ACHIEVING SUSTAINABLE DEVELOPMENT THROUGH SILVICULTURE: FOCUS ON TREE DOMESTICATION

BY

ADEJOKE OLUKEMI AKINYELE

2018/2019 FACULTY LECTURE

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2018/2019 FACULTY LECTURE
FACULTY OF RENEWABLE NATURAL RESOURCES

delivered

on Wednesday, 17 July, 2019

by

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Ibadan University Press
Publishing House
University of Ibadan
Ibadan, Nigeria

First Published 2019

ISBN: 978 – 978 – 8529 – 97 – 2

Printed by: Ibadan University Printery

The Dean, Faculty of Renewable Natural Resources, the Head, Department of Forest Production and Products, Heads of Other Departments, Sub-Deans Undergraduate and Postgraduate, the Faculty Officer, Distinguished Ladies and Gentlemen

Introduction

I developed interest in the domestication of indigenous tree species when I started my PhD programme after I discovered that there was little on-going research on most indigenous tree species of Nigeria. Over time, I have focused on the domestication of endangered indigenous tree species, which have suffered great neglect over the years. In the recent past, most of the indigenous tree species were considered to be of negligible commercial importance. This was because economic activities relating to these species were not documented in international trade reports of FAO, CBN and the World Bank. These indigenous tree species were only sourced from wild populations and could only be identified by experienced foresters, botanists, ecologists, hunters and traditional herbal practitioners. As a matter of fact, most of the indigenous/ non-timber forest species have not been processed beyond the identification and observation stages. Rather, attention was focused on the characterisation and evaluation of temperate tree species of economic importance like *Abies* spp. (Fir) (Davidson and El-Kassaby 1997), *Eucalyptus* spp. (Eucalypts), *Pinus* spp. (Pines) (El-Kassaby et al. 1987; 1993), *Picea* spp. (Spruce) (Bergmann and Ruetz 1991; Thomson et al. 2010) and *Quercus* spp. (Oaks) (Plomion et al. 2016). Inevitably, many threatened tree species experiencing loss of genetic diversity are those of the least current economic importance; with knowledge about their potentials being greatly restricted.

Nigeria and the African continent as a whole have a history of over-exploitation of forest resources. This has resulted in deforestation, land degradation, a decline soil fertility and unsustainable management of renewable natural resources. Nigeria has over 200 million people with an annual growth rate of 2.6% (United Nations 2019). This population growth is confounded by limited land and renewable natural resources, thus creating crisis in the efforts to achieve sustainable development. Historically, the utilisation of indigenous trees has contributed greatly to poverty reduction in Nigeria and the African continent, with rural populations depending on the timber and non-timber products from trees for their livelihood sustenance. Hence, forest trees are key to the actualisation of most of the Sustainable Development Goals (SDGs) such as eradicating extreme poverty (SDG 1) and zero hunger (SDG 2), good health and well-being (SDG 3), gender equality (SDG 5), climate action (SDG 13) and life on land (SDG 15), to mention but a few. Ironically, many tropical tree species have not been fully described and classified, with most of the information on their tangible and intangible uses being limited to indigenous knowledge (Morgenstern 1996). Most tropical trees are undomesticated and are usually collected from the wild for medicinal, culinary and trade purposes. However, these tree species have potentials for use in the pharmaceutical, cosmetic, food and manufacturing industries (Akinnifesi et al. 2007).

Oldfield (2008) reported that 1,002 tree species were listed as Critically Endangered in the International Union for Conservation of Nature (IUCN) Red List. Unfortunately, many of the tropical indigenous trees are listed among IUCN species that are threatened or vulnerable to extinction. From the IUCN red list, 120 threatened tree species were found in Nigeria, with 12 of them being critically endangered, another 10 were classified as endangered and the remaining 98 were vulnerable (Borokini 2014).

The loss of genetic resources of tree species in tropical forest ecosystems through selective logging, subsistence agriculture (particularly shifting cultivation and forest fragmentation) has led to a significant negative impact on most indigenous tree species. For instance, many tree species growing even within protected areas, when tagged for research monitoring purposes are indiscriminately felled and evacuated before the expiration of such field experiments. Many of these indigenous tree species are not domesticated and harvested from the wild as timber and non-timber products providing alternative sources of income to farmers, forest dependent communities and urban dwellers. This further deepens the gene erosion in Nigerian and the West African vegetations.

Global Forests

The bulk of the world's forests is natural, with reported natural forest area amounting to 93 percent of global forest area, or 3.7 billion ha, as at 2015 (FAO 2016). According to Millennium Ecosystem Assessment (2005), the global forest cover had declined by 50 percent in the last three centuries, with 90 percent of forest cover already lost in twenty-nine countries. The FAO (2010) reported that the annual global gross deforestation was 160,000 km^2 from 1990 – 2000 and 130,000 km^2 from 2000 – 2010. However, there was a reduction in the net annual natural forest loss from 10.6 million ha per year for the period 1990 to 2000 to a net of 6.5 million ha per year from 2010 to 2015 (FAO 2016). Between 2000 and 2012, the tropical forests in South America, Africa, and Asia decreased by an area as large as the whole of Spain (Hansen et al. 2013) (fig. 1).

FAO (2010) reported that about 50% of the global forests are located in tropical countries with Latin America (without Argentina and Chile) having the largest tropical forest area (810 million hectares), Africa (without Mediterranean countries) having 627 million hectares and Asia consisting of South Asia, Southeast Asia and Oceania having 489 million hectares. Global assessments have shown high reductions in forest area in Sub-Saharan Africa and South America, when compared to other parts of the world (United Nations 2017) **(**fig. 2).

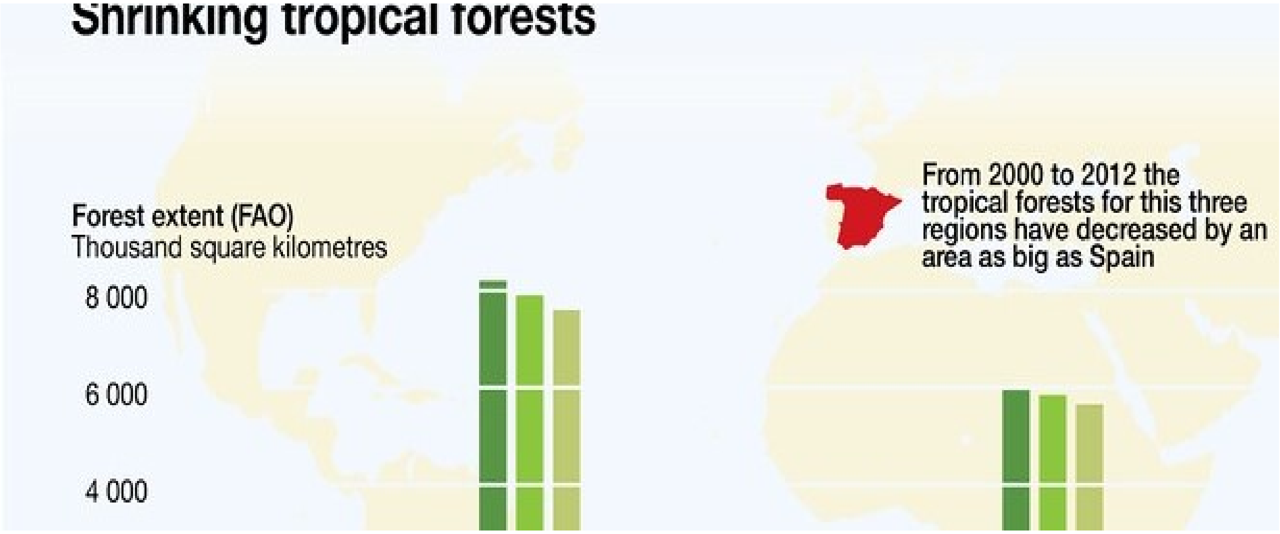

Fig. 1: Shrinking tropical forests.

Source: Based on Hansen/UMD/Google/NASA; FAO & JRC 2012-2014

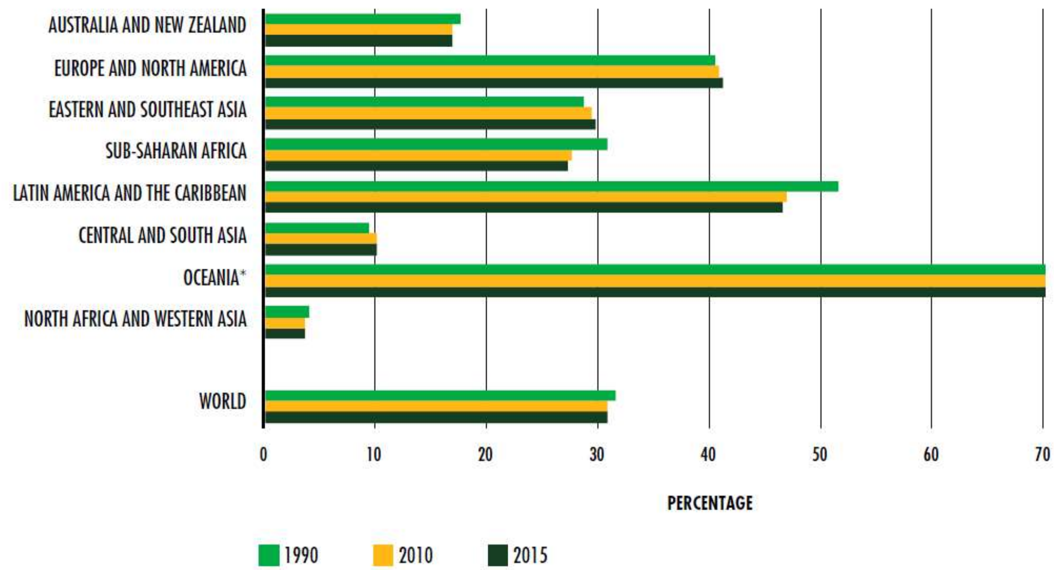

Fig. 2: Forest area as a proportion of total land area in 1990, 2010 and 2015.

Note: excluding Australia and New Zealand; *Source:* United Nations (2017).

This loss has been attributed mainly to the conversion of forest lands into agricultural land, which has contributed significantly to the extent of annual deforestation (Günter 2011). Many authors have confirmed that relative rates of deforestation are highest in tropical countries with 4.0% in Nigeria, 5.8% in Togo and 9.7% in the Comoros Islands (Günter 2011). In fact, Nigeria ranks high among the countries with highest rate of deforestation, which continues to increase at an alarming pace (table 1) (Popoola 2014; FAO 2016). Ladipo (2010) reported that annual deforestation in Nigeria, translated to the loss of about 350,000 – 400,000 hectares of forest land. Between 1990 and 2005, Nigeria lost 21% of its forest cover in comparison to the global forest loss of 3.3%.

Table 1: Top Ten Countries reporting the Greatest Annual Net Loss of Forest Area, 2010-2015

		Annual forest area net loss	
	Country	**Area (thousand ha)**	**Rate (%)**
1	Brazil	984	0.2
2	Indonesia	684	0.7
3	Myanmar	546	1.8
4	Nigeria	410	5.0
5	United Republic of Tanzania	372	0.8
6	Paraquay	325	2.0
7	Zimbabwe	312	2.1
8	Democratic Republic of Congo	311	0.2
9	Argentina	297	1.1
10	Bolivia (Plurinational State of)	289	0.5

Source: FAO (2016)

Deforestation, which is mainly as a result of the conversion of forest land to agriculture and livestock areas, threatens not only the livelihoods of foresters, forest communities and indigenous peoples, but also the variety of life on our planet (FAO 2018). When land-use changes occur, it results in the loss of valuable habitats, land degradation, soil erosion, decrease in clean water, and the release of carbon into the atmosphere. FAO 2018 highlights evidences of the critical contributions of forests to livelihoods, as well as the essentiality of healthy and productive forests to sustainable agriculture. It provided proof of the significance of forests and trees to the quality of water, energy needs, and for design of sustainable, healthy cities. In addition, the Royal Botanic Gardens (2017) reported that at least 28,187 plant species are currently of medicinal use in the world, and are contributing to healthcare delivery on a global scale.

Genetic Diversity of Tropical Tree Species

An assessment of the genetic component of indigenous tree species will provide information on existing variations within and between species, which could be harnessed for domestication. This is achievable through the identification and enhancement of the silvicultural requirements of such species, especially in a changing climate. Thus, domestication and propagation of tree species would provide numerous benefits to mankind including economic and valuable high-quality wood, medicinal plant parts, nitrogen-rich litter, and important tree crops for a functional ecosystem.

Despite the numerous benefits, there is limited effort on the domestication and improvement of most indigenous trees species. In addition, less than 5% of Nigeria's landmass is under forest reservation. This will lead to continuous loss of germplasm of indigenous tree species outside the protected areas. Hence, there is an urgent need for domestication and mass propagation of indigenous tree species in order to complement the exotic tree plantations being established by government and private investors. Many of the woody plants are of nutritional importance to households. These species are mostly propagated through seeds, which are also consumed by humans and animals. This therefore results in competition for the available seeds; germination and seedling production of indigenous woody species in the nurseries is limited and many of them are not available. To this end, the difficulty in accessing seeds and poor knowledge of required nursery techniques make it necessary for alternative sources of planting materials.

Another constraint in silviculture, which is cultivation of forests, with the integration of qualitative measures or thresholds for best management practices, is that numerous attempts at establishing large plantations of some indigenous forest tree species have yielded little or no result. The failure has been attributed to the paucity of information on the silvicultural knowledge and management techniques related to mode of planting, soil requirements, nursery handling, and early growth characteristics. These are essential for effective seed germination and high growth vigour of young plants (Akinyele 2010).

Consequently, I am passionately committed to conducting cutting-edge experiments that will produce results, valuable for addressing anticipated and unanticipated questions that will be useful in the promotion of forest science. This is particularly important and critical at this period because of the role of forests and the indigenous trees in the current discussions on climate change vulnerability, mitigation, adaptation and carbon storage processes. For example, there are various research trials comparing genetic variations within and between species in response to predicted future climatic conditions. Most Governmental and Non-Governmental Organisations (NGOs) like United Nations Framework Convention on Climate Change (UNFCCC) have placed high emphasis on environmental research with the aim of mitigating some of the severe impacts of climate change in Africa and the world. Based on these challenges, I have investigated tree species molecular biology, physiology, and improvement of traits in wood products; how plant traits can increase carbon sequestration; and value addition to enhance income-generating potentials of indigenous tree species. Some of my research outputs have identified suitable provenances of tree species that could adapt and thrive in regions with low amounts of rainfall in Nigeria.

Sustainable Development

Sustainable development is 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (Brundtland 1987). Sustainable development became a global concept in response to the need for development that is enduring without jeopardising the opportunities of a safe world. In the past, the Man and the Biosphere Programme spearheaded by the United Nations Educational, Scientific and Cultural Organisation (UNESCO) raised concerns on environmentalism, nature preservation, and conservation, the role of ecology in tropical development, ecological managerialism, ecological impacts of development, global environmental crisis, as well as human population explosion. There was a progressive rise of careers in 'environment and development,' and commensurate funding for research in the area (e.g. Global Environmental Facility). The global debates focused on politics, economics and sociology of development in nexus with science of environmental change. Furthermore, international concern grew on the anthropogenic impacts on global climate change and the broader arguments on sustainability. Hence, it became a challenge to intervene and mitigate the impacts of climate change and other global issues, while ensuring economic growth, environmental protection, reduction of biodiversity depletion and pollution. The global community was also mandated to tackle global inequality and poverty, while not allowing the wheels come off the world economy, hence the term: sustainable development (Adams 2009). The concept of sustainable development became more prominent at the United Nations Conference on Environment and Development held in Rio in 1992 (UNCED, or the Earth Summit) (Okali 2005). Of course, wildlife or nature conservation had always been the most entrenched root of 'sustainable development thinking.'

At Rio, sustainable development was put forward as a concept promoting nature preservation and conservation. The concept of sustainable development is to create a system that is in a stable equilibrium meeting present needs, and not compromising future generations' ability to meet their own needs (fig. 3). Innovations must of a necessity take place for nations to be able to sustain development within the context of a stable environment.

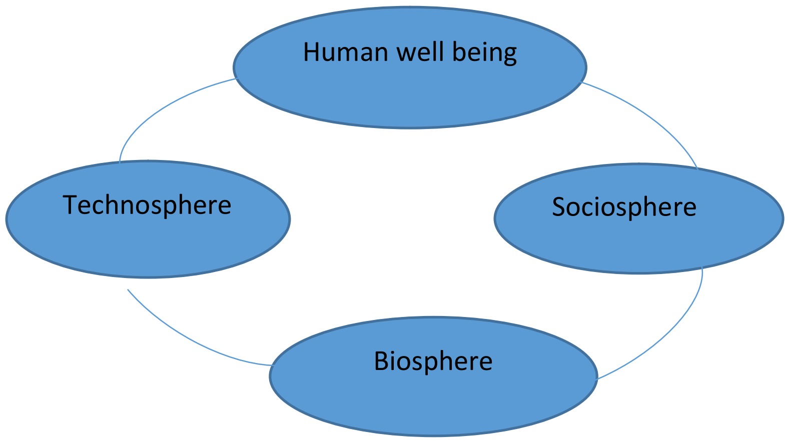

Fig. 3: System interaction for stable equilibrium.

Source: Akande (2000)

A major threat to many indigenous tree species is over-exploitation, with approximately 25% of the threatened tree species having at least one recorded use; the most common of which is harvesting for timber. Sustainable forestry takes into consideration the ecological, economic and social criteria of management. The application of these criteria creates an atmosphere that promotes sustainability and the supply of forest products obtained from sustainably-managed sites, which are certified for the marketplace (Oldfield 2008).

Newton (2008) proposed five conditions that would ensure the conservation of tree species. They include:

(1) Sustainable harvesting of forest products in terms of maintaining viable populations of the tree species being harvested;
(2) Harvesting of forest products must not have positive interaction with other threats;
(3) Economic viability of commercialisation of the forest products;
(4) Economic benefits from commercialisation must be received by those harvesting the wild resources; and
(5) Income received from commercialisation must act as an incentive to conserve the tree species being harvested.

The elements of the sustainable development ideas representing a blend of environmental and developmental concerns are as listed in table 2.

Table 2: Critical Objectives for Environment and Development Policies that follow from the Concept of Sustainable Development

1	Reviving growth
2	Changing the quality of growth
3	Meeting essential need for jobs, food, energy, water and sanitation
4	Ensuring a sustainable level of population
5	Conserving and enhancing the resource base
6	Reorienting technology and managing risk
7	Merging environment and economics in decision-making

Source: Brundtland (1987)

Tropical Silviculture

The term, 'silviculture' was derived from the Latin words silva (meaning "forest") and cultura (meaning "cultivation") (Günter 2011). It comprises the strategic plan for vegetation management during the entire life span of a forest stand. 'Silviculture' considers the forest as an ecosystem with the aim to control all life's processes in the ecologically-established forest, while ensuring stability and regeneration, with all the needs related to the forests being accomplished in the best way possible and in a sustainable manner. It attempts to create and sustain the type of forest that will best satisfy the objectives of the owner and the prevailing need of the society (Knoke 2010). Although timber production is usually the most frequently occurring objective of silviculture, it may neither be the only one nor essentially the main one.

Silviculture, therefore, aims at alleviating and harmonising the objectives of conservation of forest ecosystems, its functions, and the several anthropogenic uses. It is important to look for a long-term balance between the needs of humans and nature conservation because forest goods and services are becoming rare though not exhausted. Today, silviculture has been able to set the course for economically-profitable and ecologically-sustainable forest management in the future. In many tropical countries (including Nigeria), forests meet the subsistence needs of humans making them to be continuously exposed to all forms of anthropogenic pressures. They are sometimes converted into alternative land-use forms to provide either food or cash crops with higher and quicker economic returns, based on a point of view that is both non-sustainable and short-term.

There are three basic treatments used in silvicultural systems. These include: tending, harvesting, and regeneration. Tending is the treatment given to the forest stand from the period of establishment to final harvest. Intermediate treatment activities during tending include release, thinning, improvement, pruning and salvage felling. Harvesting is the procedure during which logging takes place with the aim of meeting logging requirements, while simultaneously attaining silvicultural objectives. It is the process of gathering the timber crop, during which activities such as felling, skidding/ forwarding, onsite processing, and removal of products from the site, take place. Cutting (as part of logging process) involves the felling of trees or stands. The process of harvesting could be an intermediate or final cutting that extracts saleable trees (Smith et al. 1997). In silviculture, regeneration is the act of renewing tree cover by establishing young trees either naturally or artificially. The establishment of young trees through natural seeding, sprouting, suckering, or layering is natural regeneration while artificial regeneration is the establishment of the young trees through planting or direct seeding.

'Clearcutting' refers to the total removal, in a single operation, of all the trees in one stand while 'partial or selective cutting' is the removal of only a portion of the trees in a stand. These cutting methods are different from the natural regeneration method, where the terms 'clearcut' and 'selection' refer to specific planned natural regeneration methods. With few exceptions, most indigenous tree species of Nigeria are naturally regenerated. Thus, cultivation techniques for raising them artificially are scarce and little is known about their genetic qualities. Regrettably, most tropical natural forests are still managed without sound knowledge of sustainable yields or the impacts of human interventions on their ecosystem functions and services (Günter 2011). These limitations constrain tropical forest management with uncertainties and attendant risks. The lack of ecological knowledge (especially regarding yields and long-term damage to the remnant stand), further limits the ability to achieve sustainability in the future. In Nigeria, the destruction of pristine ecosystem and loss of biodiversity (flora and fauna), intensification of agriculture on forest lands, or aggressive exploitation of high-timber value species (such as mahogany: *Entandrophragma spp, Khaya spp.*) have made natural regeneration difficult, having exceeded the threshold capacities of the forest ecosystems (Horan et al. 2003; Eastwood et al. 2007). Hence, current research efforts are on domestication of indigenous tree species, conservation of genetic resources and biodiversity, ecosystem services, ecotourism, ethno-forestry and broadening of science of silviculture (Bertault et al. 1995).

Climate Change Adaptation and Mitigation

Much of the global demand for energy had been met by burning fossil fuels, which increases the levels of carbon dioxide and other 'greenhouse gases' in the atmosphere. This situation is worsened by methane emissions from animal husbandry, and the release of industrial chemicals such as chlorocarbons, chlorofluorocarbons, nitrous oxides, and sulphur dioxide. Hence, human induced influences have led to changes in climate. For instance, a 25% increase in atmospheric CO_2 since 1850, has been strongly correlated with increasing global temperature. If present emission trends continue, emission pathways are projected to reach warming in the range of 3.5°C to 5°C by 2100 (IEA 2012; UNEP 2012).

Climate change is an emerging challenge in tropical silviculture, requiring the reconciliation of sustainable forest management with mitigation and adaptation management. This is because the type of forest management embarked on can either increase or decrease carbon flows between forests and the atmosphere. Increasing plants' ability to sequester carbon would accelerate the mopping up of atmospheric CO_2. This atmospheric CO_2 is a foremost gas in relation to the causes of climate change. It is estimated that about 40% of the carbon in terrestrial biomass is found in the tropical forests, while 30–50% are from terrestrial productivity (Dixon et al. 1994; Phillips et al. 1998; Watson et al. 2000). Unfortunately, about 17% of the total anthropogenic greenhouse gas (GHG) emissions result from forest destruction and degradation, predominantly in the tropics (IPCC 2007a, b).

Since forests serve as sinks or sources of carbon, any activity or management practice that changes the biomass in an area would have direct effects on carbon budget (Moura-Costa 1996). For instance, if forest management is improved by at least 10%, the potential for emission reductions could be compared with that obtainable by curbing tropical deforestation (Putz et al. 2008). Sustainable management of forests for climate change mitigation involves the maintenance of high carbon stocks in natural forests, increasing the amount of carbon held within managed forests and reducing carbon losses due to management interventions (Guariguata et al. 2008). Some silvicultural practices that could be used to maintain and enhance the adaptive capacity of natural and planted tropical forests are highlighted below.

Non-wood Forest Products

Gathering of other forest resources apart from wood, such as berries, mushrooms, fruits, herbs, and bush-meat, to provide food, energy, or construction material has been carried out by humans since historical times. García-Fernández et al. (2008) reported that there has been increased interest on a global scale for the use of non-wood forest products (NWFPs) as additional sources of income. The integration of timber and non-timber forest uses in forest management provides diverse opportunities for subsistence and market economies of rural communities to enhance their well-being and to reduce the risk of losses.

Biomass Energy

Biomass energy is the energy obtained by passing plant and animal materials through different conversion processes like direct burning, gasification, fermentation and digestion to give heat and/gases, liquid or solid fuels. According to World Bioenergy Association (2017), the total biomass energy derived from wood based sources is over 87%, with fuelwood contributing 67% of the total (fig. 4). Fuelwood plays an important role in many developing countries, being the dominant source of heat energy particularly in rural households. In Africa, many urban and rural households depend on fuelwood for cooking, heating and steam production. Many proponents of renewable energy utilisation have suggested a shift from fossil to biomass fuels. Energy produced from fossil fuels cause 57% of the total GHG emissions, and a switch to biomass energy is a major strategy for reducing GHG emissions (IPCC 2007a).

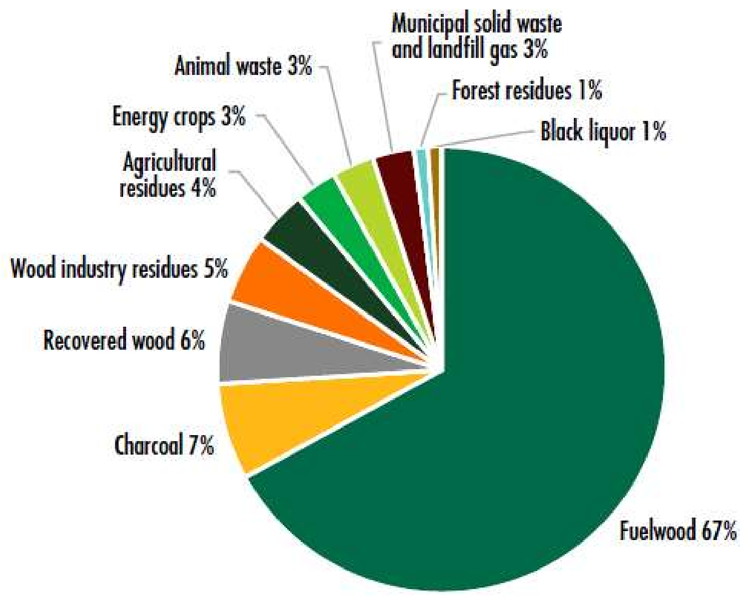

Fig. 4: Contribution of fuels derived from wood to global biomass energy resources.

Source: World Bioenergy Association (2017)

Other examples of biomass energy include briquettes, densified wood, and biogas. Efforts are being made to provide alternative fuel sources like biofuel in place of fossil fuel (Zimbabwe Biomass News 1996; Trabi et al. 1997; Achten et al. 2008; Akinyele 2010); for example, the use of different plant species like *Jatropha curcas* in the provision of plant-based fuel. Although a large proportion of "modern" fuelwood comes from agricultural areas or from non-woody biomass, the situation also provides new opportunities and challenges for silviculture and tree domestication.

New forest stands could be established with the sole objective of biomass production on marginal land that previously had not been available for forestry (e.g. grassland, fallow land, marginal and mine spoil). The domestication of tree species that could thrive on such marginal land could be carried out purposely for biofuel production. Silviculture could develop concepts to produce biomass for energy purposes under different conditions in an ecologically, economically and socially sustainable way.

Ecosystem Services

Ecosystem services are defined as benefits which people obtain from ecosystems. Natural and managed forest ecosystems provide numerous services that are in demand from different interest groups but these services cannot be directly monetised by the forest owners. These amenities include regulating (air quality, climate, water) cultural (recreation, spiritual enrichment) and supporting (nutrient or water cycling, photosynthesis) services (MEA 2005). Some of these services are locally or regionally relevant while some have global relevance. For example, the maintenance of water quality or erosion protection are most relevant to a locality or region while CO_2 sequestration is more effective at a global scale. In addition, the provision of some ecosystem services is ensured by the plain existence of a forest in an environment (e.g. photosynthesis), while others rely on or can be improved by silvicultural intervention (e.g. recreation).

Ecotourism

Many tropical forests serve as habitats for biodiversity and refuge for endangered species. This usually increases their importance for conservation and recreation of local people which also attracts ecotourism. It is important that the general character of the stands be maintained as natural, biodiverse and attractive sites as much as possible. Therefore, attention must be given to landscape effects of silviculture and its compatibility with the presence and abundance of attractive animals. In managed forests, the income that can be generated by ecotourism has to be balanced against possible losses or increased costs due to, e.g., reduced removal volumes or growth rates, maintenance of infrastructure, or security aspects. Nevertheless, several studies have shown that ecotourism can provide significant increases in the livelihood and purchasing power in rural communities (Tobias and Mendelsohn 1991; Wunder 1999).

Importance of Biodiversity in Tropical Silviculture

Initially, the focus of tropical forest management was on timber production. However, post 1990 environmental campaigns have shifted attention to other possible goods and services obtainable from tropical forests. This has promoted the establishment of the economic feasibility of sustainable forest management.

Weber (2011) opined that changes in societal and environmental situations at global and regional levels had resulted in considerable shifts in the circumstances and requirements for the use of forest resources. The observed changes included the following:

- In 1999, the world population reached six billion, and continued to grow by 83 million per year and it was estimated to reach seven billion by 2011 (PRB 2009).
- From 2000 to 2010, there was a net loss of 5.2 million hectares per year in the global forest coverage. A reduction of 40 million hectares had been reported in primary forests since 2000, while areas designated mainly for productive purposes reduced by 50 million hectares since 1990 (FAO 2010).
- The number of undernourished people estimated to be 1.02 billion between 1995 – 1997 and 2004 – 2006, increased in all regions except Latin America and the Caribbean Islands (FAO 2009).
- There was an increase in global atmospheric CO_2 concentration from the preindustrial level of 280 to 379 ppm in 2005. The global mean surface temperature increased by 0.76ºC from 1850 – 1899 to 2001 – 2005 as a result of the build-up of anthropogenic GHGs in the atmosphere (IPCC 2007a).

- MEA (2005) estimated that biodiversity, which had always contributed to human welfare and livelihood, was decreasing at alarming rates. It was estimated that about 10 – 50% of mammals, birds, amphibians, conifers, and cycads were threatened with extinction due to habitat changes caused by land-use change, climate change, invasive alien species, over-exploitation and pollution.

Consequently, requirements for different silvicultural treatments are changing due to the direct or indirect effects of ecological processes, particularly with different scales of intensity and time on conditions for forest management. These changes are taking place due to the increasing CO_2 concentration in the atmosphere with the resulting global climate change (IPCC 2007a), continuous loss of species and biodiversity leading to loss of genetic resources (CBD 2004) as well as anthropogenic emissions into the ecosystems (Fabian et al. 2005; Boy and Wilcke 2008; Boy et al. 2008).

FAO (2010) proposed that 12% of the world's forests (460 million hectares) be designated to conservation of biological diversity. Putz et al. (2000) mentioned that the neglect of biodiversity outside of the protected areas could lead to the disappearance of thousands of species. Therefore, the valuable option that is increasingly being accepted in successful conservation strategies is conservation through careful use e.g. biodiversity-sensitive silviculture in managed forests. Other management options which contribute to the maintenance of biodiversity or limit negative effects of silvicultural interventions include: seed tree retention, germination seedbed modification, adequate supply of nutrients, mechanical scarification, herbicide treatment, enrichment planting, liberation thinning, vine cutting and mimicking natural disturbances (Nwoboshi 2000; Putz et al. 2000; Putz et al. 2001; ITTO 2009; IUCN 2009).

Several authors (Johns 1992; Lambert 1992; Kobayashi 1994; Bawa and Seidler 1998; de Graaf et al. 1999;

Pariona et al. 2003; Finkeldey and Ziehe 2004; Günter et al. 2008 Weber et al. 2008; Wilcke et al. 2009) have confirmed the substantial improvements in the understanding of the effects of silvicultural activities on forest ecosystems and forest science around the world. Putz (2011) emphasised the need for clear differentiations among biodiversity features at different scales (landscape, ecosystems, community, species and genetic levels). This is because there is a direct influence on the evaluation of specific measures under different economic conditions and spatial levels. Furthermore, access to modern training and up to date information have created a forum for the application of more sophisticated silvicultural concepts in forest science.

The Convention on Biological Diversity (CBD) has played a significant role in nature conservation, although little attention was initially paid to tropical silviculture and forest management (Global Forest Coalition 2002). Nevertheless, the second and third objectives of CBD referred to sustainable use and related equity issues. Hence, there is a growing recognition that the multilateral environmental governance framework on global public goods, such as biodiversity, is shaping national policy and legislative frameworks. This framework has corresponding impacts on technical subjects such as tropical silviculture. The CBD provides the most important legally binding framework for biodiversity in forest ecosystems. Issues relevant to tropical silviculture were addressed under the expanded Programme of Work on Forest Biodiversity, the Addis Ababa Guidelines on sustainable use, the Akwé:kon Guidelines and in cross-cutting issues such as traditional knowledge, and the ecosystem approach (table 3).

Table 3: Selected Convention on Biological Diversity Programmes and Topics containing relevant Aspects for Tropical Silviculture

CBD programs and topics	**Relevant aspects for Tropical Silviculture**
Expanded programme of work on forest biodiversity	Goal 1.1: Apply the ecosystem approach to the management of all types of forests. Goal 1.2: Objective 1: Prevent the introduction of invasive alien species. Objective 4: Prevent and mitigate the adverse effects of forest fires and fire suppression. Objective 5: Mimic natural disturbances such as fire, wind-throw, or floods to mitigate the effects of natural disturbance.
Addis Ababa guidelines on sustainable use: principles	Practical principle 4: Adaptive management should be based on monitoring results with direct feedback on silvicultural decisions. Practical principle 5: Sustainable use management goals and practices should avoid or minimise adverse impacts on ecosystem services, structure and functions, as well as other components of ecosystems, avoid clear cut in watersheds; use appropriate harvesting techniques; apply precautionary approach in management decisions. Practical principle 7: Spatial and temporal scale of management should be compatible with the ecological and socioeconomic scales of the use and its impact. Practical principle 9: An interdisciplinary, participatory approach should be applied at the appropriate levels of management and governance related to the use.
Akwé:kon guidelines	Procedure and information requirements for the conduct of cultural, environmental and social impact assessments regarding developments proposed to take place on, or which are likely to impact on sacred sites and on lands and waters traditionally occupied or used by indigenous and local communities.

Table 3 contd.

Ecosystem approach: 12 complementary and interlinked principles	Principle 3: Ecosystem managers should consider the effects (actual or potential) of their activities on adjacent and other ecosystems. Principle 5: Conservation of ecosystem structure and functioning, to maintain ecosystem services, should be a priority target of the ecosystem approach. Principle 6: Ecosystem must be managed within the limits of their functioning. Principle 8: Recognising the varying temporal scales and lag-effects that characterise ecosystem processes, objectives for ecosystem management should be set for the long-term.
Traditional knowledge Programme of work on Article 8 (j) and related provisions	Respect, preserve and maintain the knowledge, innovations and practices of indigenous and local communities embodying traditional lifestyles relevant for the conservation and sustainable use of biological diversity, to promote their wider application with the approval and involvement of the holders of such knowledge, and encourage the equitable sharing of the benefits arising from the utilisation of such knowledge.

Source: Uebelhör and Drews (2011)

Concepts of Domestication

Among other definitions, domestication is the process of taking a wild plant species and bringing it under management and cultivation. According to Nichols and Vanclay (2012), it involves the process of bringing into human use, species that are originally in the wild, and subsequently improving on desired characteristics possessed by the species. It implies moving a species from the wild and settling it as a member of the homestead. The main aim of domestication is to bring out the maximum human benefit within a species as it is genetically refined from a wild species to a domesticated one. Therefore, the need for domestication of a new species must be justified by the benefits that is expected to accrue to both the producers and consumers of the domesticated products (Leakey et al. 2004). The domestication of new species is a major and continuous process of improvement. Selection of species for domestication is usually based on priority setting.

Tree Domestication

Trees are the largest plants and, when growing together in forests, constitute the most impressive manifestation of plant life and diversity (Morgenstern 1996). Tree improvement is the application of forest genetic principles and other disciplines like tree biology, silviculture and economics, to produce genetically improved variety of trees which will improve the quantity and quality of harvested products (White et al. 2007). Tree domestication is a human-driven deliberate change in the genetic makeup of particular tree species to conform to the agroecosystem and people's needs (Akinnifesi et al. 2007, Jaramillo et al. 2011).

Priority setting is carried out to determine the species that are most likely to have the highest impact, based on the specific objectives of the domestication process (Simons and Leakey 2004). This is usually considered as the first stage of the domestication process. Prioritising the species to be domesticated is very important, especially in developing countries like Nigeria, where resources are scarce (Bartlett et al. 2012). People are given opportunity through interview to select species suitable for domestication based on their market potential and researcher's inputs based on technical points such as genetic variability. From the outputs received from the farmers, a priority list of species is then made (Leakey and Tchoundjeu 2001).

The second stage involves collection of species germplasm from its geographical range. The third stage of domestication process is the identification of superior trees within the wild population and using vegetative propagation methods such as grafting, air-layering and rooted cuttings to multiply them (Leakey and Tchoundjeu 2001). Vegetative propagation methods to be used should be simple, cheap and robust such that it can be adopted by the rural communities.

Selection of species for tree improvement for a typical plantation is usually straightforward as a single end-product (timber) is involved (Franzel et al. 2007). However, selection of species for improvement in an agroforestry setting is more complicated as there are several factors to be considered. Therefore, the need for domestication of a new species must be justified by the benefits that are expected to accrue to both the producers and consumers of the domesticated products (Leakey et al. 2004). The factors could range from ability of the species to provide fruits, timber, fuelwood, windbreak or shelter. Leakey and Akinnifesi (2007) identified two pathways for the domestication of agroforestry tree products (fig. 5).

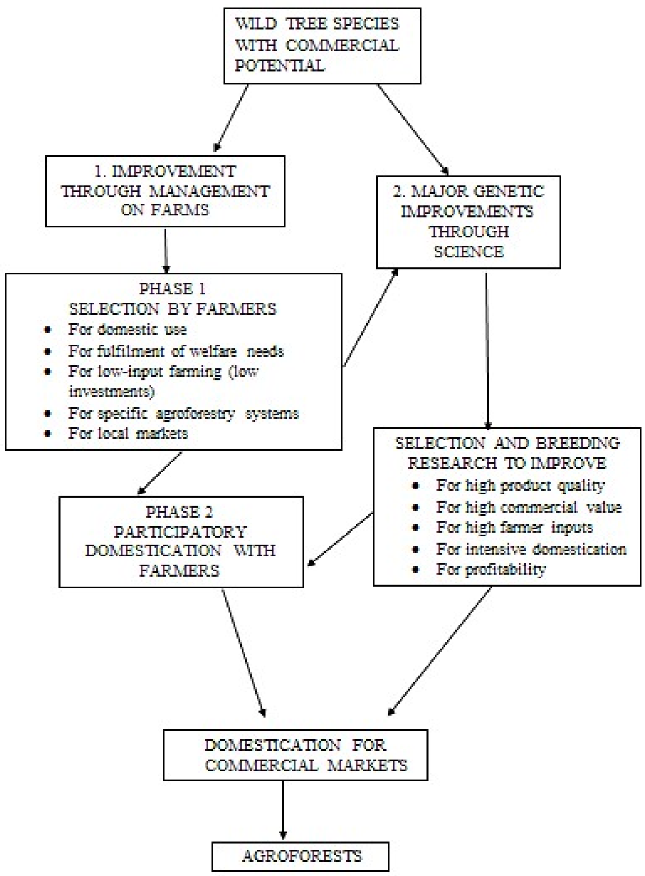

Fig. 5: Two pathways for the domestication of agroforestry tree products.

Source: Leakey and Akinnifesi (2007)

Human beings have been carrying out the process of plant domestication for several thousand years, mainly for food crops and ornamentals. For tree species, most efforts have concentrated on those species with edible parts, particularly to select better fruit and nut varieties. In Nigeria, when tree species are selected and domesticated they become what Agriculturists call 'cash crops.' In effect, without tree domestication, there is no cash crop.

Globally, many agricultural and horticultural crops of the world have been domesticated and cultivated for several generations. In the past, exotic plant species had been given more attention when compared to indigenous ones which people had depended on for several generations (Sekatuba et al. 2004). Some of these indigenous species had gone into extinction, some are endangered and others are threatened due to unsustainable land management practices and overexploitation, among other factors (Buyinza et al. 2015). Domestication of indigenous trees, unlike exotic is advantageous because people are already used to them and the species are well adapted to the environment (Bartlett et al. 2012). Domestication of some of the indigenous fruit trees of different tropical ecoregions are just commencing from gene pools that exist only in the wild (Leakey and Simons 1998). Domestication requires a good understanding of the potentials and diversity of the genetic base of the plant species, to ensure that the domestication is carried out wisely, efficiently and within the limitations that are imposed by the Convention on Biological Diversity, while maintaining and protecting the diversity of the genetic resource (Leakey et al. 2004). The domestication of trees used in agroforestry systems would promote sustainable land use practices, rehabilitate degraded farmlands, sequester carbon and other GHGs as well as enhance biodiversity and agroecosystem functioning while maintaining productivity of the soil (Bada 1992; Leakey 2001). Identification of good seed sources from within the natural population followed by the development of appropriate propagation and silvicultural practices are usually the beginning of the process of domestication. To achieve desired results, genetic and cultivation traits must be improved and made available to farmers (Bartlett et al. 2012). Domesticated species satisfy a variety of subsistence needs and also generate cash income through products which they supply (Brilis et al. 1996).

Domestication is a highly species-specific and highly variable process (Thomson et al. 2002). Therefore, strategies for individual plant species vary depending on its peculiar biology, economic value, and target environment. According to Morgenstern (1996), domestication can influence genetic diversity in two ways: (1) indirectly: by the method of seed collection, extraction, and storage; and by nursery and plantation culture; and (2) directly: by deliberate artificial selection to increase the occurrence of desirable physical attributes, such as straight stems, narrow crowns, finer branches, and more rapid growth than in wild trees. Domestication can assist silviculturists to achieve species identification, propagation, management, and the adoption of desirable tree germplasm. This is because the process involves selection, re-introduction, and management. During the process, scientist can discover good seed sources and develop appropriate propagation and cultural practices for domesticated tree species (Leakey et al. 2010; Dawson et al. 2012).

In forestry, early stages of domestication process usually commence through provenance selection due to the long gestation period of most trees. This involves the transfer of geographically-discrete sub-populations to new environments that are usually similar to their natural range, but may differ in ways that could enhance either the growth rate, or physical growth form of the species (Leakey et al. 2004). For tree species of commercial importance, complete domestication process may involve systematic sampling and characterisation of genetic variation, development of optimal propagation and silvicultural techniques, and intensive breeding, which could involve the use of molecular genetics technologies and sometimes hybridisation. A schematic representation of the domestication process is presented in figures 6 and 7.

From Wild Population to Broad Social Use

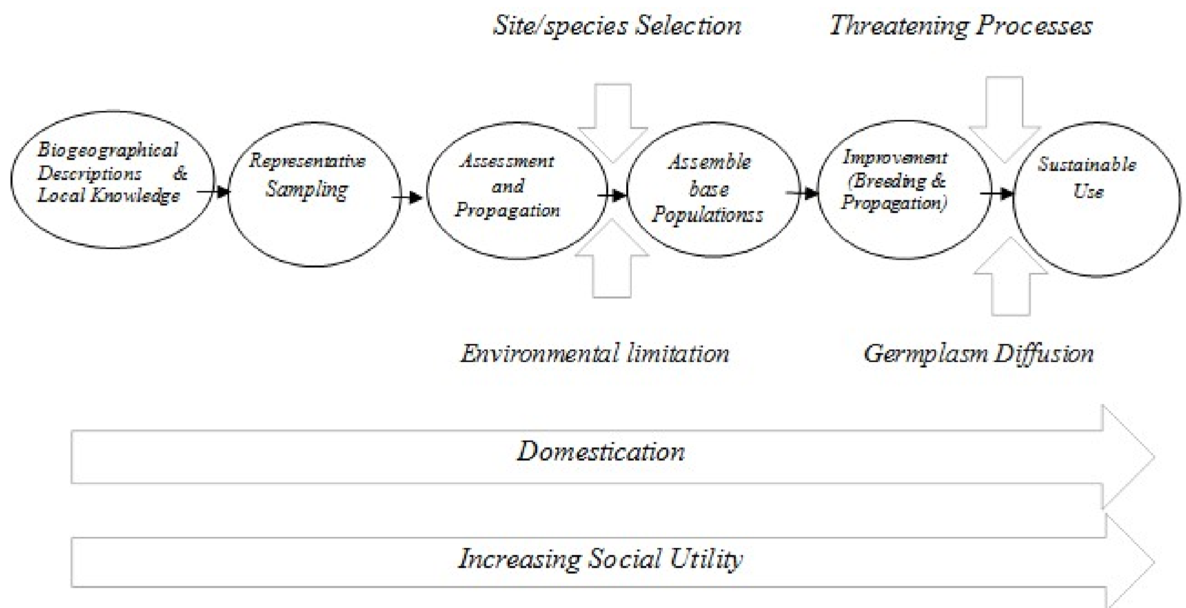

Fig. 6: The process of tree domestication.

Source: Midgley (1995)

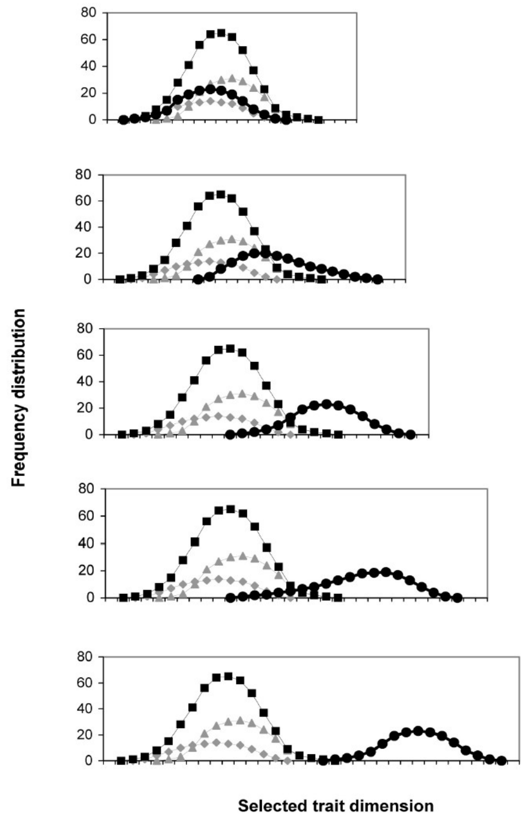

Fig. 7: Hypothetical stages of domestication. 1 = A wild population made of 3 sub-populations. In stages 2 – 5, one of these sub-populations, is domesticated by truncated selection to form a variety.

Source: Leakey et al. (2004)

Domestication derives its urgency from the massive reductions in the extent and availability of wood products from native forests, and the need to develop alternative plantation resources to combat dwindling resources. The successful candidates of tree domestication would provide timber and fibre, among other forest benefits from man-made sources, for a growing local and global population (fig. 8).

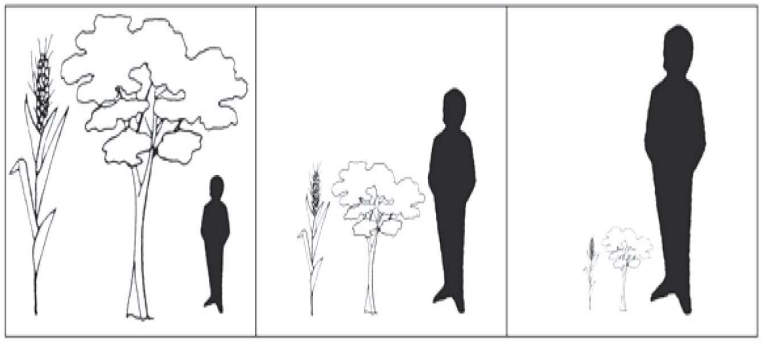

Fig. 8: Depletion of living resources, as portrayed by the World Conservation Strategy (after IUCN 1980). Relative rates of degradation of arable land are shown by the stalk of wheat symbol, reduction in unlogged productive tropical forest is shown by the tree symbol, and the global population growth is shown by the human figure.

Influence of Genetic Diversity on the Domestication of Tropical Trees

The genetic composition of tree species can be altered negatively or positively by intensive forest management. A wide range of management practices could be carried out without significantly eroding genetic diversity, if sound genetic principles are observed (White et al. 2007). Genetic diversity among forest trees thrive on the variation that occur within species in the stands of the forest. Schaberg et al. (2008) refer to species variation as the building block for any domestication and improvement programme. The outward appearance of the tree, which is the phenotype, is influenced by both the genetic potential of the tree and the environment in which the tree grows.

Phenotype (P) = Genotype (G) + Environment (E) + GE

These two factors are the underlying causes that produce the final phenotype of the tree as shown in figure 9 (White et al. 2007).

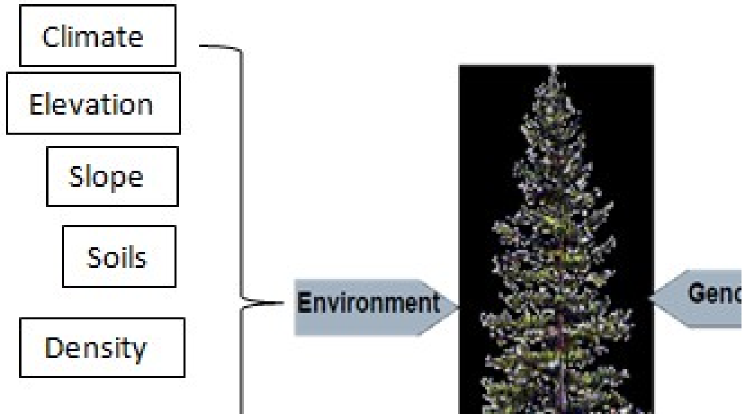

Fig. 9: Schematic diagram showing different environmental and genetic factors that contribute to a tree's phenotype. Differences in any of these factors cause differences among tree phenotypes leading to abundant phenotypic variation among trees in forest stands.

Source: White et al. (2007)

It is necessary to understand the factors that contribute to the loss of genetic diversity and species extinction to be able to develop effective domestication strategies for tropical trees. The major cause is the uncontrolled and unsustainable exploitation of forest resources which diminishes genetic resources in the ecosystem. Selective logging of high-quality individual trees reduces population size, may increase inbreeding and random drift, and exposes some species to extinction. Deforestation, when entire forests are cleared of trees, burned, and converted to agricultural land or low-quality grass or shrub vegetation is very dangerous. Such destruction of forests on large scale had resulted in the loss of entire regional populations and perhaps particular species. Environmental deterioration which has accelerated substantially in recent times, poses another threat to forest genetic resources. Predicted climatic changes are expected to alter the established pattern of forest ecosystem distribution and genetic variation. An increase in temperature will lead to an increase in grasslands and a southward shift of forests.

This could lead to narrower belts of rain forests, and eventual disappearance of species growing in higher altitudes. Many southern or low-elevation populations may also become smaller or disappear altogether. Natural or artificial regeneration of forests with local seed may no longer be possible, but introduced provenances may be viable. The emergence of new insect and disease problems will become more frequent with introduced provenances. Hence, gene conservation efforts and domestication must be accelerated to prepare for the many issues that could arise from climatic change.

Indication of errors in seed source selection and lack of knowledge of variation in trees and the biological factors involved have been observed in many failed plantations. The tree species found in the tropical ecosystem are for the most part still wild plants and little affected by domestication and breeding. Some have been introduced to new regions and continents, where they are now important in forestry and agroforestry. The wide distribution of such species exposes them to diverse environments and to natural selection by very different light conditions, temperatures, soils, and many other physical and biotic factors. Many within-species variations related to geographic origin have been observed and have been the object of domestication.

Many traits in plants – such as height and diameter, phenology, and development in general – are not inherited in a simple fashion like the flower colours, but are controlled by several or many genes (Morgenstern 1996). Breeding and silviculture use genetic variation as the raw material of evolution and genetic change induced by man. The domestication process capitalises on survival due to natural selection that the tree species go through. Most individuals differ in viability and fertility, and these cause differences in gene and genotype frequencies from one generation to the next (Endler 1986). Natural selection is the dominant genetic process which regulates adaptation and influences organisms at every stage of reproduction and development. Therefore, the formation of gametes, pollination, fertilisation, germination of seed, and development of new individuals are all influenced by natural selection (Onokpise and Akinyele 2012). In addition, at each of these stages, physical factors (temperature, moisture, and nutrients) and biotic agents (microorganisms, animals, and plants) influence gene and genotype frequencies.

State of Knowledge in Tree Domestication

During the process of domestication, there is an interface of the environment, populations and the genetic system as shown in figure 10. Physical factors vary across the range and presumably lead to the genetic differentiation of populations within species. These factors including temperature, light, water, nutrients, are harnessed during domestication. In natural stands, measurements of trees; collection of leaves, branches, fruits, seeds, and other materials could be of taxonomic interest, but they may not provide enough information about genetic variation because of the interaction between the environmental and genetic components (Kimmins 1987).

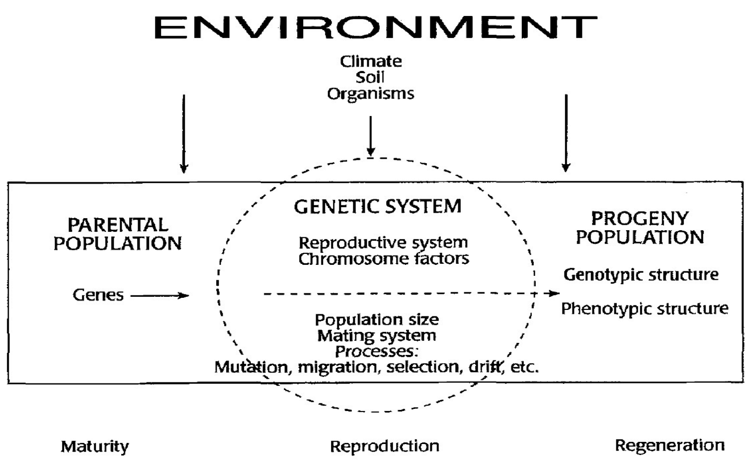

Fig. 10: The interface of environment, populations, and the genetic system.

Source: Morgenstern (1996)

These two factors (genes, and the environment) are the major drivers of growth, development, and reproduction of all living organisms. In natural forests, genetic variation arises as a consequence of genetic processes operating under the control of the environment and gives rise to patterns of variation that are distinctive of individual species (fig. 11). Hence, silvicultural methods and techniques that have a genetic effect need to be applied in the domestication of tree species.

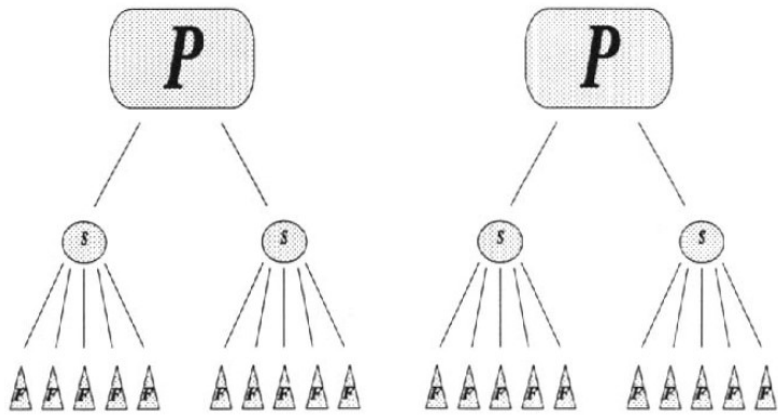

Fig. 11: Structure of a provenance experiment-based sampling at the level of populations, P (regions); subpopulations, S (stands within regions); and families, F (progeny from individual trees).

Improved tree selection can be achieved through controlled environment and biological components in the process of domestication (fig. 12). Silvicultural systems (such as clear-cutting or the shelterwood or seed-tree method) and the forms of intermediate treatment (such as the thinning method) are examples of measures that have genetic consequences in the domestication process (Matthews 1989). Figure 13 shows a general scheme for using both environmental and genetic information in the domestication process.

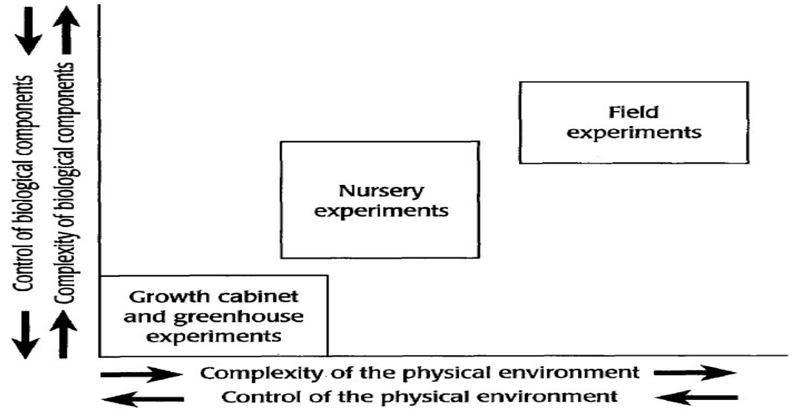

Fig. 12: Possibilities of control of the environment and control of biological components in three types of experiments (modified from Snaydon 1980).

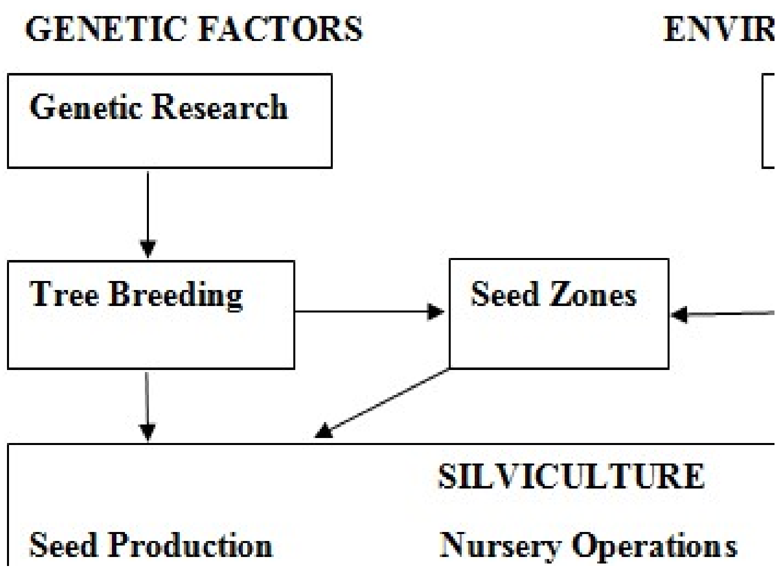

Fig. 13: Integration of genetic and environmental factors in silviculture.

Source: Morgenstern (1979)

There are three main reasons why the use of genetic information is important.

(1) There should be a careful consideration of the genetic quality of the seed/germplasm used especially for a crop with a long gestation period. The planted forest must be ecologically well adapted, vigorous, and healthy. Crop security over the whole length of rotation is absolutely essential.
(2) In many parts of the world, forest trees are still wild plants with a distinct geographic variation. Such variation must be considered in all procedures and regulations for seed and plant distribution.
(3) Forestry is not an intensive but extensive form of management. It is concerned with large, often remote areas and much site variability (usually poorer sites not suitable for agriculture). It is practised with relatively little cultivation and protection of the crop. It is often limited to the management of natural stands, and if trees are planted, post-planting maintenance is minimal.

Each of these reasons suggests important differences between forestry and crop production in agriculture, where the selected seed is always used, where intensive cultivation and protection are the rules, and where most crops mature within one year (Morgenstern 1996).

The Use of Vegetative Propagation in Tree Domestication
Application of vegetative propagation in the domestication of trees provides opportunities for research, sustainable development and use of plant genetic resources. Prolonged gestation period and access to superior parent planting stocks for propagation and distribution are major constraints in the establishment of plantations of most indigenous tree species. The use of vegetative propagation brings solution to the challenges of poor seed germination and storage behaviour, reduction of gestation period of fruit-bearing species, selec-

tion of superior genotype, plantation uniformity, introduction of plus traits of two or more plant genotypes into a single stand and control of phases of tree development, among others (Leakey 2000; Jaenicke and Beniest 2002). Vegetative propagation is the regeneration and mass production of plant kinds using vegetative parts like buds, leaves, single cells/ tissues and nodal cuttings of roots and stems. These plant parts contain all genetic information required to reproduce a whole plant (totipotency) in their cells. Totipotency is the persistence of cell division in plants during their normal growth and development processes. It is the capacity of the cells to re-form a meristem, which divides and produces any lacking part. Through vegetative propagation, similar copies of the genetic make-up of mother tree are replicated in the offsprings (Oni and Abiade 1989). Therefore, all offsprings produced through vegetative propagation from a mother tree are genetically identical (clones of the mother tree), except occasionally where chimeras (i.e. rare somatic mutations) occur and are perpetuated (Hartmann et al. 2007). Vegetative propagation is widely used in tree domestication and several plant genetic resources conservation programmes. Desired traits/characters available in the wild population are introduced into new ones with the ultimate aim of mass-producing improved seedlings for interested users (Tchoundjeu et al. 1997; Verheij 2004).

Vegetative propagation provides opportunities for research in tree species domestication, while actualising the objectives of sustainable development and use of plant genetic resources. According to Jaenicke and Beniest (2002), plant regeneration by root or stem cuttings, budding and grafting, air-layering and micro-propagation techniques are the most viable vegetative propagation options for tree domestication programmes. Adventitious roots are induced from stem cuttings through the use of growth hormones. A section of the plant shoot with axillary bud and the nodal point is severed from the parent stock and placed in a high humid environment in a propagator chamber. Root induction could commence after some weeks, leading to the production of an independent plant from the stem section. Chadha (2009) reported that when propagules from young, vigorously-growing and less-lignified parts such as seedlings or coppiced shoots are used, the success rate of tree multiplication is usually high.

Budding and grafting techniques are used to join portions of two or more plants to form a single plant which continues its growth as one plant. These methods are used to preserve clones that may not be easily multiplied by similar regenerative propagation methods. Grafting takes advantage of the adaptation of the rootstock to introduce a selected variety that is used as ‘scion’. This procedure has been applied in the mass-production of many important fruit trees and ornamental woody plants (Verheij 2006; Hartmann et al. 2007).

Air-layering or marcotting is another well-established vegetative propagation method through which adventitious roots are induced on a stem while the stem remains attached to the parent plant. Marcotting has been used because of its versatility, adaptability and the success rate recorded in improvement programmes for several indigenous tree species (Jaenicke and Beniest 2002; Scrase 2009; Tchoundjeu et al. 2012). After root induction, successful marcots are cut off and become independent plants growing from their own roots. Marcots have been known to commence fruiting earlier than slower-growing stem cuttings or grafted trees, though they possess shallow root systems (Jaenicke and Beniest 2002; Asaah et al. 2012; Awodoyin et al. 2015). Grafting, budding, and marcotting have been used to achieve early fruiting and tree dwarfing, producing trees that are more compact at harvest, and easing fruit collection (Akinnifesi et al. 2009; Assah et al. 2010).

Micropropagation utilises the totipotent potential of plants to reproduce whole new individuals from miniature living tissue or single cells through *in vitro* culture under an aseptic and controlled environment. This application makes it possible to mass-produce virus-free seedlings/propagules from limited stock plant materials. Micropropagation is a capital intensive and technologically-advanced form of vegetative propagation, therefore, its practice is mostly justified in cases of high premium or rare/endangered plants where other vegetative propagation options have proved unsuccessful (Hartmann et al. 2007; Chadha 2009; Ahuja and Ramawat 2014).

Some indigenous fruit species of sub-Saharan Africa have benefited remarkably from the enhanced use of vegetative propagation for the reduction of their gestation periods and subsequent early fruiting. They include *Adansonia digitata* L. from 10 years to 4 years; *Dacryodes edulis* (G. Don) H.J. Lam (African pear tree) from 5 years – 2 years; *Irvingia gabonensis* (Aubry-Lecomte ex O'Rorke) Baill. and *I. wombolu* (bush mango) from 7 years – 3 years; and *Vitellaria paradoxa* from 20 years to below 5 years (Jaenicke and Beniest 2002; Jamnadass et al. 2011).

Emerging Trends in Tree Domestication

Genomic Selection

It is well established that traditional genetic improvement of forest tree species takes longer duration when compared to agricultural crops (Harfouche et al. 2012). The use of marker-assisted selection (MAS) has been found to be limiting when it comes to within-family selection (Grattapaglia and Kirst 2008). To overcome this challenge, genomic selection has been proposed as most suitable for accelerating domestication process in forest trees with long breeding cycle (Harfouche et al. 2012). Genomic selections, unlike marker-assisted selection can be regarded as all in one marker, as it involves the combination of all available genetic markers for developing prediction models using phenotypic and genotypic data. These models can be used to predict the genomic breeding value of progenies in future generation (Goddard and Hayes 2007).

Next-generation Sequencing Technologies

Deployment of next-generation sequencing (NGS) technologies in the field of DNA sequencing has greatly increased outputs and reduced the costs associated with sequencing species (Shendure and Ji 2008)). With next-generation sequencing for example, resequencing of entire genomes and resequencing a limited number of genes or genomes for different types of variation can both be achieved in genetic diversity study (Harfouche et al. 2012). Gene discovery, ecotilling in candidate genes and individual genotyping are the identified areas in which next-generation sequencing technologies can be applied to speed up domestication process of forest trees (Harfouche et al. 2012).

Discovery of genes or traits of particular interest to breeder had been a major challenge. However, NGS has the ability to sequence entire genome, thereby revealing traits of interest. This has been done to reveal genotype-specific molecular responses to water deficit in eucalyptus (Villar et al. 2011; Harfouche et al. 2012). The NGS can also be used to identify mutation present in species, thereby accelerating the identification and utilisation of beneficial mutation. However, this is only possible if the genes responsible for phenotypic characteristics are known (Harfouche et al. 2012).

Genetic Engineering

Genetic engineering is a promising area that has the potential to shorten the long gestation period which is typical of many tree species. For example, lignin modified hybrid polar trees (*Populus tremula*) was developed through genetic engineering (Leple et al. 2007; Mansfield 2009). Cold-tolerant hybrid *Eucalyptus grandis* and *Eucalyptus urophylla* was also developed using genetic engineering (Hinchee et al. 2009). Genetic engineering plays a complementary role in tree domestication programme (Harfouche et al. 2012).

Tree Domestication, Food Security and Conservation

Tree domestication has contributed significantly to ensuring food security and the conservation of genetic resources in sub-Saharan Africa. Protocols for vegetative propagation techniques and silvicultural requirements have been developed for the successful mass multiplication of some indigenous tree species. These include *Adansonia digitata* L. (baobab) (Askira 2008; Jamnadass et al. 2011), *Allanblackia* *spp*. (Jamnadass et al. 2011), *Alstonia boonei* De Wild (Akinyele and Adzandeh, 2016), *Enantia chlorantha* Oliv. (Gbadamosi and Oni 2005, 2006), *Irvingia gabonensis* (Aubry-Lecomte ex O'Rorke) Baill. and *Irvingia wombolu* Vermoesen (Bush mango) (Nzekwe 2002; Tchoundjeu et al. 2010), *Gambeya albida* (G. Don) Aubrév. & Pellegr. (syn. *Chrysophyllum albidum* G. Don) (African star apple), *Dacryodes edulis* (G. Don.) H. J. Lam. (African pear) (Kengue 2002; Asaah et al. 2010), *Dennettia tripetala* Baker f. (English pepper fruit) (Onefeli and Akinyele 2014), *Griffonia simplicifolia* (Vahl ex DC.) Baill. (Awosan et al. 2014). *Massularia acuminata* (G. Don) Bullock ex Hoyl. (African chewing stick) (Oni and Ojo 2002; Usman and Akinyele 2015), *Parkia biglobosa* (Jacq.) Benth (locust beans) (Oni and Fasehun 1987; Abdullahi and Akinyele 2013), *Pcynanthus angolensis* Welw. (African nutmeg) (Onefeli and Akinyele 2013; Bello and Akinyele 2016a, b), *Synsepalum dulcificum* (Schumach & Thonn.) Daniell. (miracle berry) (Akinyele and Orosun 2016), *Terminalia superba* (Engl. and Diels) (Oni 1987), *Terminalia ivorensis* (Oni and Bada 1991), *Treculia africana* Decne. (African bread fruit) (Nzekwe 2004), *Tetrapleura tetraptera* (Schum & Thonn) Taub. (*Aidan* tree) (Akinyele and Maradesa 2013), *Vitellaria paradoxa* C.F. Gaertn. (Sheabutter) (Sanou et al. 2004), and *Uapaca kirkiana* Mull.Arg. (Wild loquat) (Akinnifesi et al. 2007), *Zanthozylum xanthoxyloides* Lam. (prickly ash) (Onefeli and Akinyele 2013), and many others (Atangana et al. 2001; Kengue 2002; Leakey et al. 2002; Anegbeh et al. 2003; Asaah et al. 2003; Leakey et al. 2005; Tabuna 2007; Tchoundjeu et al. 2010).

My Contributions to Tree Domestication in Nigeria

My work in the domestication, improvement, and conservation of genetic resources of indigenous tree species, has galvanised support for the cultivation of local tree species for technical, social and environmental reasons. It is likely that several generations of selection from a broad genetic base will lead to the development of better-adapted landraces for specific, difficult or unusual sites.

I have focused on *ex-situ* conservation of genetic resources of underutilised and threatened indigenous tree species of Africa using macro-and microforms of vegetative propagation. The information obtained on the genetic variations within and between tree species ensures informed selection of plus trees, in order to improve their qualities and availability in perpetuity. The research outputs from these studies have led to the development of appropriate protocols suitable for achieving improved propagules using macro-and micropropagation techniques. Different populations of indigenous tree species have been compared with the aim of raising germplasms of plus trees with improved yield and form. These invariably would enhance the ability of timber and non-timber forest produce to further provide food, fibre and income generation.

For instance, my study on the vegetative propagation of *Buchholzia coriacea* (wonderful kola), revealed that single node cuttings of the species were amenable to cloning with or without auxin treatment (fig. 14). The cuttings required a growth medium that was not too porous but still allowed for good drainage and sufficient spaces to prevent waterlogging, thus promoting subsequent rooting of the cuttings (table 4). The retention of active leaves on the cuttings was also important with the best result obtained from cuttings with whole leaf (table 5). Indeed, the introduction of low-level hormone hindered the production of roots in this species (Akinyele 2010).

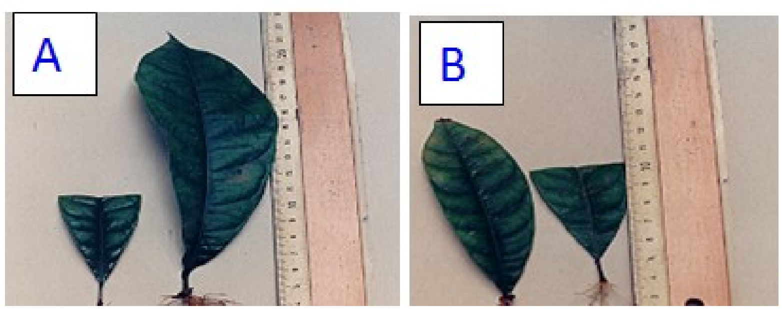

Fig. 14: Vegetative propagation of single node cuttings of *Buchholzia coriacea* raised in topsoil (A), riversand (B) and sawdust (C).

Table 4: Effect of Rooting Media on Root length and Total Root Length of Juvenile Stem Cuttings of *Buchholzia coriacea*

Rooting medium	Root length (cm)	Total root length (cm)
Topsoil	3.8[a]	12.5[a]
Sawdust	3.4[a]	11.4[a]
Riversand	1.4[b]	5.2[b]

Note: Mean values in the same column with same superscript were not significantly different at $p = 0.05$

Table 5: Effect of Leaf area, Rooting media and Hormone concentration on the Number of Roots, Total root length and Percentage Survival of Juvenile Stem cuttings of *Buchholzia coriacea*

Variables	Number of roots	Total root length	Percentage survival
Leaf area			
Whole leaf	4.9[a]	13.5[a]	97.2[a]
Half leaf	2.6[b]	5.9[b]	93.5[b]
Concentration of hormones			
Control	4.8[a]	13.2[a]	94.4[a]
50mg/l	3.0[b]	7.8[b]	92.6[b]
100mg/l	3.0[b]	6.6[b]	96.3[c]
150mg/l	4.0[a]	11.2[a]	98.1[c]
Rooting medium/ hormone concentration			
Topsoil x Control	4.3[a]	14.2[a]	83.3[a]
Topsoil x 50 mg/l	3.6[b]	12.1[a]	94.4[b]
Topsoil x 100 mg/l	3.1[b]	9.6[b]	100.0[c]
Topsoil x 150 mg/l	3.6[b]	14.1[a]	100.0[c]
Sawdust x Control	7.3[d]	20.7[c]	100.0[c]
Sawdust x 50 mg/l	2.9[c]	7.4[d]	94.4[b]
Sawdust x 100 mg/l	2.8[c]	5.3[d]	94.4[b]
Sawdust x 150 mg/l	4.3[a]	12.3[a]	100.0[c]
Riversand x Control	2.8[c]	4.7[d]	100.0[c]
Riversand x 50 mg/l	2.5[d]	3.9[e]	88.9[b]
Riversand x 100 mg/l	3.2[b]	4.9[d]	94.4[b]
Riversand x 150 mg/l	4.2[a]	7.2[d]	94.4[b]

Note: Mean values in same column with same superscript were not significantly different at $p = 0.05$ level.

In addition, the study on the use of seeds for propagation of *B. coriacea* revealed that seed size had a great influence on seedling growth when they were young. However, with availability of sufficient nutrient and light, effect of seed size on seedling growth and development could disappear as seedlings attained maturity (fig. 15), (Akinyele and Adegeye 2011).

Fig. 15: Six month old seedlings of *Buchholzia coriacea* from (A) small seed weight class (B) medium seed weight class (C) large seed weight class.

Another study evaluated the use of marcotting for the propagation of *Synsepalum dulcificum* (miraculous berry), a shrub that is used extensively in traditional medicine (as a natural sweetener) (Akinyele and Orosun 2016). Result showed that the highest number of marcots were from those set in the middle position of the shrub and treated with IBA at 500 mg L^{-1} (table 6). The study revealed that marcotting was a potential, viable and economical method for vegetative propagation of *S. dulcificum* (fig. 16).

Table 6: Effect of Growth Hormones on Survival and Rooting of *Synsepalum dulcificum* Marcots

Variables	Marcotti position	IBA 500	IBA 1000	IBA 1500	IBA 2000	Control	NAA 500	NAA 1000	NAA 1500	NAA 2000
Survival percentage	Base	50	0	16.7	50	0	16.7	50	16.7	66.7
	Middle	100	66.7	83.3	83.3	0	83.3	66.7	66.7	33.3
	Upper	33.3	50	33.3	50	0	33.3	16.7	50	33.3
Percentage rooting (%)	Base	16.7	0	0	0	0	0	0	0	0
	Middle	83.3	33.3	50	50	16.7	33.3	16.7	33.3	0
	Upper	0	16.7	0	50	0	0	0	0	0
Root Length (cm)	Base	3.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Middle	6.04	10.50	8.00	11.10	0.20	4.97	6.50	5.00	0.00
	Upper	0.00	11.60	0.00	5.20	0.00	0.00	0.00	0.00	0.00
Root diameter (mm)	Base	2.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Middle	6.04	9.43	10.60	11.42	0.43	1.15	1.26	1.92	0.00
	Upper	0.00	6.49	0.00	6.52	0.00	0.00	0.00	0.00	0.00
Number of rooted marcot	Base	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Middle	5.00	2.00	3.00	3.00	1.00	3.00	1.00	1.00	0.00
	Upper	0.00	1.00	0.00	3.00	0.00	0.00	0.00	0.00	0.00
Number of callused Marcot	Base	2.00	0.00	1.00	2.00	0.00	1.00	3.00	1.00	4.00
	Middle	0.00	2.00	4.00	4.00	0.00	6.00	4.00	5.00	4.00
	Upper	4.00	2.00	1.00	2.00	0.00	3.00	3.00	3.00	4.00

IBA= Indole-3-butyric acid, NAA= Naphthalene acetic acid

Fig. 16: Rooted marcots of *Syncepalum dulcificum.*

Further research which assessed the genetic diversity of *Syncepalum dulcificum* in Nigeria, using Randomly Amplified Polymorphic DNA (RAPD), showed that there was high similarity in the genetic composition within and among the populations studied (Iloh et al. 2016). It could be inferred that *S. dulcificum* does not have a genetically-diverse population (table 7). This may be attributed to the plant's breeding system which is mainly autogamous. In-situ conservation was recommended as an immediate management strategy for improving the genetic diversity of the plant species. Table 8 shows Nei's genetic distance (D) measured from Nei's unbiased measures of genetic identity and distance. Results show that the highest genetic identity/ distance was between germplasms from Forestry Research Institute of Nigeria (FRIN) and Cocoa Research Institute of Nigeria (CRIN). The lowest genetic identity/distance was reported between germplasms from CRIN and Alonge.

Table 7: Nei's Generic Variation Statistics for All Loci per Population of *Synsepalum dulcificum*

S/N	Population	Sample Size	na*	ne*	h*	I*	No of PPI	% PPI
1	Alonge	4	1.40±0.50	1.25±0.33	0.15±0.19	0.22±0.28	10	40
2	CRIN	3	1.36±0.49	1.20±0.30	0.12±0.17	0.19±0.26	9	36
3	FRIN	3	1.48±0.51	1.31±0.38	0.18±0.20	0.27±0.30	12	48
4	IJEBU ODE	10	1.60±0.50	1.25±0.32	0.15±0.17	0.25±0.25	15	60
5	NACGRAB	10	1.68±0.48	1.28±0.33	0.18±0.18	0.28±0.25	17	68
6	UI	10	1.52±0.51	1.25±0.30	0.16±0.18	0.24±0.26	13	52

*na: Observed number of alleles. *ne: Effective number of alleles. *h: gene diversity. *I: Shannon's Information index. PPI: Polymorphic loci.

CRIN- Cocoa Research Institute of Nigeria, FRIN- Forestry Research Institute of Nigeria, NACGRAB-National Center for Genetic Research and Biotechnology; UI- University of Ibadan.

Table 8: Nei's Original Measures of Genetic identity (above diagonal) and Genetic distance (below diagonal) of *Synsepalum dulcificum* across Oyo and Ogun States, Nigeria

Population identity	ALONGE	CRIN	FRIN	IJEBU ODE	NACGRAB	UI
ALONGE	****	0.9907	0.9292	0.9695	0.9280	0.9588
CRIN	0.0094	****	0.9184	0.9725	0.9280	0.9534
FRIN	0.0734	0.0851	****	0.9571	0.9389	0.9652
IJEBU ODE	0.0309	0.0279	0.0439	****	0.9730	0.9800
NACGRAB	0.0747	0.0748	0.0631	0.0274	****	0.9691
UI	0.0421	0.0478	0.0354	0.0202	0.0313	****

CRIN - Cocoa Research Institute of Nigeria, FRIN - Forestry Research Institute of Nigeria, NACGRAB -National Centre for Genetic Research and Biotechnology; UI- University of Ibadan

Another species that I have researched on is *Alstonia boonei* De Wild, a tree species that has been traditionally used as anti-malaria, aphrodisiac, anti-diabetic, antibiotic, anti-microbial and anti-pyretic activities (Akinyele and Adzandeh 2016). In a study, we tested the effect of organic and inorganic growth hormones on the sprouting of *Alstonia boonei* stem cuttings. It was discovered that 20 cm stem cuttings, treated with coconut water at 100% concentration, using topsoil as rooting medium, had the highest leaf sprouts.

No sprouting was observed in cutting lengths of 5 cm and 10 cm, treated with rooting hormones, in either topsoil or river sand (figs. 17 & 18). However, further investigation, is required to determine the effect of growth hormones on the survival and rooting of the propagules.

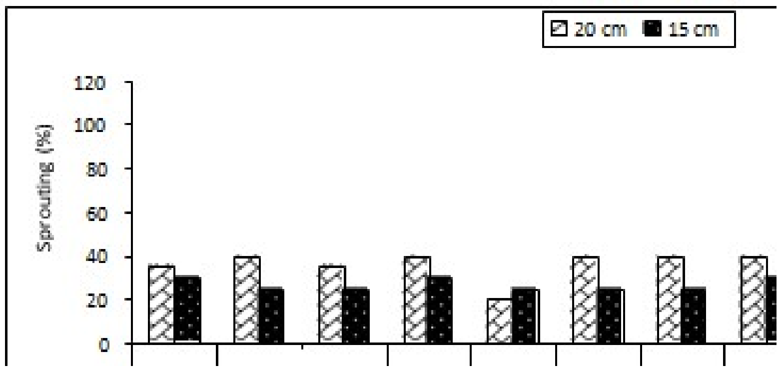

Fig. 17: Sprouting of 15 cm and 20 cm (length) stem cuttings of *Alstonia boonei* subjected to varying concentrations of growth hormones.

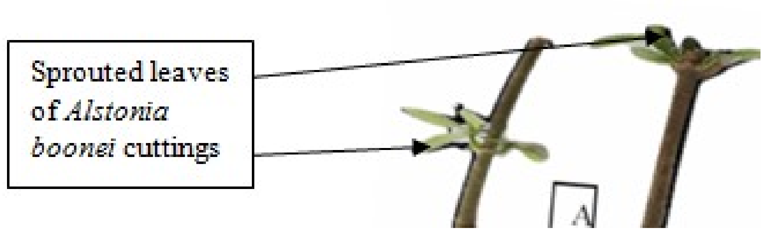

Fig. 18: Stem cuttings of *Alstonia boonei* treated with 100% coconut water grown on river sand (A) and top soil (B).

Garcinia kola H. is an endemic tree of the humid lowland rainforest vegetation of the West and Central Africa. The fruit is in high demand globally for direct consumption; as a stimulant, as well as an active ingredient in the confectionery and pharmaceutical industries. In a study, we determined the effect of scion source on growth performance of grafted seedlings of *Garcinia kola*. The species was successfully grafted on one-year old rootstocks using modified cleft grafting method (fig. 19). Flowering of the grafted seedlings commenced five months after grafting (fig. 20). Scion collection from long distances affected the grafting success and survival of the grafts. Therefore, the location of plants where scion are collected should not be too far from the grafting site (table 9).

Fig. 19: Insertion of the scion into the root stock.

Fig. 20: Seedlings of *Garcinia kola* flowering at five months after grafting.

Table 9: Effect of Sscion Source on Survival, Height, Collar Diameter and Number of Leaves of Grafted *Garcinia kola* Seedlings

Scion source	Survival percentage (%)	Height (cm)	Collar
Gambari forest reserve	52ᵃ	60.35±2.83ᵃ	12.63±
Omo forest reserve	46ᵇ	59.40±4.28ᵃ	11.64±
[illegible]	36ᶜ		

Means with the same superscript along the same column were not significantly different at p =0.05

Dacryodes edulis (African pear/Safou) is another multipurpose tree species that serves several purposes including food and carbon sequestration in rural environments. In our study on the marcotting of *Dacryodes edulis* (fig. 21), we observed that the type of hormone and concentration levels did not have any effect on rooting of marcots. However, there was significant difference in the effect of marcotting position on the mother tree, where marcots set at the upper section of the main stem had the longest roots (tables 10 & 11). Hence, the ability of cuttings to form roots is determined by the position where the cutting is obtained. Also, the application of hormones may not be necessary for marcotting of *D. edulis* (Agwu et al. 2017).

Fig. 21: Marcotting of *Dacryodes edulis.*

Table 10: Effect of Hormone Type, Concentrations and Marcotting Position on *Dacryodes edulis* Marcots

Variables	Marcotting Position	GA 1000 PPM	GA 2000 PPM	IB PI
Rooted marcots (%)	Lower	94	93	9
	Middle	82	84	8
	Upper	76	78	7
Number of Roots	Lower	8.4	8.53	8.:
	Middle	11.38	11.23	11
	Upper	12.12	12.27	12
Root Length (cm)	Lower	5.11	5.12	5.:
	Middle	6	5.99	5.!
	Upper	7.72	7.72	7.:

Table 11: Effects of Marcotting position on Root length, Collar Diameter, Root Number and Root Biomass of *Dacryodes edulis*

Marcotting position	Root Length (cm)	Root collar diameter (mm)	Number of roots	Root biomass (g)
Lower	5.10^{a}	2.92^{a}	8.35^{a}	2.43^{a}
Middle	5.92^{b}	3.24^{b}	11.36^{b}	3.61^{b}
Upper	7.70^{c}	3.59^{c}	12.28^{c}	4.72^{c}

Mean values with the same superscript along the same column were not significantly different at $p = 0.05$

Some other indigenous species that I worked on with my students and collaborators include *Massularia acuminata* (Usman and Akinyele 2015), where we monitored the effects of organic and inorganic growth hormones on the sprouting and rooting ability of the species stem cuttings (figs. 22 and 23); *in vitro* culture of *Tetrapleura tetraptera* (fig. 24;

Akinyele and Maradesa 2013), *Parkia biglobosa* (fig. 25; Abdullahi and Akinyele 2013) and *Pycnanthus angolensis* (fig. 26; Onefeli and Akinyele 2013; Bello and Akinyele 2016a); macropropagation of *Centella asiatica* Linn. (Gotu kola) (Akinyele and Mbadikwe 2014), *Dennettia tripetala* (Onefeli and Akinyele 2014), *Griffonia simplicifolia* (Awosan et al. 2014) and *Zanthoxylum zanthoxyloides* (Lam.) (Bello and Akinyele, 2016b), using different growth media, growth hormones and cutting positions. Different protocols for vegetative propagation of these species have been developed and documented.

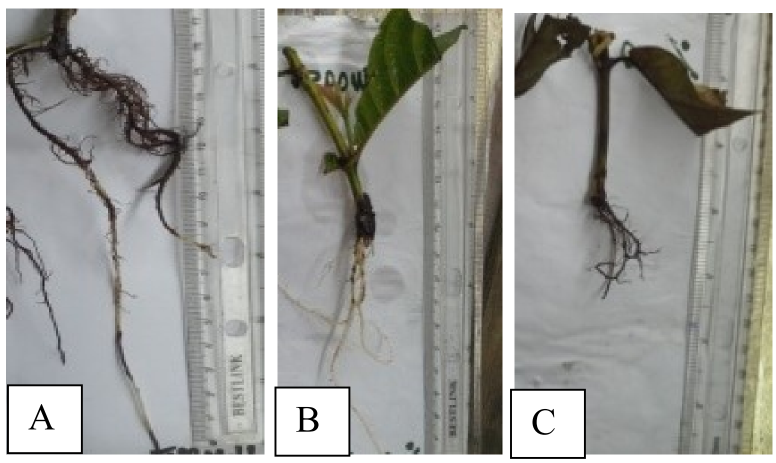

Fig. 22: Rooted stem cuttings of *Massularia acuminata* using Naphthalene acetic acid (A), Coconut water (B) and Indole-3-butyric acid (C).

Fig. 23: Rooted stem cuttings of *Massularia acuminata* using different concentrations of Naphthalene acetic acid.

Fig. 24: Plantlets of *Tetrapleura tetraptera* grown in culture media (*in vitro* propagation).

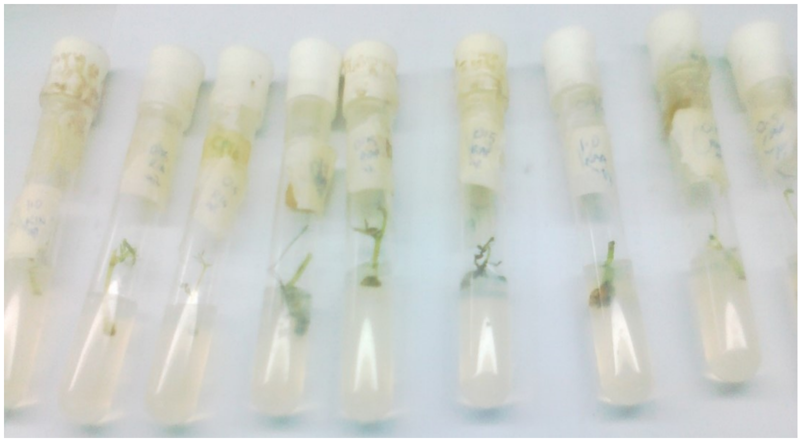

Fig. 25: Eight weeks old axillary and apical nodes of *Parkia biglobosa* at 2 weeks after inoculation.

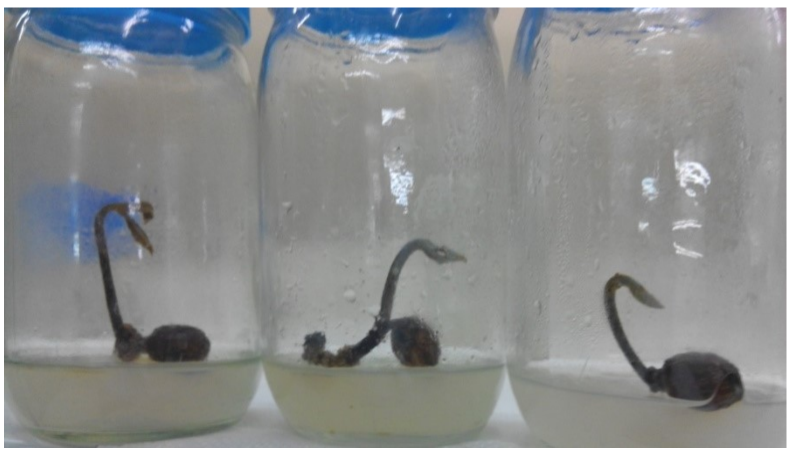

Fig. 26: *In vitro* germination of *Pycnanthus angolensis* in different combinations of growth media

Another aspect of my research focused on the response of indigenous tree species to various environmental factors, providing insights into their growth and development under future climatic conditions. Specifically, the effects of arbuscular mychorriza, water status, and inorganic fertiliser on selected species, under varying environmental conditions, highlight their limiting effects on the biology and productivity of the plants. My efforts have yielded procedures for enhancing the growth of these species in the nursery before they are transferred to the field. Hence, appropriate pre-treatment methods, sowing media and light intensity requirements for seed and seedling growth have been developed.

For instance, *Tetrapleura tetraptera* (Schum. and Thonn.) is a species with great potentials for environmental protection. It is well-recognised for its timber and non-timber products especially in its application in medicine and nutrition. Akinyele and Wakawa (2017) investigated the response of the species to soil, water and light with a view to domesticating and introducing the species in different ecological regions of Nigeria. *Tetrapleura tetraptera* exhibited some level of tolerance to varying soil texture, drought and light intensities (table 12). Therefore, the species has the potential for growth in different ecological zones characterised by difference in soil, rainfall and light intensity. However, since this research was only on early growth studies, the information may not be adequate to categorically recommend the species for domestication and introduction to different ecological zones. Further research that would expand the scope over a wide spatial and temporal scale has been proposed.

Table 12: Responses of *Tetrapleura tetraptera* Seedlings Under varied Environmental Factors

	Mean										
	CD	***SH***	***NL***	***RL***	***R/S***	***CHL* a**	***CHL* b**	***CHL* a/b**	***TCHL***	***LRWC***	***RGR***
Soil textural class											
Loamy sand	2.282^{a}	12.898^{a}	19.929^{a}	22.011^{a}	0.964^{b}	0.121^{a}	0.342^{a}	0.454^{a}	0.463^{a}	27.444^{a}	0.037^{a}
Sandy clay loam	2.213^{b}	10.571^{b}	13.061^{c}	22.456^{a}	1.516^{a}	0.126^{a}	0.306^{a}	0.427^{a}	0.431^{a}	25.111^{a}	0.030^{b}
Sand	2.157^{b}	11.073^{b}	15.457^{b}	23.544^{a}	1.079^{b}	0.161^{a}	0.33^{a}	0.574^{a}	0.497^{a}	22.111^{a}	0.036^{a}
Watering regime											
Daily	2.250^{a}	11.144^{a}	15.929^{a}	20.889^{a}	1.143^{a}	0.153^{a}	0.321^{a}	0.52^{a}	0.474^{a}	26.111^{a}	0.035^{a}
Twice a week	2.240^{a}	11.529^{a}	15.714^{a}	22.844^{a}	1.137^{a}	0.153^{a}	0.314^{a}	0.599^{a}	0.468^{a}	24.556^{a}	0.035^{a}
Once a week	2.148^{b}	11.451^{a}	16.804^{a}	24.278^{a}	1.279^{a}	0.107^{a}	0.342^{a}	0.337^{a}	0.448^{a}	24.0^{a}	0.033^{a}
Light intensity											
100%	2.284^{a}	12.284^{a}	15.699^{a}	23.0^{a}	1.481^{a}	0.136^{a}	0.318^{a}	0.493^{a}	0.453^{a}	28.667^{a}	0.035^{a}
75%	2.259^{a}	11.588^{a}	16.585^{a}	22.367^{a}	1.022^{b}	0.123^{a}	0.324^{a}	0.477^{a}	0.447^{a}	24.889^{a}	0.032^{a}
50%	2.106^{b}	11.810^{a}	16.162^{a}	22.664^{a}	1.056^{b}	0.154^{a}	0.336^{a}	0.486^{a}	0.490^{a}	21.111^{a}	0.036^{a}
Soil×Light											
Loamy sand×100%	2.465^{a}	13.254^{a}	21.158^{a}								
Loamy sand×75%	2.262^{b}	12.739^{a}	20.168^{a,b}								

Table 12 Contd.

Loam sand×50%	2.121^{e}	12.702^{a}	18.461^{b,c}								
Sandy clay loam×100%	2.237^{b,c}	10.745^{b,c}	12.357^{e}								
Sandy clay loam×75%	2.268^{b}	10.154^{c}	13.543^{e}								
Sand clay loam×50%	2.133^{c,e}	10.025^{c}	13.284^{e}								
Sand×100%	2.150^{b,e}	11.983^{a,b}	13.584^{e}								
Sand×75%	2.248^{b}	11.212^{a,b}	16.045^{d}								
Sand×50%	2.071^{e}	10.813^{b,c}	16.741^{c,d}								
LSD (0.05)	*0.628*	*1.387*	*4.099*	*3.910*	*1.377*	*0.053*	*0.096*	*0.288*	*0.122*	*10.673*	*0.004*

Note: CD, Collar diameter (mm); *SH*, Stem height (cm); *NL*, Number of leaflets, Root length (cm); *R/S*, Root/shoot ratio (cm); *TCHL*, Total chlorophyll (mg mL^{-1}); *LRWC*, Leaf relative water content (%); *RGR*, Relative growth rate (mg g^{-1}).

Artocarpus heterophyllus Lam. (Jackfruit) is one of the largest fruits in the world, valued for the heavy yield of nutritious fruits and durable timber. In Nigeria, it either grows in the wild or it is semi-conserved. Morphological and physiological response of *Artocarpus heterophyllus* seedlings to different light intensities and watering regimes have been carried out (Bolanle-Ojo et al. 2018). The findings revealed that the species could be raised in the nursery under different light intensities and limited moisture (tables 13 & 14). This is because the height and other growth parameters of *A. heterophyllus* as well as biomass accumulation did not depend on the light intensities or moisture received at early growth stage (fig. 27). The propagation and availability of this species will allow its sustainable use in food security, and medicine, thus improving human health status, income generation and carbon sequestration.

Table 13: Effect of Light intensity and Watering Regime on Seedling Height, Number of Leaves and Collar Diameter of *Artocarpus heterophyllus*

Light intensity	Watering regime	Plant height	Number of leaves	Collar diameter
L1	W1	37.82	5.95	5.03
	W2	42.61	6.48	5.12
	W3	41.97	6.7	5.19
	W4	41.15	6.57	5.01
L2	W1	36.8	6.16	4.77
	W2	41.41	6.33	4.74
	W3	43.64	6.4	4.81
	W4	42.95	6.31	4.72
L3	W1	38.19	5.96	4.66
	W2	43.14	6.46	4.78
	W3	40.03	6.25	4.38
	W4	42.8	6.06	4.61
L4	W1	40.13	5.85	4.48
	W2	40.41	5.93	4.31
	W3	39.39	5.89	4.4
	W4	35.5	5.81	4.29

Table 14: Effect of Light Intensity and Watering Regime on Shoot: Root Ratio of *Artocarpus heterophyllus* Seedlings

Light intensity	Watering regime	1st month	2nd month	3rd month	4th month
L1	W1	01:01	02:01	03:01	02:01
	W2	01:01	02:01	03:01	02:01
	W3	01:01	02:01	05:01	02:01
	W4	01:01	01:01	03:01	04:01
L2	W1	01:01	02:01	02:01	03:01
	W2	01:01	02:01	03:01	02:01
	W3	01:01	01:01	02:01	03:01
	W4	02:01	02:01	03:01	04:01
L3	W1	01:01	02:01	04:01	04:01
	W2	01:01	02:01	03:01	05:01
	W3	01:01	01:01	03:01	01:01
	W4	01:01	01:01	02:01	05:01
L4	W1	02:01	02:01	02:01	04:01
	W2	02:01	02:01	03:01	03:01
	W3	01:01	02:01	02:01	04:01
	W4	01:01	01:01	02:01	03:01

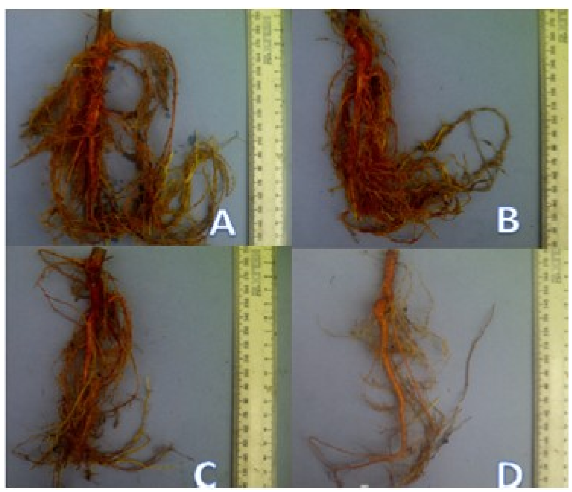

Fig. 27: Root accumulation of *Artocarpus heterophyllus* seedlings under different light intensities A: 100% light intensity, B: 75% light intensity, C: 50% light intensity and D: 25% light intensity.

My research activities on some other aspects have documented information on the silvicultural requirements for domestication of tree species such as *Afzelia africana* (Kareem et al. 2012) and *Terminalia superb* (Akinyele and Dada 2015) where we investigated the response of the species to mycorrhiza, watering regime and light intensity. Optimum storage duration and storage media for seeds of *Caesalpinia bonduc* (L.) Roxb (table 15; Kazeem-Ibrahim et al. 2012), *Albizia lebbeck* (L.) Benth. and *A. odoratissima* (L.F.) Benth. (Akinyele and Ajayi 2017) were reported. Adegoke et al. (2014) reported the effect of seed size and source on early seedling growth of *Terminalia ivorensis* (Chev.) while Akinyele et al. (2016a, b) and Oyedeji and Akinyele et al. (2016) investigated the effects of different sowing media, watering regimes and light intensity on the growth of *Entandrophragma cylindricum* (Sprague), *Annona muricata* Linn. (table 16) and *Dialium guineense (*Willd*)* (table 17), respectively. Other areas of investigation include provenance variation of seed and seedlings of *Jatropha curcas* L. (JCL) in South Western Nigeria (Akinyele and Salami 2014), seed pre-sowing treatment methods to improve germination of *Dacryodes edulis* (fig. 28; Akinyele and Orosun 2010) and *Tetrapleura tetraptera* (figs. 29 and 30; Akinyele and Onasanya 2014; Wakawa and Akinyele 2016).), response of *Khaya senegalensis* (Akinyele et al. 2013) and *Treculia africana* Linn (Salami et al. 2015) to inorganic fertilizer treatment, and many others. This information is particularly important for the management of the natural and artificial forest ecosystems, where many of these species are found.

Table 15: Effect of Storage Duration and Temperature on Seed Germination of *Caesalpinia bonduc*

	Mean Daily Germination	Peak Value	Germination Value	Germination Percentage
Duration Control	0.33±0.005[ab]	0.33±0.05[a]	0.45±0.01[ab]	20.00±0.00[b]
2 months	0.35±0.02[bc]	0.35±0.15[a]	0.48±0.03[b]	19.75±0.25[b]
4 months	0.37±0.02[c]	0.38±0.01[b]	0.57±0.04[c]	19.25±0.31[b]
6 months Period	0.31±0.01[a]	0.32±0.02[a]	0.39±0.03[a]	17.62±0.92[a]
Cold temperature	0.35±0.01	0.36±0.01	0.51±0.03	19.75±0.17
Room temperature	0.33±0.01	0.33±0.18	0.43±0.02	18.56±0.52

Note: Means with the same superscript alphabet in a column are not significantly different at 5% probability level.

Table 16: Mean Plant height, Collar diameter and Number of leaves for *Annona muricata* across Potting Media

Treatment	Height (cm)	Collar diameter (mm)	Number of leaves
T_1S	4.78±0.07[b]	2.86±0.07[d]	3.20±0.03[d]
T_1D	10.96±1.02[a]	4.48±0.09[a]	8.70±0.07[a]
T_2S	3.71±0.04[c]	3.64±0.06[b]	4.10±0.04[d]
T_2D	5.19±0.07[b]	3.03±0.01[c]	6.00±0.08[b]
T_3S	0.92±0.02[f]	2.82±0.05[c]	0.20±0.00[g]
T_3D	2.15±0.03[d]	2.18±0.03[e]	1.40±0.01[f]
T_4S	1.18±0.04[e]	1.54±0.02[e]	0.30±0.01[g]
T_4D	2.67±0.03[d]	2.94±0.04[c]	2.20±0.02[e]
T_CS	4.41±0.05[b]	2.52±0.05[d]	5.20±0.05[c]
T_CD	2.17±0.07[d]	3.48±0.06[b]	2.50±0.03[e]

Mean carrying the same alphabet along the same column are not significantly different ($p \leq 0.05$) from each other
T_1= 63.6% topsoil: 27.3% granite: 9.1% green manure; T_2 = 45.4% topsoil: 27.3% granite: 27.3% green manure
T_3 = 27.3% topsoil: 27.3% granite: 45.4% green manure; T_4 = 9.1% topsoil: 27.3% granite: 63.6% green manure
Tc Control = 77.0% Topsoil, 33.0% granite; S = single node cuttings; D = double node cuttings

Table 17: Relative Growth Rate of *Dialium guineense S*eedlings Under different Light Intensities (g/wk)

Intensity	2 – 4	4 – 6	6 – 8	8 – 10	10 – 12
Relative growth rate					
L1 (100%)	0.9714	0.0120	0.0176	0.0092	0.0518
L2 (75%)	0.2342	0.0124	0.0303	0.0427	0.0628
L3 (50%)	0.3019	0.0447	0.0147	0.0768	0.0410
L4 (25%)	0.3696	0.0654	0.0020	0.0326	0.0529
Absolute growth rate					
L1 (100%)	0.2810	0.0080	0.0120	0.0060	0.0360
L2 (75%)	0.0965	0.0065	0.0165	0.0230	0.0345
L3 (50%)	0.0485	0.0100	0.0035	0.0200	0.0120
L4 (25%)	0.0580	0.0155	0.0005	0.0085	0.0300
Net assimilation rate					
L1 (100%)	0.0373	0.0008	0.0013	0.0008	0.0021
L2 (75%)	0.0357	0.0029	0.0046	0.0045	0.0065
L3 (50%)	0.0226	0.0034	0.0008	0.0072	0.0043
L4 (25%)	0.0221	0.0070	0.0002	0.0079	0.0065

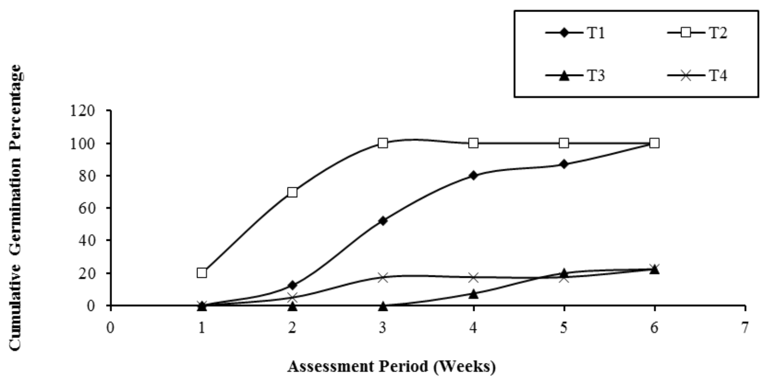

Fig. 28: Cumulative germination percentage of *Dacryodes edulis* seeds under different pre-treatments across the assessment period.

T1 = Depulped seed with seed coat; T2 = Depulped seed without seed coat; T3 = Seed planted without depulping; T4 = Decayed seeds

Fig. 29: Cumulative germination percentage of *Tetrapleura tetraptera* using different sowing media.

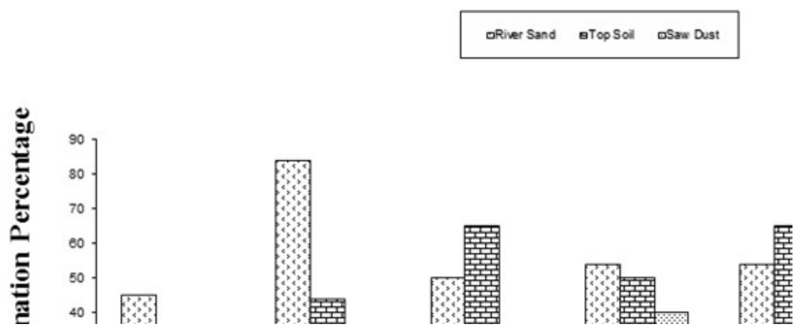

Fig. 30: Effect of sowing media and seed pre-treatment on germination percentage of *Tetrapleura tetrapleura.*

Institutions of Collaboration for my Research

I have had the privilege of collaborating with the following institutions locally and internationally on different aspects of my research.

(1) Florida Agricultural and Mechanical University, Tallahasse, USA
(2) University of Florida, Gainesville, USA
(3) Bangor University, Wales, United Kingdom
(4) Technische Universitat, Dresden, Germany
(5) Cranfield University, United Kingdom
(6) University of Cambridge, United Kingdom
(7) Wageningen UR, The Netherlands

(8) Moi University, Kenya
(9) Forestry Research Institute of Nigeria
(10) National Horticultural Research Institute
(11) Institute of Agricultural Research and Training, Moor Plantation
(12) Cocoa Research Institute of Nigeria
(13) National Center for Genetic Research and Biotechnology
(14) International Center for Genetic Engineering & Bio-technology, National Biotechnology Development Agency, Abuja.

Conclusion

The domestication of tree species for indigenous plantation establishment has been a major thrust of my research endeavour. It is hoped that plantations of such valuable species could potentially provide alternative sources of income generation for the general populace. This will improve their livelihoods and alleviate poverty in many communities in Nigeria. In particular, rural women who are mainly involved in the production, processing, and marketing of Africa's forest products, could benefit immensely from the domestication of these species. My research on the improvement of targeted indigenous tree species has impacted on the sourcing, quality and availability of planting materials. These could increase the contribution of these forest resources to food security and rural poverty alleviation. The multipurpose nature of the indigenous tree species would ensure that they provide numerous benefits such as food, energy, and income, while acting as a safety net during hard times. In addition, scientific knowledge and documentation would influence the choice of species, for restoration of degraded lands. The reduction of the gestation or rotation age of indigenous tree species through improvement could encourage private investment in plantation forestry. This would reduce the pressure on natural populations, thus curtailing the erosion of forest genetic resources. It would also promote planned tropical ecosystem conservation strategies that would be influenced by the development of relevant policies.

Tropical forests are centres of high biological diversity with most tropical trees showing a high level of intraspecific diversity. My studies have contributed to the conservation of the genetic diversity of indigenous tree species which are endangered and under threat of extinction. It is possible to manage forests sustainably, restore degraded forests and increase the global forest area, so as to avoid potentially damaging consequences for the planet and all its inhabitants. From tackling poverty and hunger to mitigating climate change and conserving biodiversity, the impacts of forests and trees go well beyond SDGs to contribute to achieving multiple goals and targets across the 2030 Agenda. Managing forests sustainably benefits both urban and rural communities and is essential to the planet's healthy and productive future. Domestication of indigenous tree species contributes to sustainable development by enhancing their conservation and preventing them from going into extinction thereby preserving them for posterity. The needs of the present would be met without compromising future generations' ability to meet theirs.

Recommendations

- Identification of tree species for domestication should be carefully done to ensure that the most promising species are selected.
- Biological characteristics that hasten domestication and improvement process in trees species should be evaluated. For example, intra-specific variation, rapid early growth, early flowering and seed set, ease of propagation (including vegetative propagation) and short rotation age.
- Provenance or species trials that would provide baseline information on the most suitable seed sources are required for many promising species.

- Documentation of indigenous knowledge on indigenous tree species would aid selection and the development of suitable propagation techniques need to be documented.
- Multidisciplinary and collaborative approaches involving biological and social scientists should be encouraged to ensure better progress in the domestication of tree species.

Appreciation

'He raised me up, so I can climb on mountains, He raised me up to walk on stormy seas; I am strong when I am on His shoulders, He raised me up to more than I can be'.

My first appreciation goes to my Heavenly Father, the Maker of the heaven and the earth, the One who calls those things that be not as though they are. He calls me His own and I am precious in His sight. He has been ordering my steps in the path of destiny and for that, I am eternally grateful.

I recognise the trust bestowed on me by my Dean, Professor B.O. Omitoyin and my Head of Department, Professor O.Y. Ogunsanwo. It is indeed a great honour for me to present the first faculty lecture on behalf of the Faculty of Renewable Natural Resources, University of Ibadan. I am forever grateful to my Ph.D. supervisor, Late Dr. Oluwatayo Oni for his fatherly role during my M.Sc. programme and in the course of my Ph.D. research. I am also grateful to my teachers, Professor S.O. Bada and Professor Adebola O. Adegeye, who completed the supervision of my PhD thesis at the demise of Dr. O. Oni; and my Ph.D. internal/external examiner, Prof. A.O. Togun, who monitored my academic progress over the years. I also appreciate the roles played by Emeritus Professor S.K. Adeyoju, Emeritus Professor D.U.U. Okali, Professor J.S.A. Osho, Professor Labode Popoola, Dr. L.A. Adebisi and many others.

I sincerely acknowledge the contributions of all the staff and colleagues in the Department of Forest Production and Products; and the Department of Social and Environmental

Forestry. I appreciate Professor B.O. Agbeja, Professor A.O. Oluwadare, Professor A.O. Omole, Professor S.O. Jimoh, Professor O.I. Ajewole, Dr. I.O. Azeez, Dr. S.O. Olajuyigbe, Dr. O.F. Falade, Dr. A.O. Alo, Mr. A.O. Onefeli and Mr. F.N. Ogana. They made the work environment very conducive. I thank Professor R.O. Awodoyin, Professor S.O. Jimoh and Dr. S.O. Olajuyigbe, who out of their busy schedules still made time out to proofread the manuscript of this lecture. I appreciate the contributions of Dr. O.A. Abimbade and Dr. Adetunmibi L. Akinyemi, Educational Technology Unit, Department of Science and Technology Education, for the design of the faculty lecture visual presentation.

I appreciate my students who have in one way or the other, contributed to the success of this lecture. They include Drs. D. Akinyemi, O. Ogunwande, O.A. Okunlola, K.D. Salami, Mr. I.N. Abdullahi, A. Adaja, P. Agwu, O.A. Akinrinola, T. Bolanle-Ojo, G.I. Dada, A.A. Kareem, O. Omidun, O.D. Onasanya, A. Onefeli, O.F. Oyedeji, J.T. Riki, F. Yakubu, Mrs. F.F. Adegoke, F.B. Adesokan, A.M. Adzandeh, O. Ajayi, S. Alonge, E.A. Awosan, O.A. Bello, F. Kazeem-Ibrahim, I.A. Usman; Ms B.O. Orosun, B.O. Maradesa and I.V. Mbadikwe.

I appreciate the support of the University of Ibadan Women's Society (UIWS), and in particular, members of Agro Impact Projects Empowerment Initiative as well as the Organisation for Women in Science for the Developing World (OWSD), University of Ibadan chapter.

I appreciate the fellowship of the Jesus' people, Ibadan Varsity Christian Union Alumni Fellowship; and New Covenant Church. I celebrate my loving parents, Late Prince Emmanuel Adegoke and Mrs. Janet Ibidun Onibokun; and Late Pa Phillip Ayinla and Mrs. Margaret Modupeola Akinyele. My biological parents sacrificed a great deal for every one of their EIGHT girls to be who we are today while my parents-in-love welcomed me wholeheartedly as a daughter in their home. I am grateful for the tremendous support I get from my brothers and sisters of the Onibokun clan – Mr. Adesola and Mrs. Adebukola Jebutu, Dr. Vincent and Dr. Adefoyeke Aduramigba-Modupe, Dr. Sunday and Dr. Adetunmibi Akinyemi, Dr. Samson and Dr. Kehinde Olanipekun, Professor Olusola and Dr Taiwo Ojurongbe, Mr. Olatunde and Mrs. Adebola Folorunso, and Miss Tolulope Onibokun; the Akinyele clan – Mr. Olalekan and Mrs. Ruth Akinyele, Mr. Abayomi and Mrs. Abosede Bamgbade, Mr. Oluseun and Mrs. Olayinka Raji. You are simply the best.

I am especially grateful for the overwhelming support I get from the home front. I have the full backing of my beloved husband, Engr. Dr. Joseph Olawale Akinyele and our children, OreOluwa, OoreOluwa and AdeOluwa. With God on our side and with them cheering me on, the sky is not our limit, but our stepping stone!!!

To Him who is able to do exceedingly, abundantly, above all that I could ever dream or imagine, be all the glory, honour and praise, forever and ever, Amen.

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