch volume	1	-9.5351^{S}	2.3573^{S}		0.5976	0.4911	0.8403	85.3213	1.1955
	2	-9.5351^{S}	1.1786^{S}		0.5986	0.4912	0.8403	85.3342	1.1964
	3	-9.6297^{S}	2.0748^{S}	0.5056^{NS}	0.5927	0.6299	0.8429	85.5275	1.1929
	**** 4**	**-9.6201^{S}**	**0.9115^{S}**		**0.5936**	**0.4072**	**0.8424**	**84.7213**	**1.1927**
Stem volume	1	-10.6044^{S}	2.7798^{S}		0.8044	3.5454	0.8003	112.6209	1.3781
	**** 2**	**-10.6044^{S}**	**1.3899^{S}**		**0.8004**	**3.5434**	**0.8013**	**111.6235**	**1.3771**
	3	-10.631^{S}	2.7004^{S}	0.1419^{NS}	0.8092	3.564	0.7969	113.5425	1.3874
	4	-10.372^{S}	1.6805^{S}		0.8827	3.4723	0.7583	120.4326	1.4764
Total tree volume	**** 1**	**-9.4111^{S}**	**2.6044^{S}**		**0.6477**	**3.593**	**0.8435**	**93.955**	**1.2315**
	2	-9.4111^{S}	1.3022^{S}		0.6478	3.693	0.8413	93.965	1.2414
	3	-9.4258^{S}	2.5606^{S}	0.0784^{NS}	0.6654	3.686	0.8376	95.9301	1.2478
	4	-9.404^{S}	0.9958^{S}		0.6924	3.589	0.8242	98.5887	1.2709

** Selected model; **S=** Parameter estimate significant ($p < 0.05$); **NS=** Parameter estimate not significant at ($p > 0.05$).

4.2 Allometric Models for Estimating Above Ground

Four general model forms (MFs) were fitted in order to develop equations for estimating above ground and below ground biomass stock.

4.2.1 Above ground biomass models

The results showing TOF are often shorter in height and thicker in diameter than forest trees, thus indicating a different tree allometry. These results are similar to studies by Harja *et al.* (2012) and Zhou *et al.* (2011), and lead directly to the problematic estimation of single tree biomass.

Model form 2 was selected to be the competent model over other models as it has low AIC and RSE (Table 2). The model indicate that 82.58% of the variability in above ground biomass is explained by the predictor parameter Dbh and Dbh^2. The results concurs with Litton and Kauffman (2008), who reported that basal diameter accurately predicted above ground biomass in the shrub Dodonaea viscosa. Contrary, tree height was not as good a predictor of biomass, either alone or in combination with tree Dbh.

Allometric models that estimate above ground biomass (AGB) at the individual tree level are extremely rare for TOF (McHale *et al.*, 2009). Only a few studies have developed TOF-specific allometric biomass equations and made a comparison to forest models (e. g. Yoon *et al.*, 2013; Kuyah *et al.*, 2012; McHale *et al.*, 2009; Zhou *et al.*, 2007; Kumar *et al.*, 1998).

4.2.2 Leaves and twigs biomass model

Model form 1 (Table 2), was selected as the best model in the category of models with Dbh as independent variables for estimating single tree biomass for leaves and twigs compared to other models.

4.2.3 Branch Biomass Model

Generally branch biomass as a function of Dbh or combination of Dbh and Ht had strong realationship, (R^2> 85%). This differs from other studies done in M iombowoodland that there was a poor relationship between biomass and their predictors (Mugasha *et al.,* 2013; Mate *et al.,* 2014). The difference in the observed relationship could be the result of branch morphologies, tree management and tree species.

Model form 1 was selected for branch biomass estimation (Table 2), as the results gave low RSE and AIC. Model 3 was discarded; it explains high values of AIC and other parameter was not significant ($p > 0.05$). During biomass prediction, the log-transformation of the data entails a bias in the final biomass estimation, these models were back transformed. In order to reduce biasness in biomass estimation, correction factor was added to account for back transformation of models' errors (Mugasha *et al.,* 2013; Chave*et al.,* 2005; Chave *et al.,* 2014), and uncorrected biomass estimates are theoretically expected to underestimate the real value.

4.2.4 Stem biomass model

Model form 4 (Table 2) was selected to be the best model for biomass estimation in stems of cashew trees. The model has low AIC and RSE compared to other models for stem biomass estimation. It meets other criterion like, low RMSE and high R^2. About 77% ($R^2 = 0.7722$; $p < 0.05$) of the variation in stem biomass was explained by (Dbh and Ht) predictor variables.The findings of R^2 in this study concers with ranges of other studies done in miombo wood land.

Table 2: Models parameters and performance criteria for biomass estimation

	Model	Regression coefficients			RSE	RMSE	R^2	AIC	CF
		a	**b**	**c**					
Leaves and twigs	**** 1**	**0.6339^{S}**	**1.1981^{S}**		**0.652**	**147.6564**	**0.5392**	**93.1662**	**1.237**
	2	0.6339^{S}	0.599^{S}		0.653	147.6888	0.5292	93.1677	1.238
	3	0.6484^{NS}	1.2421^{S}	0.07888^{NS}	0.6595	148.0352	0.5184	95.1304	1.243
	4	0.6614^{NS}	0.4554^{S}		0.6639	151.5734	0.5119	94.7904	1.2466
Branches	**** 1**	**-3.2574^{S}**	**2.3019^{S}**		**0.551**	**142.3374**	**0.8507**	**79.626**	**1.1639**
	2	-3.2574^{S}	1.51^{S}		0.561	142.4246	0.8507	79.636	1.1704
	3	-3.3393^{S}	2.0574^{S}	0.4377^{NS}	0.578	182.763	0.8522	80.105	1.1685
	4	-3.3285^{S}	0.8888^{S}		0.5718	106.2406	0.8502	79.758	1.1709
Stem	1	-2.3028^{S}	2.0672^{S}		0.6617	141.6047	0.767	94.4922	1.2447
	2	-2.3028^{S}	1.0336^{S}		0.6617	126.2715	0.767	94.4922	1.2447
	3	-2.3987^{S}	1.7809^{S}	0.5123^{NS}	0.6585	188.4153	0.7693	94.9946	1.2421
	**** 4**	**-2.3917^{S}**	**0.801^{S}**		**0.6543**	**113.1769**	**0.7722**	**93.4805**	**1.2387**
Above ground	1	-0.1684^{S}	1.7756^{S}		0.4739	359.2	0.8258	64.454	1.1188
	**** 2**	**-0.1684^{S}**	**0.8873^{S}**		**0.4738**	**359.2**	**0.8268**	**64.444**	**1.1178**
	3	-0.2256^{NS}	1.6037^{S}	0.3057^{NS}	0.4741	393.72	0.8257	65.42	1.1189
	4	-0.2166^{NS}	0.6844^{S}		0.477	319.488	0.8235	65.035	1.12
Below ground	1	-2.3765^{S}	1.8788^{S}		0.4685	54.8319	0.8453	63.2481	1.1155
	****2**	**-2.3765^{S}**	**0.9394^{S}**		**0.4675**	**54.7319**	**0.8553**	**63.2181**	**1.1145**
	3	-2.4321^{S}	1.7127^{S}	0.2973^{NS}	0.4677	67.4035	0.8451	64.2135	1.1156
	4	-2.4222^{S}	0.7241^{S}		0.4731	44.643	0.8415	64.304	1.1184

** Selected model; **S=** Parameter estimate significant ($p < 0.05$); **NS=** Parameter estimate not significant at ($p > 0.05$).

4.2.5 Below Ground Biomass Models

Results showing the fitted equations for estimation of biomass below ground using Dbh and height as independent variable are presented in (Table 2). Model form 2 was selected and recommended for determination of biomass stocks below ground. The selection of the best model was based on the low RSE and Akaike's Information Criterion (AIC). Other criteria used in best model selection were RMSE, and coefficient of determination (R^2). A model with low AIC, RMSE, RSE and R^2 was regarded as a best model.

4.2.6 Model for estimating main Roots and Other Roots biomass

The weights of unexcavated roots were estimated using model form 3, the model was selected to be the best model (Table 3); as it had high R^2 and low RSE compared to other model.

Table 3: Regression equations and their goodness of fit for three different models of main roots

Model forms	Regression Coefficients		RSE	R^2
	A	b		
1. $Wt=a+b(Dtdr)$	-11.823^S	3.0054^S	10.2	0.6035
2. $Wt=b(Dtdr)^2$		0.1487^S	9.46	0.58
3. $LnWt=a+b\ln(Dtdr)^{**}$	**-2.3148^S**	**2.0935^S**	**0.91**	**0.79**

** Selected model; **S**= Parameter estimate significant ($p < 0.05$); **NS**= Parameter estimate not significant at ($p > 0.05$)

4.2.7 Root-shoot Ratio

The calculated root to shoot ratio (R:S), for all destructed cashew sample trees had the overall average of 0.18, for all diameter classes. These results are slightly low comparable to those reported by Mugasha *et al.* (2013) where R:S of 0.4. However, these differences might have been attributed by site conditions, wood properties and management regimes. Furthermore, the trend shows that, R:S, increases with increasing rate of diameter class, and tend to decrease at diameter grater than 41cm, (Table 4). The computed R:S, varies significantly across DBH classes ($p < 0.05$).

Table 4: Root shoot ratio

Variable		R:S Ratio			
Dbh class (cm)	n	Mean	Min	Max	STD
0 – 20	8	0.16	0.035	0.541	0.16
21 – 40	17	0.19	0.088	0.35	0.08
41>	20	0.18	0.09	0.36	0.08

4.2.8 Biomass and Volume Model Predictions

All developed models for biomass and volume were tested using available data to find how they over or under estimate the biomass and volume. The results showed that the model for above ground biomass is capable to predict the biomass by 92%, model for below ground biomass is capable to predict by 95.54%. Moreover, models for stem, branches and leaves and twigs are capable to predict their biomass by 84.4%, 97.55% and 83.43% respectively.

Developed volume models for branches, stem and total volume of cashew trees are capable to estimate their volume by 84.42%, 58.45% and 70.31% respectively. Model for stem volume is higher under estimating its volume compared to other models, this can be contributed by field decision as there is no clear cut between stem and branch for some cashew trees, and mult stemic effect especially when they branch at Dbh above 1.3m.

4.2.9 Estimation of Biomass Stocks and Carbon Stock

The average biomass estimates for total tree biomass from all sample plots was 34.41± 4.96tC/ha with standard error of 2.47% and standard deviation of 17.45%. The Total carbon stock was estimated to be 16.17±2.33tC/ha. These values are within the range reported in Philippines tree farms by Sales *et al.* (2005) where carbon figures ranged from 0.98 tC/ha to 63.94tC/ha. A study done by Elverfeldt *et al.* (2009) reported that the net carbon accumulation in three agroforestry systems ranged from 17 to 18 tC/ha).

4.2.10 Cashew Tree Biomass and Volume Component Contributions

The finding reveals that every component of the cashew tree has its contribution to total biomass. It shows that stems, branches, leaves and twigs their biomass contributes by 33.82%, 28.57%, and 23.96% respectively, while below ground biomass contributes by only 13.64%. Interms of volume, the findings reveals that, the stems contributes by 73% while the branches contributes by 27.99%.

4.3 Cashew Farm Structure

4.3.1 Stem density and basal area estimates

In this study, number of stems per hectare, basal area (m^2/ha), volume (m^3/ha), total biomass and carbon (tC/ha) were also reported. Finding in (Table 5) indicates that the average number of stems per hectare was 168±22.65 stems/ha at average spacing of 12m by 12m. These findings are slightly higher compared to Muriga *et al.* (2012) who reported Mean tree density of TOF as 156 stems/ha in communal tenure regime. Also Yossi and Kouyate (2002) who studied TOF in Mali reported less. They came up with stocking density of 8 – 20 stems/ha in village fields which had been cultivated. Njuguna *et al.* (1998) reported higher tree density of 250 stems/ha on tree farms in Kenya.

Basal area was 5.15 ± 0.86m^2/ha. These findings are in line with Muriga *et al.* (2012) who reported the basal area in TOF that varied between 4.12 ± 1.01 to 8.61 ± 3m^2/ha. The variation in stocking and basal area can be caused by number of factors such as site productivity, and silvicultural management.

4.3.2 Wood basic density

The results show that the wood basic density for cashew tree was 176Kg /m^3. The wood basic density was calculated as average from branches and stems of all cashew trees

4.3.3 Total volume

The results in (Table 5) explain that for all 50 plots inventoried, the average volume was 48.88±11.67m^3/ha with standard error and standard deviation of 5.81% and 41.08% respectively. These findings are in line with (Kumar and George, 1994) who reported the volume of home gardens ranged from 6.6 to 50.8 m^3/ha. Number of studies have been done on allometric models for forests and forest plantations, but very rare have been developed for species specific for trees outside the forest.

Table 5: Cashew farms structure, total volume, biomass, and carbon stocks

	Stocking (N) stems/ha	**Basal Area (G) m^2/ha**	**Volume (V) m^3**	**Total Biomass t/ha**	**Total Carbon t/ha**
Mean	168	5.15	48.88	34.41	16.17
Standard error	11.27	0.43	5.81	2.47	1.16
Standard deviation	79.71	3.01	41.08	17.45	8.2
Confidence interval	22.65	0.86	11.67	4.96	2.33
Observation	50	50	50	50	50

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Allometric models for assessing Volume and Biomass estimation equations for different tree components of *Anacardium occidentale* grown and privately owned by farmers in Liwale District have been developed.

Allometric models for estimatin below ground biomass and above ground biomass for cashew trees have been developed. For above ground biomass models developed were stem, branches, leaves and twigs and above ground biomass. For below ground biomass, allometric models were developed which combines biomass for root crown, main roots and other roots.

The stand structure of cahew farms revealed that, the cashew trees had tree density of 168 + 22.65 stems per ha and basal area of 5.15 ± 0.86m^2/ha at a spacing of 12m X 12m, and the wood basic density of cashew tree was 176Kg/m^3

5.2 Recommendations

The models discussed above are species and site specific. Where no volume estimation equations for *Anacardium occidentale e*exist, it is recommended to use developed equations for estimating volume.

Developed allometric models for estimating biomass above ground and biomass below ground can be applied where no biomass equations exists.

Cashew tree farms (stand structure) revealed that have additional value to farmers. From the cashew farms inventoried by using the developed models it is revealed that the total volume estimate was 48.88 ± 11.67 m^3/ha, and the total biomass estimate was 34 ± 4.96 tC/ha. Futhermore, the total carbon estimate was 16.17 ± 2.33 tC/ha.

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APPENDICES

Appendix 1: Individual tree measurements

TreeNo	Species name	Dbh (cm)	RCD (cm)	Height (m)	Remarks

Appendix 2: Above ground biomass

Section	Stems			Lab sample	Branches			Lab sample	Twigs and Leaves	Lab sample
	Length (cm)	Mid Diameter (cm)	Green Weight (Kg)	Dry Weight (Kg)	Length (cm)	Mid Diameter (cm)	Green Weight (Kg)	Dry Weight (Kg)	Green Weight(Kg)	Dry Weight (Kg)
1										
2										
3										
4										
5										
6										

Appendix 3: Below ground biomass

Root sample		Root section	Mid Diameter (cm)	Green Weight(Kg)	Lab sample	Broken roots(billets)			Lab sample	Fine roots	Lab sample
					Dry Weight (Kg)	Length (cm)	Mid Diameter (cm)	Green Weight (Kg)	Dry Weight (Kg)	Green Weight (Kg)	Dry Weight (Kg)
Smallest	Main	1									
	Branch	2									
		3									
		4									
Medium	Main	1									
		2									
		3									
	Branch	4									
		5									
		6									
Large	Main	1									
		2									
		3									
	Branch	4									
		5									