GROWTH AND PRODUCTIVITY OF SOME SELECTED INDIGENOUS TREE SPECIES IN MONOCULTURE PLOTS IN MOROGORO – TANZANIA

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A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN FORESTRY OF SOKOINE UNIVERSITY OF AGRICULTURE. MOROGORO, TANZANIA.

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ABSTRACT

Growth and productivity of four indigenous tree species (*Miliciaexcelsa, Afzeliaquanzensis, Darbegiamelanoxylon*and*Khayaanthotheca*) was evaluated in 23 year old rectangular 400 m^2 (20 x 20 m) plots planted at Tanzania Tree Seed Agency (TTSA) Arboretum in Morogoro, Tanzania. Data was collected on survival, diameter at breast height (Dbh), total height, stem form and wood basic density. A t-test of the collected data (dbh, total height and wood basic density) have shown that there were significant (P = 0.05) differences in Dbh and total height. The survival (untransformed) ranged from 93.75% (*Afzelia quanzensis)* to 100% (*M. excelsa, D. melanoxylon* and *K. anthotheca). K. anthotheca*was better with mean Dbh of 32.25 cm and BA of 36.48 m^2ha^{-1}than the rest of the species. *K. anthotheca* attained mean height of 28.09 m and MAI of 1.221 myr^{-1} followed by *A. quanzensis, M. excelsa* and the least was *D. melanoxylon* with mean height of 9.4 m and MAI of 0.413 myr^{-1}. The expected mean yield ranged from 402.6 m^3ha^{-1} (*K.anthotheca*) to 123.8 m^3ha^{-1} (*D.melanoxylon*) and MAI ranged from 5.38 m^3ha^{-1} $year^{-1}$ (*D. melanoxylon*) to 17.50 $m^3ha^{-1}year^{-1}$(*Khaya anthotheca*).*A. quanzensis*had the poorest rank in stem form (12.5% of the trees with crooked stems) followed by *D. melanoxylon* and *K. anthotheca* while*M. excelsa* was better in form. Though there were no significant (P>0.05) differences in wood basic density, the species differed markedly and *D. melanoxylon*had the highest basic density (423.5 kgm^{-3}) while *K. anthotheca* had the lowest (329.4 kgm^{-3}). Overall,*K. anthotheca*had better performance (survival and growth) compared to the other species. However as a way of broadening the availability of indigenous species and based on their economic values,all the assessed species showed good performance and all shouldbe considered for further studies and planting in a small scale.

DECLARATION

I, AUGUSTO MATOVO MUIAMBO, do hereby declare to theSenate of Sokoine University of Agriculture that this dissertation is my own original work done within the period of registrationand that it has neither been submitted nor being concurrently submitted in any other institution.

____________________________ ____________________________

Augusto MatovoMuiambo **Date**

(M.Sc (For) candidate)

The above declaration is confirmed by;

____________________________ ____________________________

Prof. S.A.O. Chamshama **Date**

(Supervisor)

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I thank God almighty for the opportunity and his light for the days of my life here on earth and by enabling me to sincerely finish this work. Though only my name appears on the cover page of this dissertation, many people have contributed to its production and I owe my gratitude to all those people who have made it possible.

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DEDICATION

I dedicate this work to my beloved mother **Joaquina Jaime dos Santos**, and to my brothers and sisters and friends, whom I missed a lot when I was away for my studies. And to almighty God who gave me a new life through the spirit while still in this country. What then shall I say in response to this, If God is for us, who can be against us.

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LIST OF ABBREVIATIONS AND ACRONYMS

C	Carbon
cm	Centimetre
CO_2	Carbon dioxide
Dbh	Diameter at breast height
Ha	Hectare
Ht	Total height
Km	Kilometer
Kg	Kilogramme
m	Meter
mm	Millimeter
MAI	Mean annual increment
N	Nitrogen
NGOs	Non – governmental organizations
NWFPs	Non-wood forest products
P	Phosphorous
spp.	Species
SUA	Sokoine University of Agriculture
TTSA	Tanzania Tree Seed Agency
UNEP	United Nations Environment Programme
Yr	Year

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Pioneering attempts for establishment of forest plantations in Tanzania started in the 1890s in order to supplement wood supplies from natural forests (Nshubemuki *et al.,* 2001). This was followed by large scale industrial forest plantations establishment between 1920-1961.These plantations are dominated by exotic trees species which are fast growing and are easy to manage (Nshubemuki *et al.,* 2001). With the introduction of the fast growing and supposedly ‘economically’ superior exotic species, most of the local species have been ignored, and their great potential has been overlooked (Mtuy, 1996).

To date, Tanzania has 19 such plantations covering 89 000 hectares(ha) whereby conifers and broad-leafed trees account for 84.7% and 15.3% of this area respectively.Approximately 17 species are planted and the dominant species include *Pinuspatula*(60% of the plantation area), *Cupressuslusitanica*(13%), *Eucalyptus maidenii*and *Eucalyptus saligna*(4.3%) and *Tectonagrandis*(3%) (Nshubemuki *et al.,* 2001). Most of these forests are in poor condition because of having trees of poor form and lack pruning and thinning and this state of affairs is due to use of seed of inferior genetic quality and low budgetary allocations resulting in the skipping of some silvicultural operations (Chamshama and Nshubemuki*.,* 1998). There are privately owned plantations covering about 100 000 ha and are dominated by *Acacia mearnsii, Eucalyptus species, Pinuspatula*and *Tectonagrandis*(Nshubemuki *et al.,* 2001).

Since the 1980s, scientific interest has increasingly focused on appropriate strategies for forest plantations to provide multiple ecosystem services and a broader range of goods while meeting the economical demand for high timber productivity (Kelty, 2006; Paquette and Messier, 2011). Whereas former plantation forestry has traditionally concentrated on monocultures based on a few well-known exotic tree species (Holmgren and Carle, 2006; Kelty, 2006), exotics were favoured over natives because of their wide adaptability and tolerance to stress, thus they were perceived to grow faster than native species, their germplasm was widely available, and their silviculture was better understood (Tolentino, 2008).

However recent research has emphasized the potential advantages of indigenous over exotic species, planted/domesticated in monocultures and mixed stands (Lamb *et al.,* 2005; Piotto*et al.,* 2010).

In many cases, especially in the tropics, opportunities that exist in the forestry sectors are hampered by the poor state of knowledge of potential indigenous species and markets (Nichols and Vanclay, 2012). Thus, there are few trials on performance of indigenous tree species in Tanzania, as well as other countries of the tropics. Some of the reasons for this include the thinking that indigenous species have very slow growth rates, are difficult to propagate and have long rotation periods thus would not meet future wood and non-wood forest products (NWFPs) needs (Chamshama and Nwonwu, 2004). Further, Plath *et al.* (2011) believe that planting indigenous trees is perceived as a risky activity due to limited knowledge of their performance and due to marked losses of newly established seedlings attributed to insect pests.

However indigenous tree species may have more positive effects on the environment, fulfil traditional services to local landholders and require less financial investmentby eliminating dependency on external seed sources and foreign technologies (Plath *et al.,* 2011). Over the years, more knowledge on performance of indigenous species in monoculture has been generated and this will lead to the inclusion of indigenous species in monoculture or mixed forest plantations.

1.2 Problem Statement and Justification

1.2.1 Problem statement

For over four decades from the 1950s, indigenous tree species were thought to be slow growing and not much was known on their establishment also some thought they are not amenable to plantation culture (Chamshama, 2014; Chamshama and Nshubemuki, 1998).

However forest products from tropical indigenous tree species are of particular interest because of their quality, but are increasingly becoming scarce because of illegal harvesting and overexploitation. Despite this potential role, there has been relatively little attention devoted to the process and practice of domesticating indigenous tree species for use in plantations, especially for non-industrial plantations (Nichols and Vanclay, 2012; Nichols *et al*., 2006).

Leakey and Akinnifesi (2008)showed that while tree management of indigenous species has increased, the documentation of the logic and the approach has been generally scant in the Tropics. A few case studies of indigenous tree domestication strategies have been documented (Leakey and Akinnifesi, 2008). Most part, tropical plantations are of the fast-growing exotic industrial species, in spite of the large number of tropical indigenous species with premium timber (Weber *et al.,* 2008).

For decades, there have been calls for tropical native forest trees to be domesticated (Leakey and Akinnifesi, 2008; Lamb *et al.,* 2005). Current market forces tend to favour single species/mixture plantings (Nichols *et al.,*2006), and greater diversity and resilience of plantations will not be achieved without domesticating additional indigenous species.

Indigenous tree planting is partly due to the concern that the promotion of exotic monoculture in place of naturally diverse forest would accelerate the loss of biodiversity. Currently, reforestation projects seek to promote the cultivation of indigenous species as a desirable alternative to exotic stands in an attempt to enhance and sustain biodiversity of the forest ecosystem (Prebble, 1997), and to reduce pressure on the miombo woodlands. Also there are few studies on wood basic density and basal area on indigenous trees currently used in rotational woodlots/mixed plantations (Luhende *et al.,* 2006). Therefore, it is upon these considerations that assessment of growth and productivity of some selected indigenous tree species in monoculture is vital in Tanzania taking into account the challenges facing the silvicultural sector.

1.2.2 Justification

The study evaluated growth and productivity of the four indigenous tree species namely: *Miliciaexcelsa, Afzeliaquanzensis, Darbegiamelanoxylon*and*Khayaanthotheca*. The species were selected for their (1) commercial importance on national,regional and international scale, and (2) their availability as trees and seedlings in local nurseries. Information generated from this study will be of importance to policy and decision markers, communities, public and private sector plantation managers, development, research and training institutions and Non-Governmental Organizations (NGOs).

1.3 Objectives

1.3.1 Main objective

To evaluate the growth and productivity of the selected indigenous tree species planted in monoculture.

1.3.2 Specific objectives

i. To assess growth and survival of four indigenous tree species;
ii. To determine basal area, volume production and mean annual increment (MAI);
iii. To determine stem form;
iv. To determine wood basic density.

1.3.3 Hypothesis

The null hypotheses:

- The assessed tree species do not differ in survival, growthand wood basic density.

Alternative hypothesis:

- The assessed tree species differ insurvival, growth and wood basic density.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Forest Plantation as Sustainable Land Use Practice

Forest plantations refer to those forest stands established by planting and/or seeding in the process of afforestation or reforestation. They are either of introduced or indigenous species that meet a minimum area requirement of 0.5 ha, tree crown cover of at least 10% of the land cover, and total height of adult trees above 5 meter (m) (Carle *et al*., 2002). MacDicken (2015) defined a forest plantation as a land spanning more than 0.5ha with trees higher than 5 m and a canopy cover of more than 10%, or trees able to reach these thresholds *in situ*. It does not include land that is predominantly under agricultural or urban land use. This definition is also accepted by FAO.

Forest plantations are grown to supply raw materials for industry and for other uses, such as fuelwood (Carle *et al.,* 2002). Plantation forestry, with some exceptions, is substantially a land use system based either on successive rotation of plantations or on 'new forests' established on land often degraded by other activities including agriculture (Nambiar, 1999). Forest plantations are not natural assets in the same sense as native forests; they are assets deliberately grown, often described as tree farms, for one or more specific purpose.

Forest plantations can be categorized in single species or mixed species plantation concepts. For commercial purposes in Tanzania, many fast growing exotic species were used (Appanah and Weiland, 1993). Exotic fast growing species have been favoured in the past because the volume increments of these are high and consequently can be harvested at shorter rotations compared to indigenous tree species. However, the economic value of fast-growing exotic species is now being questioned and the potential gained from using slow-growing but higher-valued native species are looking rather more commercially and environmentally attractive (Sokhun, 2005).

In Tanzania, government plantations (89 000 ha) are the main suppliers of wood raw materials and Sao Hill Forest Plantation alone is currently supplying over 85% of raw material consumed by industries (Ngaga, 2011). Given the age structure and current harvesting levels, it is predicted that after year 2017, there will be severe deficits for some ten years to come. Only after 20 years from today, the harvesting can come back to current levels. Individual private plantations andwoodlots, also known as non-industrial private forests are currently supplying an estimated 200 000 - 250 000 m^3 of round wood (Ngaga, 2011; SUA, 2014).

Over the past 15 years, the Government of Tanzania has been creating an enabling environment to promote private forestry to maximize the potential and existing opportunities in forestry (Ngaga, 2011). Consequently, Private Forestry Programmewas initiated in 2013 with the intention of increasing rural income, thereby reducing poverty and inequality through developing sustainable plantation forestry (SUA, 2014). However, as predicted by Ngaga (2011), if Tanzania economy grows at the same pace as now, and also the population and urbanization continue to grow, the forecast is that demand for wood from plantations will exceed supply by about 2 200 000 m^3 by year 2030. This represents a deficit in the rate of establishing new plantations of about 7 000 – 8 000 ha/year. In search of more areas for expansion of forest plantantions in the country, it is advised that new technology to boost the use of native indigenous tree and lesser known species must be considered so as to bring out good and satisfactory information on technical knowledge of such species (Sokhun, 2005; Heryati *et al.,* 2011a).

During World War II in Tanzania, the main indigenous tree species planted were Cedar (*Juniperusprocera*), Podo (*Podocarpusgracilior*), E.A. Camphor (*Ocoteausambarensis*), Mvule (*Miliciaexcelsa*), East African cordia (*Cordiaabyssinica*) and various mangroves, while exotic species included teak (*Tectonagrandis*), *Pines, Cypress, Cassia* and *Eucalyptus* spp. (Mtuy, 1996; Chamshama and Nshubemuki, 1998). Also, it was at this time that pilot plantings with various exotic species started at Olmotonyi, Rongai, Mbeya, Mufindi and Shume. After World War II, in the late 1940s, proper afforestation and reforestation plans were drawn up which resulted in the establishment of the present softwood and hardwood plantations (Mtuy, 1996; Chamshama and Nshubemuki, 1998). It was also realized that the rate of growth of indigenous trees was slow and it was therefore decided that fast growing exotic tree species be planted instead to complement production from natural forests thus indigenous species were sidelined (Chamshama and Nwonwu, 2004). Later in the 1950s, the potential to supply plantation grown wood in deficit areas and for export was noted and plantations were therefore distributed all over the county as seen today (Fig. 1). But not one indigenous tree species plantation has been kept for trials and many private projects are on trial and error to find suitable and preferred species for small scale planting.

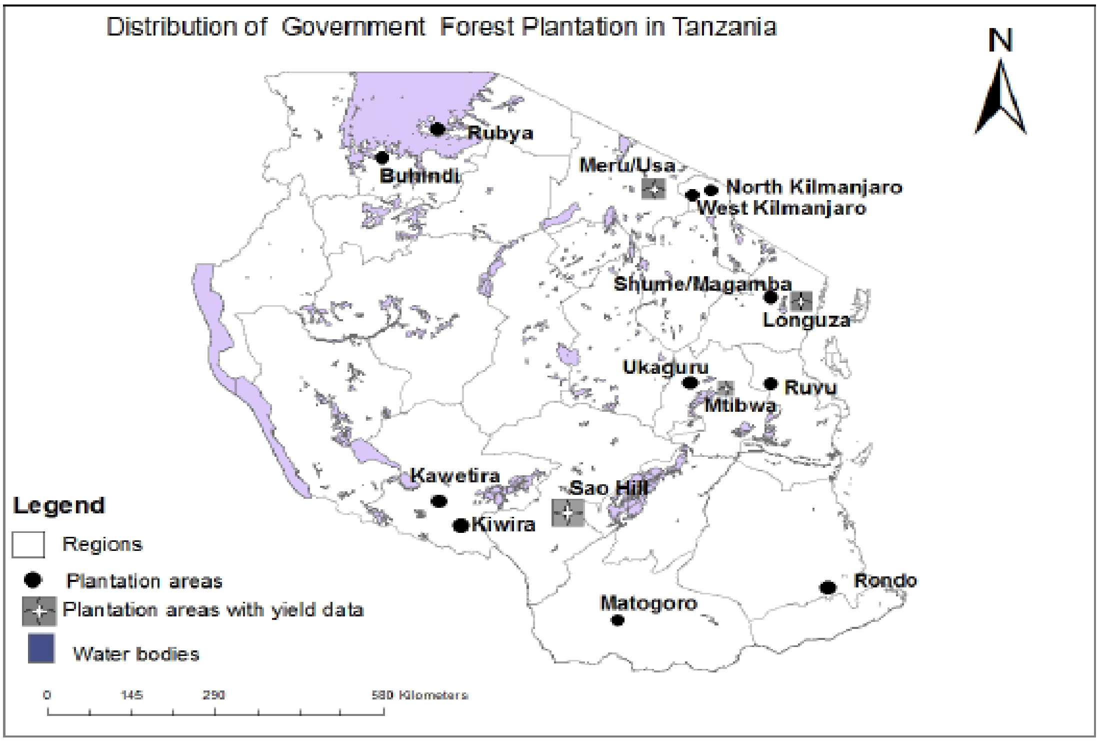

Figure 1: Distribution of government forest plantations in Tanzania.

Source: Modified from Ngaga (2011)

2.2 Preference of Indigenous Tree Species in Various Land Uses

Indigenous tree species are not only desirable in forestry plantations but also for other land uses. So far most agroforestry interaction studies in the Sub Saharan Africa have not explored suitability of indigenous tree species (Chamshama*et al.*, 2006; Kimaro, 2009; Byers *et al.,* 2012). Smallholder farmers desire to raise native trees, however, are inhibited by factors such as tenure security and insufficient knowledge and skills on propagation, management and protection (Mangaoang and Pasa, 2003). Farmers, based on perceived ecological and economic usefulness of the species, consider native trees important (Lawrence, 1997; Patindol, 1998). In Tanzania, indigenous trees and shrubs are of value in agriculture as they directly or indirectly contribute to crop and livestock production. They provide fodder to animals and replenish soil fertility unlike most exotic tree species (Komwihangilo *et al.,* 1995).

Native trees species are commonly considered by farmers and foresters as slow growing trees, but field observations proved that in fact some of these species grow at least as fast as some exotics (Magcale-Macandog *et al*., 1999). Therefore the domestication of native trees is dealing with an imperfect knowledge base, since these species have often been virtually overlooked by science, and are little known commercially, except in their local areas. However, it is now recognized by the scientific community that the bias to native tree improvement needs to be readdressed by the development of novel approaches that take into consideration the requirements of small-scale, resource poor farmers and their farming systems. Given that improvement is as much a social and political challenge as a biological one, it will only be through experimental implementation of a range of approaches that methods and strategies will progress (Magcale-Macandog *et al*., 1999).

2.3 Selected Indigenous Tree Species

2.3.1 *Miliciaexcelsa* (*Chlorophoraexcelsa*) familyMoraceae

*Milicia excelsa*is indigenous in Tanzania and other East African countries. The common name is Mvule. Ecologically it is characterized as a giant deciduous tree of lowland forest and wet savannah. The tree is logged commercially throughout its range (Mbuya *et al.,* 1994).

Miliciaexcelsa is among the most valuable indigenous timber species in Africa because of its natural durability and good working properties (Ofori and Cobbinah, 2007). The species is grown in plantations in a small scale and is mostly extracted from natural forests at an unsustainable rate. Efforts at establishing plantations of *Milicia* spp. have been constrained by the gall forming psyllid*Phytolymalata* that causes extensive damage to the young plants but studies are being done to counter the pest (Ofori and Cobbinah, 2007).

Miliciaexcelsa can grow up to 47 m high or more and 2.5 m in diameter (Taylor, 1960).It hasthick barkwhich is pale, ash grey to nearly black, then brown, usually fairly rough and flaking off in small scales, but seldom fissured, slash thick, fibrous, cream coloured with brown spots, exuding white latex. The trunk is lofty, straight and cylindrical, up to 20 m or more to the first branches, usually with short, blunt buttresses. Crown is high, umbrella-like and growing from a few thick branches.Branchlets are thick, rather zigzag and angular, all more or less horizontal. Branches of female trees hang down but male individuals have upright branches (Berg, 2010). Leaves in young trees are sandpapery and green above, paler and pubescent below, older leaves often becoming bright yellow, serrulate at the margin, simple, alternate, 9-20 x 5-10 centimeter (cm), broadly elliptic or ovate, very shortly acuminate, usually unequally glabrous above and beneath except for minute hairs between the network of veins, about 15 pairs thick parallel, upcurving, pale-coloured lateral nerves, very prominent beneath and looped close to the margin; ultimate veins are thick and forming a highly characteristic, more or less rectangular network on the under surface, base subcordate, apex shortly acuminate; edge is finely toothed. Stalk is 2.5-6 cm, stout, glabrous (Berg, 2010). Flowers are dioecious, axillary, greenish, all floral parts in four. Fruits are arranged along a longitudinal axis with one seed on each side, 5-7.5 x 2-2.5 cm, green, wrinkled, fleshy and resembling a fat green caterpillar; no change in the colour of the syncarp when mature, but the flesh between the actual fruit softens. Seeds are hard, small and lie in the pulp.

The timber is strong, moderately hard, very durable with interlocked and sometimes irregular grain. It seasons well in air or kiln and does not warp or shrink afterwards (Farmer, 1975; Irvine, 1961). It is highly resistant to termites and fungal attack (White, 1996).

The distribution of *Milicia* spp. ranges from Senegal and Gambia in West Africa through Central and East Africa to Mozambique (White, 1966; Irvine, 1961; Taylor, 1960). The tree prefers well-drained soils and is intolerant of impeded drainage. It is an intense light demander and cannot stand very deep shade, for example in young secondary forest, where it cannot compete with the climbers and shrubs (Taylor, 1960). Exploitation of *Milicia*spp. is mainly done from the natural forest, however, regeneration has proven to be inadequate to match with the rate of exploitation mainly due to their susceptibility to *Phytolyma gall* attack (White, 1966; Wagner *et al.,* 1991). Heights of 6 month-old healthy seedlings have been found to vary between 65 and 105 cm, and in 1 year, the plants may grow up to 1.8 m high. The tree resembles Teak and is mainly used for outdoor construction work, furniture, boats, cabinet work, panelling, frames and floors and it fetches high market value (Monitor, 2007).

The growth can however be reduced considerably because of vulnerability to Phytolyma gall attacks. It was then predicted that the species would face the danger of extinction by the turn of 21stcentury if careful measures were not taken in the management of the species. *Milicia*spp. then became the focus of increasing conservation in most African countries (Berg, 2010).

2.3.2 *Dalbergiamelanoxylon* (African blackwood*)* family Fabaceae

Dalbergiamelanoxylon is indigenous tree species and the common name in Tanzania and other East African countries is Mpingo (Mbuya *et al.,* 1994). The name *melanoxylon*is appropriate meaning literally black (*melano*) wood (*xylon*).

The tree, Tanzania's national tree, is most commonly found in dry coastal forests from the Tana River in south Kenya through Tanzania and most of Mozambique (McCoy-Hill, 1993). It is also a common component of the open miombo woodland and savannah habitat which covers about two thirds of Tanzania. The species has been described by the Cambridge Encyclopedia of Life Sciences as arguably the most important wildlife reserve in the world (Berg, 2006). However its distribution is much wider than this: the tree is native to the whole of sub-Saharan Africa, ranging from northern Ethiopia, south to Angola and the Transvaal and west to Senegal (Alvarado *et al*., 2007). It has also been introduced to the Indian subcontinent. It is present in commercially significant levels only in Tanzania and Mozambique, with some harvesting also occurring in Zambia and Malawi. Kenya's stocks are now reportedly negligible.

*D. melanoxylon*is often multi-stemmed and extensively branched. The trees grow very slowly and in very gnarled and twisted shapes.Annual increases in height and girth are small (Dale and Greenaway, 1961). The bole is typically heavily fluted and the crown irregular. Stems and branches bear characteristic 2-3 cm long woody spines (Wanga*et al.,* 2009). Bark is grey to greyish-brown and generally smooth, papery and flakes with age (Bryce, 1967). Beneath it lies yellowish sapwood (1-2 cm thick), and inside this, the purplish or brownish black heartwood (McCoy-Hill, 1993). The leaves are pinnate with 3 or more alternate-sub opposite dark green leaflets 0.8 to 3.5 cm long by 0.8 to 2.5 cm wide. They are commonly shed during the dry season. The flowers are small, whitish and sweetly scented in axillary panicles with 10 stamens united into a tube. Fruits are indehiscent, unwinged pods about 4 cm long containing 1 to 4 seeds (Lovett and Wasser 1993). Flowering and fruiting seasons are not well defined (Sharman, 1995).

In common with many other Leguminosae species, *D. melanoxylon*possesses nitrogen-fixing nodules in its roots (Etigale*et al.,* 2014). The species could therefore potentially play a very significant ecological role in the habitats where it is present (Wanga*et al.,* 2009).

The wood of *Dalbergiamelanoxylon*is East Africa's most valuable. In Lovett and Wasser (1993) reported sawn logs fetching up to US$ 9000per m^3, and processed timber selling for US$ 13 000 perm^3, with the highest prices obtained for the purest black timber. The same authors state that *D. melanoxylon*exports earned Tanzania US$ 0.5 million in 1982. Infrastructure problems subsequently caused a dip in Tanzanian export volumes in the mid-1980s, but since then exports have risen steadily. The wood is extremely hard and heavy, naturally oily and of fine texture; growth rings are usually indistinct (Bryce, 1967). These qualities make it ideal for the manufacture of musical instruments as it can hold metal fittings, and does not warp with changes in temperature and humidity, ensuring that it holds its tone well; in addition it has an attractive look to it.

Clarinets and oboes are the most common instruments made from the wood, although bagpipes, recorders and piccolos are also manufactured from it, as are piano keys and the fret boards of guitars (Lovett and Wasser 1993). According to UNEP (2010), it is the finest material available for woodwind instrument manufacture. It has been traditionally used by the African people to make various utensils and tools: hoe handles, from which the tree gains the local name mugembe, pestles, combs, cups, knife-handles and even walking sticks (although these are reportedly impractically heavy) (Bryce, 1967).

More significantly, it is the material of choice for wood-carvers throughout the region, and the distinctive carvings will be familiar to any visitor. Those of the Makonde people from Southern Tanzania have gained the most recognition for artistic merit: witches and devil spirits from traditional stories are commonest motifs, and the best examples are quite beautiful and eye-catching, demonstrating a smooth flowing style. The tradition is strong amongst carving families and passed from one generation to the next, but new styles are being continuously developed (Wanga*et al.,* 2009).

Western themes have always been catered for: chess pieces, paper knives, marquetry, and more recently Coca Cola bottles can all be purchased. Today the production of carvings for tourists is a major business, with Mwenge Carvers Society in Dar es Salaam, the largest co-operative, comprising several hundred carvers. The market is not well understood, but it is growing rapidly and could one day equal the export timber trade in value, if it does not already. More prosaically, both sapwood and heartwood are very high energy fuels, and are often used in making charcoal (Nshubemuki*et al.,* 2001). The leaves and bark of *Dalbergiamelanoxylon*also have their uses - as fodder for animals, mulch for the earth and medicines against a diverse range of complaints including headaches and diarrhoea (Sharman, 1995).

2.3.3 *Afzeliaquanzensis*(lucky-bean tree) family Fabaceae

Afzeliaquanzensis is indigenous in Tanzania and other East African countries. The common Kisiwahiliname is Mbambakofi(Mbuya *et al.,* 1994). Ecologically in Tanzania, *Afzeliaquanzensis*is found in miombo woodlands, lowland thicket or dry woodland, 0 - 1300 m above sea level. It is deep rooting and prefers medium light soils, not waterlogged (Mbuya *et al.,* 1994).

*Afzeliaquanzensis*can be described as a semi-deciduous leafy tree, usually to 12 m but can reach 35 m; thick branches near base provide timber. Bark is grey brown, flaking in large pieces leaving pale patches below. Leaves are compound to 30 cm, 4 - 9 pairs of leaflets, each one to 9 cm, oblong and the tip is rounded. Flowers have a distinct single petal, green outside, pink-red inside and 2-3 cm wide sweet-scented in small groups on erect heads. Fruits are dark-brown, flat woody pods, 20 cm long, 10 cm wide, with shiny black seeds with a soft orange-red cup (flesh aril) lying in white fibres. *Afzeliaquanzensis*propagates from seedlings (Mbuya *et al.,* 1994).

*Afzeliaquanzensis*produces a lot of seed. It has good germination, reaching up to 90% after 28 days. During treatment, the aril should be removed and nicking any side of the seed will speed up germination. It can be stored for several years at room temperature in an airtight container. It is fairly fast growing when young, later quite slow growing (Mbuya *et al.,* 1994).

A. quanzensis occurs from Somalia in the north to Kwazulu Natal in the south and is mainly found in the coastal region in Kenya. It grows in low-lying woodland, dry deciduous or sandveld forests, dense bushland, around lake basins or at edges of dry evergreen forests. It is normally the dominant species when it occurs in areas with deep sandy soils. *A. quanzensis* is very drought resistant but frost sensitive and slow growing in colder areas. It is now a protected tree in South Africa and other parts of Africa (Orwa *et al.,* 2009).

*A. quanzensis*is used for timber (construction, furniture), carving (doors, dhows, canoes, etc.), medicine (roots), shade and as ornamental, and most of the largest specimens of this tree have been felled and cut up for railway sleepers(Mbuya *et al.,* 1994). *A. quanzensis*is potential for plantation in miombo woodlands. It is also a good avenue and shade tree (Mbuya *et al.,* 1994).

2.3.4 *Khayaanthotheca*(*K.nyasica*) family Meliaceae

*Khayaanthotheca*is indigenous in Tanzania and other East African countries. The common Kiswahili name is Mkangazi(Mbuya *et al.,* 1994). It has also been introduced as an exotic in other countries like Bangladesh and is considered as fast growing tree species (Alam *et al.,* 2012).

Ecologically, *Khayaanthotheca*is a tall forest tree occurring from Tanzania south to Mozambique at medium to low altitudes in evergreen forests and riverine fringe forests. It is locally common in Tanzania as a riverine tree in the foothills of mountain ranges. It prefers deep fertile soils with subsoil moisture and can withstand seasonal flooding. *K. anthotheca*is used as firewood, timber (furniture, panelling and boat building), posts, flooring, medicine (bark), shade and as an ornamental (Mbuya *et al.,* 1994).

*K. anthotheca*is described as a semi-evergreen large to very large tree, sometimes exceeding 60 m, with a straight bole to 30 m before branching to a massive crown, markedly buttressed at the base. Bark is grey to brown, mainly smooth but flaking in characteristic rounded scales. Leaves are compound, 2-7 pairs oblong leaflets, each leaflet to 17 cm. Flowers are small, 1 cm, white and sweet scented in heads, often hidden by leaves. Fruits are up to 5 cm across, breaks into 4 - 5 sections on the tree, scattering 30 - 60 pale flat winged seeds (Mbuya *et al.,* 1994).

Khayaanthotheca propagates from seedlings, stumps and wildings. Numbers of seeds per kilogramme (kg) are 2000 - 3800. Its germination is good and uniform. Seed treatment may not be necessary. Seed can be stored for up to 3 months. It is fast growing and coppices poorly(Mbuya *et al.,* 1994).

*Khayaanthotheca*is suitable for planting under light shade in a mixture with *Chlorophoraexcelsa.* The wood weathers well and resists borers and termites. The pale pink fresh timber turns red-brown and is most popular for furniture where it is available as it is easy to work, polishes well and is durable. The timber is similar to true mahogany from South America *(Swieteniamacrophylla)*(Mbuya *et al.,* 1994).

2.4 Species Survival, Diameter at Breast Height and Height Growth

The survival of species on the site is a very important factor to be considered, and it influences the land potential for timber plantation.The fact that species are indigenous does not mean that they can survive in any environment within their range; proper site matching and appropriate species need to be determined (Appanah and Weinland, 1993). According to Gerald (2012), plants grown in close proximity tend to interact spatially in their capture of available resources, and the intensity of these interactions varies temporally under resource-limiting conditions and influences their survival. Also trees do obviously differ in their growth performance depending on the site (Magcale-Macandog*et al.,* 1999).

Currently, through observation, several indigenous tree species when growing isolated (outside the natural forest) show encouraging survival, diameter and height growth, this triggered some forest plantation project to initiate planting of high quality and selected indigenous species (Appanah and Weinland, 1993; Heryati*et al*., 2011a). There is a common belief that forestry plantations need to involve short rotation tree species (Magcale-Macandog *et al.,* 1999). But the popularity of indigenous species with long rotation periods, such as Mahogany, demonstrates that farmers are willing to wait longer than what it is commonly assumed if the quality of the final product is higher, and the trees survive and grow in plantations (Magcale-Macandog *et al.,* 1999). In Malaysia, a study showed that *Hopeaodorata*(indigenous species) is among the promising tree species for forest plantations also as an alternative to *Acacia mangium*(exotic species)(Heryati *et al.*, 2011a).

Some studies reported that several African indigenous tree species are performing better in other environments and outside Africa. *Khayaivonrensis*, native to coastal and west Africa was introduced in Malaysia in late 1950's and planted in monoculture. It has been planted at Bukit Lagong Forest Reserve (Malaysia) and achieved an average diameter at breast height (Dbh) of 12.3 cm after 4 years of planting, while in Mata Ayer, Perlis, 4 year old *K. ivorensis*planted on Penambangan soil had average MAI of 2.28 cmper year (yr^{-1})and 1.63 m^3 yr^{-1} for Dbh and height (Ht) respectively (Krishnapillay, 2002). However, the growth performance of *H. odorata*(indigenous)was higher with average MAI of 0.90 m^3 yr^{-1} for height and MAI of 1.11 cmyr^{-1} for Dbh respectively (Krishnapillay, 2002).

Heryati *et al.* (2011b) found that the amount of basal area in *K. ivorensis*stand was 9.65 m^2ha^{-1} which was higher compared with that of *H. odorata*stand (8.00 m^2ha^{-1}). It means that stand density showed a relationship with the amount of basal area, where the high stand density planting produces a high basal area. Thus the stand density in the *K. ivorensis* was 808 stemsha^{-1}, while in the *H. odorata*stand, it was 783 stems ha^{-1}showing stable survival. In Malaysia, the indigenous species like *H. odorata*(Dipterocarpacea), have been found to be suitable to be planted in plantations. Besides that, according to Evans (1992), indigenous trees have some other advantages such as resistance to pests and diseases. Based on the observation in the field, *H. odorata*stands seemed to be more healthy compared with *K. ivorensis*stands in Malaysia, while *K. ivorensis*stands were beginning to be attacked by shoot borer *Hypsiphyllarobusta*. The pest attack will actually inhibit further growth of *K. ivorensis*. Because of such findings, the species *H. odorata*(indigenous) has been planted in monoculture along the Andaman Islands, Myanmar, Thailand and Indo-China and the northern part of Peninsular Malaysia (Symington *et al*., 2004).

Bosu *et al.* (2006) found that at the forest site, *Miliciaexcelsa* survival was 10% in the short season plantation and 30% in the long season plantation in Ghana. Mean Dbh and mean Ht were significantly higher in the long season plantation than in the short season plantation 2.4 cm versus 0.43 cm Dbh and 2.95 m versus 7.4 m in Ht, 8 – 9 years after plantingrespectively. The mean Ht and Dbh growth of the surviving *Miliciaexcelsa* plants at the forest site were significantly influenced by planting season (Bosu *et al.,* 2006).

Study on performance of 45 indigenous tree species (e.g. *Sandoricumkoetjape*, *Pometiapinnata*, *Sindorawallichii*and *Syzygiumpolyanthum*) found that overall survival rates were high (> 90%) for almost all species tested (Shono*et al*., 2007). Many individuals achieved Hts of 10 m within five years of planting. Other species found to perform poorly due to slow growth rates included *Strombosiajavanica, Pouteriaobovata, Aquilariamalaccensis, Gonystylus confuses* and *Lepisanthesrubiginosa (*Shono*et al.,* 2007).

A study on performance of 60 indigenous tree species by Schneider *et al.* (2013) found that a total of 2789 individuals survived, mean growth performance of both Dbh and Ht were statistically significant. Analysis of the twenty most frequently measured species across all 25 sites assessed showed that there were significant differences between species performance, with the highest Dbh growth rates found in *Meliadubia* and *Terminaliamicrocarpa* (1.89 $cmyr^{-1}$, 1.31 $cmyr^{-1}$) and the lowest Dbhgrowth rates were found in *Podocarpusrumphii* and *Intsiabijuga (*0.31 $cmyr^{-1}$, 0.37 $cmyr^{-1}$) (Schneider *et al.,* 2013).

In the Philippines, Schneider *et al.,* (2013) found that the growthcomparison of means, the diameter growth rates of the two highest performing native species (*Meliadubia* and *Terminaliamicrocarpa*) were found to be significantly different from those of the third-fastest growing species and most widely planted exotic (*Swieteniamacrophylla*) in monoculture and concluded that certain native species can perform better than some exotic species when planted in open areas/monocultures. They also disproved the widely held belief in the Philippines that natives species cannot be planted in monoculture and suggested that they can be used successfully in plantation and reforestation. Finally, the findings show that more research is needed on species-site matching and on silvicultural management of native species plantations (Schneider *et al.,* 2013).

Petit and Montagnini (2006) found that for the 10 indigenous tree species (*Calophyllumbrasiliense, Vochysiaguatemalensis, Jacaranda copaia, Dipteryxpanamensis, Virolakoschnyi, Terminaliaamazonia, V. ferruginea, Hyeronimaalchorneoides, Genipaamericana,* and*Baliziaelegans*), the tree density (survival) remained fairly consistent amongst the plantations with one notable exception of heavy mortality in *G. americana* plots that caused a significant decrease in stand density (approximately 30–40%), while *C. brasiliense*and *D. panamensis* had significantly smaller Dbh than other species in the plantations. Also only *D. panamensis* and *G. americana* varied from their counterparts in Ht. In monocultures, *Jacaranda copaia, Vochysiaguatemalensis* and *Vochysiaferruginea* were the most productive of 10 species.

Onefeli and Adesoye (2014) studying two of the species (*Tectonagrandis*and *Gmelinaarborea*) exotic and three indigenous species (*Khayasenegalensis, Khayagrandifolia*and *Afzeliaafricana*) at 25 years showed that *K. grandifolia*(34.49 m) grew significantly better ($p<0.05$) in Ht than *G. arborea*(28.11 m) and *T. grandis*(22.36 m), while *A. africana*(28.03 m) closely followed *K. senegalensis*with 25.9mand thus the indigenous tree species showed an outstanding performance when compared with exotics in Nigeria. Based on the results, the selected indigenous species displayed promising potentials for conservation purpose.

Schneider *et al*. (2013) concluded that indigenous tree species merit further research into silvicultural management and site-species matching to improve survival and performance. The growth rates provided by this study for 44 native and sixteen exotic tree species help improve understanding of native and exotic species for future plantation and reforestation projects (Tolentino, 2008). For some of these species under study, no published data on growth performance exist, and most of the studies focus on recently established plantings. The significant differences observed in the growth of the different tree species suggest that their level of adaptation to the same environmental conditions is more or less different.

2.5 Basal Area, Volume Production and Mean Annual Increment

Planning and implementing sustainable management of forests require that a range of ecological, economic and social conditions are evaluated and considered carefully. As part of this process, forest managers and planners summarize information on the present and predicted future condition of a forest using various indicators selected for their usefulness in evaluating consequences of different management actions (Skovsgaard and Vanclay, 2007). In many situations, reliable estimates of basal area, wood production and increment are essential for sustainable forest management (Skovsgaard and Vanclay, 2007). Such estimates depend on silvicultural practices, for many purposes, the maximum mean annual volume increment is considered a suitable measure of site productivity.

Borokini *et al.* (2013) found that the total basal area for *Miliciaexcelsa* in Iroko - Ibadan was 120.63 m^2ha^{-1} out of which Ibadan Metropolis (IM) accounted for only 48.76 m^2ha^{-1} (40.4%) while that of the University of Ibadan (UI) was 71.87 m^2ha^{-1} (59.5%), and there was no significant difference ($p>0.05$) between the basal area of the two locations. The total stem volume of Iroko in Ibadan was calculated to be 1157.17 m^3 ha^{-1} (Borokini*et al.,* 2013).

Though some studies have shown high values of basal area per ha (Shono*et al.,* 2007), they mostly concluded that, there were no significant differences between species, and many of the standing basal area values corresponded with those of yield tables (Malimbwi, 1997). Several studies reviewed had species specific volume equations and volume tables for the local indigenous species.

According to West (2009), the principal commercial product of forest is wood. In the Malaysia study, stem wood of both species were estimated by using allometric equation which showed that the stem volume of *K. ivorensis*standwas 43.13 m^3 ha^{-1}, which was higher than that of *H. odorata*stand (33.66 m^3 ha^{-1}). Therefore, the MAI of stem volume for *K. ivorensis*stand was higher compared with *H. odorata*, so the exotic had higher volume that the indigenous tree species in Malaysia, but the indigenous performed better with exception of volume.

The MAI of stem volume for *K. ivorensis*and *H. odorata*were 8.63 m^3 $ha^{-1}yr^{-1}$ and 6.73 m^3 $ha^{-1}yr^{-1}$, respectively(Heryati*et al.,* 2011). Petit and Montagnini (2006) found that basal area remained consistent in plantation 1 of *Virolakoschnyi*and*Virolaferruginea* plots had a significantly higher basal area than other monocultures or mixtures in plantations 2 and 3, *J. copaia, V. guatemalensis,* and*Calophyllumbrasiliense* produced 21% more merchantable volume than a monoculture of *J. copaia*, which grew the fastest of the three species.

2.6 Stem Form and Wood Basic Density

Malimbwi (1997) defined stem form as the tree shape. Trees and stems in general have different forms, for example solitary compared to forest grown trees even when they are of same species and age (Malimbwi, 1997). The major factors influencing form are; species, tree density, age and site (Malimbwi, 1997). From mensuration point of view, there is interest in tree form because it influences merchantable volume and sawmill recovery.

Weber *et al*. (2008) and Wright *et al.* (1998) in their studies have compared stem quality for 11 years and 7 - 14 years respectively, and found that some species (*Acacia berlandieri,A. farnesiana,A. rigidula,A. wrightii,Cordiaboissieri*, *E. microtheca,Heliettaparvifolia* and*Leucaenagreggii*) showed poorest rank in stem form while others were relatively better but there were no significant differences between the species in both studies. Chamshama *et al.* (1997) found that at 14 years of age, stem from was not significantly (P>0.05) different between fourteen diferent *Cupressus* provenances grown in monoculture. No crooked stems were reported and 28% of the stems had slightly bends stems.

Mugasha *et al.* (1998) found no significant differences (P >0.05) in stem form at 22 years for *Pinusoocarpa* species.Little knowledge exists about the long-term stem form performance of native tree species under varying management regimes, including the use of pure or mixed-species plantation designs (Petit and Montagnini, 2006).

Wood density is considered as an important indicator of general wood quality, including timber strength and stiffness (Ishengoma and Nagoda, 1991). Wood with improved density can significantly increase the recovery of high-grade lumber, as assessed by machine stress grading (Bryce, 1967;Hamza *et al*., 2001).

Wood is a complex composite material that can contain significant varying amounts of water absorbed within the fibre. Therefore density needs to be defined in relation to standard conditions, such as ‘green’, ‘air-dry’, ‘oven-dry’ or ‘basic’ (Laswai *et al.*, 2013).

The most common (and useful) expression is the basic density, which is calculated as the oven-dry weight divided by the green wood volume, expressed in kg m^{-3} (Bryce, 1969). Basic density varies greatly within and between species, being strongly influenced by geographic location, site fertility, age and genetics. It can also be influenced by silviculture(Ishengoma and Nagoda, 1991; Hamza*et al*., 2001).

Chihongo and Ishengoma (1995) found that *Miliciaexcelsa* had wood basic density of 657 kg m^{-3}, while Kityo and Plumptre (1997) found that *Milicia excelsa* and *Khaya anthotheca* had basic densities of 656 kg m^{-3} and 560 kg m^{-3} respectively. And there was significant differences in basic density among the two tree species studied ($P<0.05$) (Chihongo and Ishengoma, 1995; Kityo and Plumptre, 1997). Heryati *et al.,* (2011a) found that the average wood density for *Khayaivorensis*in Malaysia was 560 kg m^{-3}. Muga *et al.,* (1998) clarified that *Dalbergia Melanoxylon* grown in Kenya may have a very heavy basic density reaching up to 1230 kg m^{-3}, while *Afzeliaquanzensis*is characterized as moderately heavy with a density reaching up to 900 kgm^{-3}.

Zziwa *et al*. (2006), found that the mean basic density of the four indigenous tree species (*Antiaristoxicaria, Celtismildbraedii, Maesopsiseminii*and*Alstoniaboonei*) ranged between 325 kg m^{-3} and 630 kg m^{-3} and there were significant differences in basic density among the four tree species studied ($P<0.05$). Heryati *et al.* (2011b) reported that the assessment of *H. odorata*in Malaysia in monoculture attained average wood density of 620 to 693 kg m^{-3}, 30 years after planting.

Tropical indigenous species are renown to be valuable resources in Carbon (C) sequestration, thus selection of tree species for forest plantation is not only to obtain the optimal timber productivity, but also potentially for increasing C stock as well as C sink in forest ecosystems (Heryati *et al.,* 2011a). As we have known that forest vegetation has the potential to absorb Carbon dioxide (CO_2) from the atmosphere during photosynthesis and store it as organic material in forest biomass per unit area and per unit of time (Evans, 1992). Furthermore, the potential of forest plantation biomass to absorb CO_2 from the atmosphere varies according to species, age and stand density. By calculating the accumulation of biomass in a forest stand,one can quantify the increment in forest yield, growth or productivity (Lovett and Wasser 1993) and estimate C content in forest and determine the amount of C that will be lost due to deforestation or harvesting since biomass is dependent on the wood density thus the density of wood play also a big role in C pools.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of the Study Area

The study was carried out at Tanzania Tree Seed Agency (TTSA) Arboretum. The TTSA Arboretum is located at KihondaMbuyuni in Morogoro Municipality, western Morogoro-Tanzania (6^{o}49’12”S, 37^{o}38’36”E, 511 m a.s.l), five km from Municipalitycenter and seven kilometres (km) away from Sokoine University of Agriculture (SUA) (Fig. 2). The Arboretum is designated in such a way that access is free during daytime for all visitors including local people. All the trees are marked with sign boards giving scientific namesand vernacular names. All this is to meet the dual purpose for recreation and study objectives.

The objective of the Arboretum is to collect and present in one place tree species and assess their performance before undertaking species and provenance trials. This Arboretum is visited by the national and international scientific community, students of forestry and related disciplines and the local population.

The Arboretum receives short rains from October to December and long rains between January and April. Average annual rainfall ranges from 750 to 1050 millimeters (mm). The annual total potential evapotranspiration averages 1760 mm and annual average temperature is 20^{o}C. Earlier vegetation was miombo woodland. TTSA site is flat.

Soil assessment prior to planting has been characterized as: texture of A horizon, clay sandy, and texture of B horizon sandy, depth deep and with good drainage. The adjacent soils of the site have been described by Msanya *et al.* (2007) as very deep and well drained, predominantly clay soils with very low organic C and Phosphorus (P) contents and low to very low Nitrogen (N) contents, with slight variation between sites.

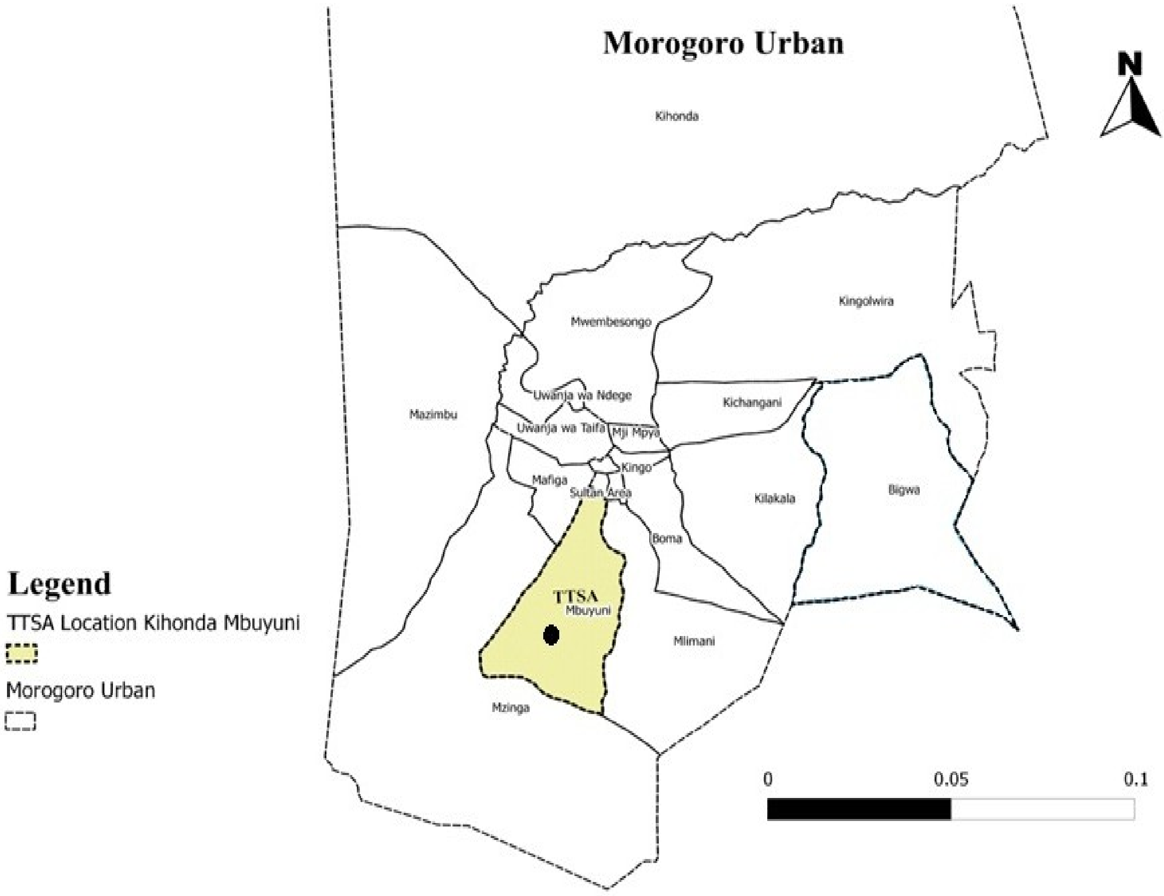

Figure 2: Location of the study area within Morogoro Municipality, Tanzania

3.2 Layout of TTSA Arboretum

TTSAArboretum is divided into plots of 400 m^2 (20 x 20 m) consisting of 36 tree planted in a square spacing of 4 x 4 m and 6 x 6 rows including one border row (16 measurement trees). Each plot is marked with a steel plate signboard giving the species scientific name and vernacular name, seed source and date of planting. A total of 67 species have been planted in the Arboretum (Fig.3).

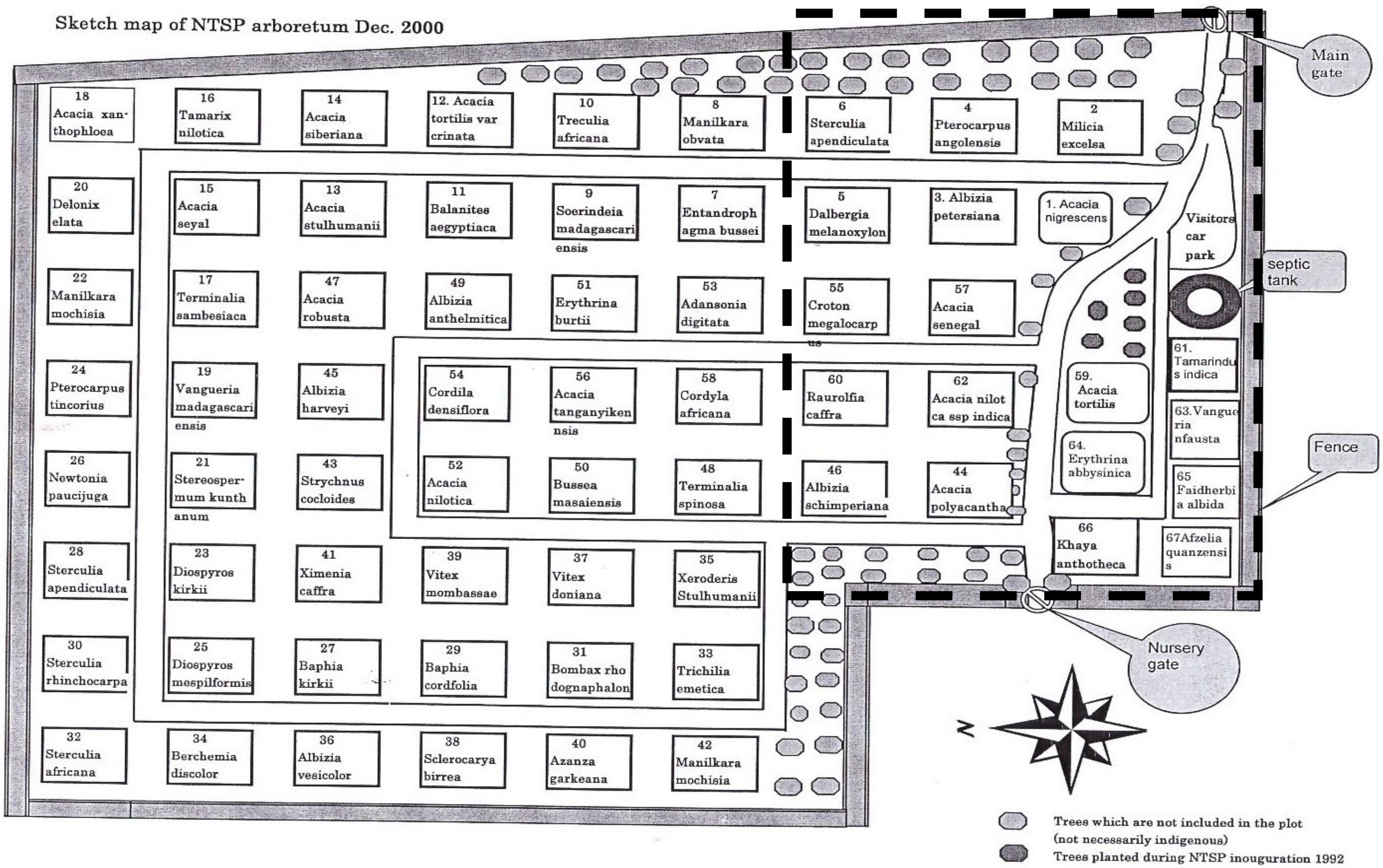

Figure 3: Quarter of the arboretum in black line where species in plots 67, 66, 5, and 2 were selected

3.3 Sampling Design and Assessment

Simple random selection without replacement was adopted to select the four study species. A quarter of the Arboretum was selected randomly, and the species were assigned random numbers and four species were picked without replacement for assessment. The selected four hardwoods being: *Miliciaexcelsa, Dalbergiamelanoxylon, Afzeliaquanzensis* and*Khayaanthotheca*with plots number 67, 66, 5 and 2 respectively.

3.4 Source of Seeds and Cultural Techniques

The seed sources for the trees in the TTSA Arboretum were from the wild stands/natural forest of selected trees of good phenotype. The trees were raised in the nursery using standard cultural techniques(Chamshama *et al*., 2006).

3.5 Field Procedures

The site was manually prepared and planted with the various tree species at a spacing of 4 x 4 m. Pits were of size 30 x 30 cmplanted in the years shown in Table 1. Weeding was regularly done at least three times a year. Pruning has taken place in the early ages and thinning has never been done.

Table 1: Age, year planted and compartment size for each species at TTSA Arboretum

Plot	Species name	Year	Age(yrs.)	Area(ha)
2	*Miliciaexcelsa*	1991	23	0.04
5	*Dalbergiamelanoxylon*	1991	23	0.04
67	*Afzeliaquanzensis*	1991	23	0.04
66	*Khayaanthotheca*	1991	23	0.04
Total				**0.16**

3.6 Data Collection

Data was collected on tree survival, Dbh, Ht, stem form and wood cores.Dbh of all surviving trees per plot was measured using caliper to the nearest 0.1 cm. The Dbh tally also gave survival data. For Ht, since the tree were few, all trees in the plot were measured using Suunto hypsometer to the nearest 0.1 m. Stem form was assessed for all surviving tress using point scoring system (Chamshama *et al.,* 1997):

1 – Straight stem;

2 – Stem with slight bend;

3 – Crooked stem.

For determination of wood basic density, six defect-free trees with straight boles and representative of the diameter range of each plot were sampled. The choice of the representatives was by sorting the Dbh and tree Ht data in each plot from the lowest to the highest (classes). One wood core for each selected tree was taken at Dbh point using increment borer (6 mm internal diameter) (Chamshama *et al.,* 1997; Chave, 2005). The cores were then stored in polythene bags sterilized with 95% ethanol. The samples were taken to the laboratory of Department of Forest Biology at Sokoine University of Agriculture and saturated in distilled water for at least 24 hours in order to regain green condition after which the volume of the cores were measured by water displacement method (Chave, 2005). The cores were then oven dried at a temperature of $103^{o}C \pm 2^{o}C$ to constant weight and cooled in dessicators before determining oven dry weight.

3.7 Secondary Data

The KihondaArboretum record of previous assessment in the early stage of growth (survival, mean Ht and mean Dbh) was obtained from TTSA.

3.8 Data Analysis

3.8.1 Survival

Survival percent of the four species *M. excelsa, D. melanoxylon, A. quanzensis* and *K. anthotheca* was determined as the number of all surviving trees (from 1991 to 2015) divided by the total number of trees at planting, multiplying by 100 (Mugasha *et al.,* 1998).

3.8.2 Height and diameter at breast height

Mean Ht was computed by taking the sum of all surviving tree heights per plot and dividing by the total number of trees observed per plot (Malimbwi, 1997).

This is the arithmetic average: $h = \Sigma h_i/N$……………………………………………..(1)

Which is estimated by: $h = \Sigma h_i/n$

Where:

h = population or sample mean height;

h^i = height of tree i;

n = number of sample trees.

Suunto correction was: recorded height x (horizontal distance/scale).

Mean Dbh was computed by taking the sum of all the surviving trees and dividing by the total number of trees per plot (Malimbwi, 1997).

3.8.3 Basal area

Basal area per ha was determined using the formula by Malimbwi (1997);

$Gi = \Sigma(g_{ij}/a_i)$, $G = \Sigma (G_i/n)$……………………………………………………..(2)

Where: g_{ij} = cross sectional area of tree $d_{ij;}$, m^2;

a_i = area of plot i, ha;

G_i = basal area of plot i, m^2ha^{-1};

n = number of sample plots;

G = average basal area (m^2ha^{-1}).

3.8.4 Volume production

Tree volume was obtained using a general volume equation (3) for miombo trees developed by Mauya*et al.* (2014)which apply Dbh as explanatory variable.

$\text{volume} = 0.00016 \times \text{dbh}^{2.463}$ ……………………………………………………….(3)

3.8.5 Mean annual increment

MAI was determined by dividing total volume production by age. This is the average change of volume over the whole life of the tree (Malimbwi, 1997).

MAI $= V/\text{Age}$ m^3yr^{-1}……………………………………………………………….(4)

Where v = volume of tree, m^3

3.8.6 Wood basic density

Basic density is computed as the ratio of oven-dry weight to green volume, where the equivalence 1 g = 1 cm^3 = 1000 kg/m^3(Chave, 2005).

Basic wood density = $(\text{oven dry weight})/(\text{green volume})$ ...……………………….(5)

3.8.7 Stem form

Stem form analysis was done by computing percentage per category of the point scoring system numbers (Chamshama *et al.,* 1997).

3.9 Statistical Analysis

Individual tree data for Dbh (cm), Ht (m), wood basic density (kgm^{-3}) were subjected to comparison of samples (Two independent samples t-test). Survival percentage was transformed to arcsine values and stem form categories were in percentage. A t-test was used to make inference that at least one of the species growth variable (Dbh, Ht and density) differs in performance from the other species. t-test Statistic was carried out using GenStat Release 14.2 (Payne*et al.,* 2011).

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Survival

Table 2 shows the survival for the study species for the period 4, 9 and 23 years.

Table 2: Survival of *M. excelsa, D. melanoxylon, K. anthotheca* and *A. quanzensis* at TTSA

Species	Survival (%) in years					
	Transformed			Unstrasfomed		
	4	9	23	4	9	23
Milicia excelsa	90[y]	90	90	100	100	100
Dalbergia melanoxylon	90	90	90	100	100	100
Khaya anthotheca	90	90	90	100	100	100
Afzelia quanzensis	90	90	75.52	100	100	93.75
	Ns	Ns	Ns	----	----	----

[y]) total number of tree in the plot divide by the total number at planting multiplied by 100.

The resultsindicate that the overall survival at final assessment (transformed) ranged from 75.5 (*Afzelia quanzensis)* to 90 (*Milicia excelsa, Dalbergia melanoxylon*and *Khaya anthotheca)* while (untransformed) ranged from 93.75% to 100% respectively.Overall, survival for all species is high, and exceeds the survival of less that 80% in forest plantations which requires beating up (Chamshama, 2014). Such high survivals are also exhibited by exotic tree species in forest plantations in Tanzania.

The superiortity in survival of these species and other indigenous when planted in monoculture have been reported by various researchers.Foroughbakhch *et al.* (2001) found that some indigenous trees species (*Acacia farnesiana, Parkinsoniaaculeata,* *Prosopisglandulosa*and*Heliettaparvifolia)* of 15 years of age, showed a minimum of 90% survival when in monoculture plots in Mexico, indicating a stable tendency in their adaptation with a low mortality.

4.2 Height

Table 3shows Ht (m) for the study species for the period 4, 9 and 23 years and MAI (m yr^{-1}) at 23 years.

Table 3: Height of *M. excelsa, D. melanoxylon, K. anthotheca*and *A. quanzensis*at TTSA

	Height (m) in years			**MAI (m yr^{-1})**
Species	4	9	23	23
Milicia excelsa	2.0	6.5	19.41a ± 6.583	0.844a ± 0.286
Dalbergia melanoxylon	1.0	4.25	9.491b ± 1.453	0.413b ± 0.0632
Khaya anthotheca	6	4.25	28.09c ± 3.308	1.221c ± 0.144
Afzelia quanzensis	3.5	----	22.89a± 3.729	0.995a ± 0.162
	Ns	Ns	***	***

Within a column figures followed by the same letter are not signficanly different at;

***) siginificant at P < 0.05;

Ns) not siginificant at P = 0.05;

±) Standard deviation

The results show that at the age of 23 years,*K. anthotheca* increased in Ht gowth and increment and attained highest total mean Ht of 28.09 m and MAI of 1.221 m yr^{-1} followed by *A. quanzensis, M. excelsa* and the least was *D. melanoxylon* with mean Ht of 9.4 m and MAI of 0.413 m yr^{-1}. The statistical analysis showed that there were highly significant differences in tree Ht and MAI ($P < 0.05$). *D. melanoxylon*though was the lowest performing in total Htand increment in relation to other species. It showed stable growth in Htas within the 15 years interval Ht grew from 4.5 m to 9.49 m taking into consideration its growth nature that it is considered to have low seed viability and seed germination and slow growth rateinitially (Washa and Nyomora, 2011).

The distribution of trees by height classes (Table 4) shows that over 60% of the measured *M. excelsa, K. anthotheca*and *A. quanzensis*trees fall into the second height class (16-30 m). This constitutes the largest percentage of the trees in the plots. This was followed by the first height class (5 – 15 m), which had 25%*Miliciaexcelsa*. The third height class captured only *K. anthotheca* (31.25%) making7.93% of the total trees in the plots. However, there was no tree from*D. melanoxylon*in the second and the third height classes and it had the highest percentage of 100%, for the first height class.

Table 4: Distribution of the trees by height classes at TTSA Arboretum

Height classes	***M. excelsa***		***D. melanoxylon***		***K.anthotheca***		***A.quanzensis***		**Pooled data for the four species**	
	Freq.	**%**	**Freq.**	**%**	**Freq**	**%**	**Freq**	**%**	**Freq**	**%**
5 - 15 m	4	25	16	100	0	0	0	0	20	31.74
16 – 30 m	12	75	0	0	11	68.75	15	93.75	38	60.31
31 - 45 m	0	0	0	0	5	31.25	0	0	5	7.93
Total	16	100	16	100	16	100	15	93.75	63	100

It was found that light competition affected productivity of *M. excelsa*, the species isa light demander thus the corner tree/border trees were very tall up 28 m and exhibited very big crown since they has umbrella-like crownsthey shaded the adjacent trees(Plate 1).Other species did not overtop each other in monocultures and showed no much intra-specific competition for light.

The categorization of the trees in height classes was to show where the lower and higher tree heights are distributed among the species. The heights obtained suggest that indigenous trees can grow well in monoculture condition just as other studies suggest.Griess and Knoke(2012)found out on the Pacific coast of the Central American Republic of Panama in Las Lajassthat native tree species of commercial relevance at rotation length of 30 years(*Hieronymaalchorneoides*, *Swieteniamacrophylla*and *Terminaliaamazonia*) out performed (*Tectonagrandis*and *Pinus* spp.) in growth and economical value.

Since rotation age for theseindigenous tree species (*Miliciaexcelsa, Afzeliaquanzensis, Darbegiamelanoxylon*and*Khayaanthotheca)*is unknown, and at this age theyhave attained Ht just similar to other studies on indigenous species. In a study in Nigeria *Khayagrandifolia*had a mean Ht of 34.49 m, *Afzeliaafricana*28.03 m, *Khaya. senegalensis*25.9 m compared to *Tectonagrandis*22.36 m (exotic) and *Gmelina. arborea*28.1 m (exotic), at 25 years of age and there were significant differences ($p<0.05$) among the species in Ht and increment per year (Onefeli and Adesoye, 2014).Also Foroughbakhch *et al.* (2001) assessed and found that the 15 indigenous species in monoculture in Mexico showed surprisingly variable Ht and Dbh increments during 15 years of development with *Leucaenaleucocephala*having the highest mean Ht of 17.83 m and lowest mean Ht of 12.36 m was for *Prosopisglandulosa*.

The Hts reported for these species are similar with those reported for some well known exotic species in Tanzania shuch as at age22 years, meanHt varied from 30.4 m to 20.1 m for*Pinuspatula*and*Pinusoocarpa* and there were significant differences at ($P >0.05$) in Ht between the species in monoculture in Mwanza, Tanzania (Mugasha*et al.*, 1998). Also at 23 years of age, mean height ranged from 22 m to 21 m for*Cupressuslusitanica, Cupressuslindleyi*and *Cupressusbenthamii*and there were significant differences ($P< 0.05$) among species in Lushoto, Tanzania (Luoga*et al.,*1994).

Plate 1: *Miliciaexcelsa*plot atTTSA Arboretum

4.3 Dbh and Basal Area

Table 5 shows mean Dbh (cm)for the study species for the period 4, 9 and 23 years and MAI and basal area (m^2 ha^{-1}) at 23 years. At final assessment Dbh ranged from 32.2 cm (*Khaya anthotheca)* to 20.2 cm (*Dalbergia melanoxylon)*, and all other parameters followed the same trend where, MAI ranged from 1.402 cm $yr^{-1}$to 0.88 cm $yr^{-1}$and basal area ranged from 14.10m^2ha^{-1} to 36.48 m^2ha^{-1}.

Table 5: Mean diameter and basal area of *M. excelsa, D. melanoxylon, K. anthotheca*and *A. quanzensis*at TTSA

	Mean Dbh (cm)			MAI (cm yr^{-1})	Basal area (m^2ha^{-1})
Species	4	9	23	23	23
Milicia excelsa	----	10.15	22.38a ± 10.19	0.973a ± 0.443	18.80
Dalbergia melanoxylon	----	----	20.26a ± 6.393	0.88a ± 0.278	14.10
Khaya anthotheca	8	15	32.25b ± 11.37	1.402b ± 0.494	36.48
Afzelia quanzensis	---	---	23.03a ± 4.738	1.001a ± 0.206	16.24
	----	----	***	****	----

Within a column figures followed by the same letter are not signficanly different at;

***) siginificant at P < 0.05;

Ns) not siginificant at P = 0.05;

±) Standard deviation

The analysis showed that there were significant differences in mean Dbh between species and MAI at final assessment (P= 0.05).*K. anthotheca* with the mean Dbh32.25 cm and MAI of 1.402 cm $yr^{-1}$was significantly better (P = 0.05) in mean Dbh than the rest of the species. The Dbh of the rest of the species were not significantly different indicating similar diameter growth rates. Assessment at 23 years indicated that the highest value of basal area 36.48m^2 ha^{-1} was recorded for*K. anthotheca,* while *M. excelsa*, *D. melanoxylon* and *A. quanzensis*showed small differences.Basal area is a useful measure of stocking, furthermore it is directly related to stand volumeand is a very important information for decision making in sustainable forest management (Malimbwi, 1997). Alder and Abayomi (1994) recommended a basal area of about 23 m^2 ha^{-1} for a fully stocked plot for timber. Going by this recommendation, in the present study *K. anthotheca*species with a basal area of 36.48 m^2 ha^{-1} (Table 5) is considered fully stocked fortimber harvesting and has no tree diameters in the lower Dbhclass of (5 – 15 cm). While the same suggest that for other two species with relatively high growth rates (*M. excelsa* and *A. quanzensis*) more time has to be given before felling. More time also before clearfellingis required for the slow growing *D. melanoxylon.*

These results show that indigenous tree can attain considerable diameter growth and basal area. In agreement with findings from this study, Petit and Montagnini (2006) found that at 22 years of age ten indigenous trees species performed better in monoculture plantation in Costa Rica (*Calophyllumbrasiliense, Vochysiaguatemalensis,Jacaranda copaia, Dipteryxpanamensis, Virolakoschnyi, Terminaliaamazonia, Vochysiaferruginea, Hyeronimaalchorneoides,Genipaamericana*and *Baliziaelegans*) and their mean Dbh ranged from 25.2 cm to 18 cm and basal area ranged from 27.9 m^2 ha^{-1} to 21.8 m^2 ha^{-1} and their stocking ranged from 517 to 872 stems per ha and some of these tree species were recommend for small scale planting.

The mean Dbh and basal area ranges in this study also fall in the same range as those of some well known exotic tree species. At 22 years of age,*Pinuspatula*and*Pinusoocarpa*at Buhindi, Mwanza, Tanzania, had mean Dbhrange of 31.4 m to 22.2 m and basal area ranged from 68.4 m^2 ha^{-1} to 54.6 m^2 ha^{-1} and there were significant differences ($P > 0.05$) in Dbh and basal area between the species (Mugasha*et al.,* 1998). Also Luoga *et al.* (1994) found that at 23 years of age mean Dbhof *Cupressuslusitanica, Cupressuslindleyi*and*Cupressusbenthamii*at Hambalawei, Lushoto, Tanzania ranged from 25.04 cm to 21.88 cm and basal area 35.20 m^2 ha^{-1} 28.45 m^2 $ha^{-1}$and differences were significant ($P= 0.05$).

The distribution of the trees by Dbhclasses (Table 6) shows that31% of the measured trees of*M. excelsa* fell in the first diameter class (5 – 15 cm) thus being the species with smaller diameter than *D. melanoxylon* that had 12% of its measured tree in the first diameter class.

Over 86% of measured *A. quazensis* tree diameter fell in the second Dbh classes (16 – 30 cm)making the highest percentageof diameter classes for all the plots. *K. anthotheca* showed relatively bigger diameter than the rest of other tree species with 18.7% of measured tree making the only diameter found for fourth the diameter class (46 - 50 cm) and also it makes the highest percentage of the third diameter class (31 – 45 cm) with 31.25%. *D. melanoxylon*have shown very promising diameter growth with 81% of its measured tree falling in the second diameter class (16 – 30 cm), this indicates that the growing conditions at the TTSA Arboretum are favourable for thesespecies.Only one tree of *D. melanoxylon*had diameter in the range of (31 – 45 cm). This was unexpected as the species has slow growth. No smaller tree diameters in the range of (5 – 15 cm) were found for the *K. anthotheca*. This species exhibited very big diameters with few exceptions.

Table 6: Distribution of the trees by diameter classes

DBH	M. excelsa		D. melanoxylon		K.anthotheca		A.quanzensis		Pooled data for the four species	
classes	Freq.	%	Freq.	%	Freq	%	Freq	%	Freq	%
0 - 15 cm	5	31.25	2	12.5	0	0	1	6.6	8	12.69
16 - 30 cm	7	43.75	13	81.25	8	50	13	86	41	65.07
31 - 45 cm	4	25	1	6.25	5	31.25	1	6.6	11	17.46
46 - 50 cm	0	0	0	0	3	18.75	0	0	3	4.76
Total	16	100	16	100	16	100	15	100	63	100

The diameter distribution percentage obtained in this study per species is typical for even aged stand, except for *M. excelsa*, that the inner tree growth were suppressed by the outer trees and corroborates the results obtained by other authors in various studies in Nigeria, Panama and Costa Rica (Petit and Montagnini, 2006;Griess and Knoke, 2012; Onefeli and Adesoye, 2014).

At the same age with some well know exotic species these indigenous trees attained close similar values in average diameter growth, this shows that thesetrees grow at the same pace as some exotic and some better performing known indigenous tree species.The thought that indigenous species cannot perform and have slow growth,it may not true since some indigenous could grow just as exotics species, under well managed situation as per findings of this study.

4.4 Volume and MAI

Table 7 shows mean volume (m^3 ha^{-1}) and mean volume annual increment (m^3 yr^{-1}) for the study species at 23 years. At final assessment volume ranged from 123.8(m^3 ha^{-1}) (*D. melanoxylon*) to402.6m^3 ha^{-1}(*Khaya anthotheca*) andMAI ranged from 5.38$m^3ha^{-1}year^{-1}$(*D. melanoxylon*) to 17.50$m^3ha^{-1}year^{-1}$(*Khaya anthotheca*).

Table 7: Volume and MAI of *M. excelsa, D. melanoxylon, K. anthotheca* and *A. quanzensis*at TTSA Arboretum

Species	Volume (m^3 ha^{-1})	MAI ($m^3ha^{-1}yr^{-1}$)
Milicia excelsa	183.8	7.99
Dalbergia melanoxylon	123.8	5.38
Khaya anthotheca	402.6	17.50
Afzelia quanzensis	145.9	6.38

The results show that volume and increment for *D. melanoxylon* was relative small compared to other species. The volume for *K. anthotheca* was higher among all the species and could becompared to some exotic tree species like*Cupressuslusitanica, Cupressuslindleyi*and*Cupressusbenthamii* (maximum 350.17 m^3 ha^{-1}) at 22 years of age when in monoculture at Hambalawei, Lushoto, Tanzania (Luoga*et al.,* 1994).

The volume values attained by these species are not much different in relation to other reported values, since it may be the first time that these hardwood volumes could be determined under known age as per these findings (Alvarado*et al.,* 2007).

4.5 Stem Form

Table 8 shows the tree form inpercent for the study species at age 23 years. Stem quality assessment indicated that*D. melanoxylon*and *A. quanzensis*had the poorest rank in stem form. Poor stem form for *Dalbergiamelanoxylon* has also been observed inLindi, Tanzania, where 72% of the tree had poor stem form (category 3)(Washa *et al.,* 2012).

Normally this tree is multi-stemmed but through careful observation (Plate 2), the tree shows a clear bole and multi-stem almost above 4 m in height.*Khaya anthotheca* stems were slighlty bent and this form has been affected by wind since the trees are in the upper side of the Arboretum and some have been swaying by adjacent falling trees from one plot to another. *M. excelsa* showed straight boles throughout the plot while for *Afzelia* only 1 tree was forked.

Table 8: Stem form of *M.excelsa, D. melanoxylon, K. anthotheca* and *A. quanzensis* at TTSA Arboretum

Species	Stem form (%)			Total
	1	2	3	
Milicia excelsa	100	0	0	100
Dalbergia melanoxylon	50	43.75	6.25	100
Khaya anthotheca	68.75	25	6.25	100
Afzelia quanzensis	62.5	25	12.5	100

Plate 2: *Dalbergia melanoxylon*at TTSA Arboretum

4.6 Basic Density

Table 9 shows mean basic density (kg m^{-3}) for the study species at 23 years. At final assessment, basic density ranged from 423.5 kg $m^{-3}$to 329.4 kg m^{-3}.

Table 9: Basic density of *M. excelsa, D. melanoxylon, K. anthotheca* and *A. quanzensis* at TTSA Arboretum

Species	**Basic density** (kg m^{-3})
Milicia excelsa	349.8 ± 13.27
Dalbergia melanoxylon	423.5 ± 45.68
Khaya anthotheca	329.4 ± 29.51
Afzelia quanzensis	388.2 ± 44.38
	Ns

Within a column figures followed by the same letter are not signficanly different at;

***) siginificant at P < 0.05

Ns) not siginificant at P = 0.05

±) Standard error of the Mean

There were no significant (P >0.05) differences in wood basic density (Table 9). *D. melanoxylon*had the highest basic density (423.5 kgm^{-3}) while *K. anthotheca* had the lowest (329.4 kg m^{-3}). The basic density for these species though insignificant varied from species to species, and differences might be attributed to genetic differences (Dinwoodie, 1981). The high density by *D. melanoxylon*is because of the heartwood that is hard and of juvenile wood that is very weak and light as it hardens as time goes (Zziwa *et al.*, 2006).

Wood density has been the focus of many researches in the past and has traditionally been the factor on which the utilization potentials of timber species are based (Akpan and Olufemi, 2007; Oyagade and Fabiyi, 2002; Poku *et al.,* 2001). This could be attributed to the fact that density has been a very good indicator of wood strength, stiffness and dimensional stability (Poku*et al.,* 2001). The values found in this study fall in the same range as shown for some indigenous tree species by Sotannde *et al.* (2010).

In general, the wood density of this indigenous tree species grown in plotscompared well with some commercial tropical African timbers and exotic tree species such as *Tectonagrandis*(480 – 850 kgm^{-3}), *Khayagrandifolia*(440 – 730 kgm^{-3}), *Tieghemellaafricana*(399 – 800 kgm^{-3}), *Miliciaexcelsa*(450 – 750 kgm^{-3}), *Pterocarpussoyauxi*(375 – 815 kgm^{-3}), *Mansoniaaltissima*(590 – 720 kgm^{-3}), *Pericopsiselata*(620 – 700 kgm^{-3}) and *Entandrophragmacylindricum*(460 – 530 kgm^{-3}) (Prota, 2009).

Wood density obtained for these species fall within the range of 350-750 $kgm^{-3}$for species suitable for furniture, sheeting and lining, paquet, veneer wood for peeling and slicing. The variation in wood density observed in this study confirmed that each wood has a range of densities reflecting differences between early and late wood, between pith and outer rings and between trees on the same site.

The basic density of *M. excelsa*and *K. anthotheca*differed from those reported by Kityo and Plumptre (1997) (Uganda – *K. anthotheca*basic density 560kgm^{-3},Chihogo and Ishengoma (1995) (Tanzania) *Miliciaexcelsa* 657 and 656 kgm^{-3}respectively, because they assessed mature trees from the wild with unknown age and such differences are possibly due to differences in age of the individual tree species and environmental factors(Prota, 2009).

The basic density values in this study are also similar to those for some exotic tree species as found by Mugasha *et al.* (1998) for *Pinuspatula*and*Pinusoocarpa* at 22 years that mean basic density varied from 394 kg m^{-3} to 521 kg m^{-3}.and there were significant differences (P >0.05) between the species in monoculture. Also Luoga *et al.* (1994) found that at 23 years of age, mean basic density of *Cupressuslusitanica, Cupressuslindleyi*and*Cupressusbenthamii*ranged from 364 kg m^{-3} to 420 kg m^{-3} and there were significant differences (P= 0.05) among species.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The following conclusions can be drawn from this study:-

i. The species showed steady survival throughout the 23 years of growth with only one tree death in *A. quazensis* plot.

ii. Growth and stem form were generally high for all species except *D. melanoxylon.*

iii. Generally the results of the selected indigenous tree species showed that they can grow well under monoculture management conditions, similar to the commonly planted exotic tree species.

iv. The wood density values found for these species were high and comparable to the commonly planted exotics but lower than those for indigenous species in the wild.

5.2 Recommendations

The following recommendations can be drawn from this study:-

i. Conduct the same study in a replicated trial with more trees in tandem with soil characteristics will be necessary to enhance the reliability for extrapolation of the study.

ii. Construction/development of planted indigenous tree species specific allometric equations.

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