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THE IMPACT OF CLIMATE CHANGE ON THE MANAGEMENT AND REGENERATION OF PARKLAND TREES IN THE SAVANNAH ZONES OF NORTHERN NIGERIA

PRIFYSGOL BANGOR UNIVERSITY

A thesis submitted to Bangor University for a degree of Doctor of Philosophy (PhD) in Agroforestry

By

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DEDICATION

To

Hauwa Sha'aban Abdullahi (1962-2019)

For having me as her first child and raising me to a man. May ALLAH (SWT) bless her soul. Amin

and

Professors ChukwuEmeka Omaliko and Adebayo Salako

For showing me the honour in teaching and research career, I am forever grateful to these retired but not tired gentlemen

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ABBREVIATIONS

Agroecological zone	AEZ
Agroecological zones	AEZs
Nigeria Meteorological Agency	NIMET
Northern Guinea savannah	NGS
Sudan savannah	SS
Southern Guinea savannah	SGS

SUMMARY

In Northern Nigeria, the savannah parklands are mixed dryland agroecosystems having landscape productivity and deforestation challenge, induced by the changing climate and affecting sustainable livelihoods. The productivity of parklands is attributed to different factors such as erratic precipitation, drought and plant mortality. Here, the study predicts the impact of climate change on tree regeneration on parklands of three savannah agroecological zones (AEZs), namely the Sudan savannah (SS), Northern Guinea savannah (NGS) and Southern Guinea savannah (SGS) AEZs across a north-south transect using a multidisciplinary approach. The approach involves the employment of Random Forest model framework to predict the future shift in AEZs from the current climate using bioclimatic variables and climatic scenarios. Three random predicted locations within each studied AEZ identified as drought-threatened areas were selected for tree preference and identification study by analysing local farmer ethnobotanical knowledge of their favourite species, before tree identification and estimation of diversity and abundance of the current parkland species on farms in the respective local communities. The research further predicted the future distribution of selected important species using Maximum Entropy and assess the efficacy of simple propagation methods (cuttings and marcotting) on respondents' farms, after an extreme drought survival test in a greenhouse. The results showed that agroecological zones are getting warmer and drier southwards, replacing the current NGS and SGS with SS between 2050 and 2070, by up to 65%. *Parkia biglobosa, Mangifera indica and Vitellaria paradoxa* are the top-ranked species by 90% of the 92 respondents in the study and are the most abundant species on farmers' field with relative species dominance ranging from 19.61-42.64%. The strong relationship between species preference and abundance increases northwards. On the future distribution and improvement of parkland species to survive under stress conditions. Maximum entropy model predicted a north-eastern shift for future spatial species distribution of *Parkia biglobosa* and

Vitellaria paradoxa under most extreme climate scenario. For tree species at jvenile stage to survive under 6 months drought regime, the research indicated that 9months old *Parkia biglobosa* seedling from SGS resisted more than other species at different ages from different AEZ species. On local adaptation strategy to improve parklands survival, there were up to 40% and 38% success rate of vegetative propagation of *Anarcadium occidentale* using cuttings and marcotting, respectively.

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CHAPTER ONE: INTRODUCTION

1.0 BACKGROUND OF THE STUDY

The parklands form the agricultural landscape in the savannah zones of West Africa sub-Sahara region where food and cash crops are cultivated under the cover of dominant, but sparsely distributed trees (Bayala *et al*. 2015, Bayala, *et al.* 2014). They provide a range of ecosystem services that enhance livelihood resilience and sustainability among sub-Saharan communities of sub-humid and semi-arid zones (Popoola 2016, Sinare and Gordon 2014, Farauta *et al.* 2011). Nigeria is a country in sub-Saharan Africa endowed with rich tropical savannah biodiversity transecting from the semi-arid plains at the northern borders with the republics of Chad, Cameroon and Niger through dry and wet forests in the central and western parts to the wet mangroves spreading across the Niger-delta in the south (Oni 2014, Judy 2013). The transect forms the classification of the agroecosystems into seven agroecological zones (See figure 1) but the sharp depletion (over 5.5% annual deforestation rate) in biological resources in the early 1990s induced by drought, land degradation and urbanisation made government recognise climate change as a problem (Bone *et al.,* 2017*;* Félix *et al.,* 2015; Minang *et al.,* 2014). The distribution and species composition of Nigeria's parklands changes along a south-north transect and the vegetation thicken southwards. This is from the major savannah agroecological zones in the south, the Southern Guinea savannah, through the Northern Guinea savannah to the Sudan savannah in northern Nigeria (Karlson and Ostwald 2016; Gbadegesin and Akinbola 1995). Local communities have managed parklands across all zones and utilize trees for food, fodder, fuel, and medicine to treat common tropical diseases (Faye, 2010).

One-third of the tree species found in West African savannahs are threatened or under extinction due to predicted changes in climate (Poudyhal 2009; Olsson *et al.* 2014), and local changes associated with a changing global climate have already impacted significantly on the survival of trees in farmlands (Vira *et al*. 2015; Ray *et al.* 2010; Lobell *et al*. 2011). Climate change impacts, such as erratic changes in rainfall patterns (Ogunbenro and Morakinyo 2014), increasing mean temperature (Eludoyin and Adelekan, 2013), increased variability both in temperature and rain patterns (IPCC 2015, Cooper *et al.* 2006), as well as soil fertility decline (Jemo *et al.* 2014, Odebiyi *et al.* 2004) affect agricultural production both directly in terms of yield, and indirectly through diminishing environmental sustainability (Palm *et al.* 2014, Iye and Bilsborrow 2013).

At the system level, a functional and sustainable agroecosystem can become less resilient to extreme climatic events such as drought (Berdanier and Clark 2015, Manley 2003), heat stress (Eludoyin and Adelekan 2013) and soil nutrient leaching (Lal, 2015) as a result of the reduction of trees on farmlands. This is because presence of trees increases agricultural productivity by over 30% (Luedeling *et al.* 2014, Mbow *et al*. 2014) and improve parkland-based livelihood strategies in West Africa (Bayala *et al.* 2015, Faye *et al.* 2010).

Without alternative livelihood strategies available to settled farmers, any negative changes in agroecosystem function are expected to lead increasingly to poverty and to resource availability-induced conflicts in these regions (Sayne 2011). Evidence suggests that over-exploitation and conflict have had severe impacts on the extent of parkland cover in semi-arid Nigeria, which has, in turn, exacerbated the frequency and intensity of drought in recent times (Abubakar and Yamusa 2013, NIMET 2015). The impacts of drought on ecosystems and agricultural productivity are complex (Carrão *et al.* 2016), and vary in different agroecological zones due to the vulnerabilities of the local population and of the ecosystem services on which they rely (Vicente-Serrano *et al.,* 2012, Rojas *et al.,* 2011). Currently, over 70 million people in Nigeria's savannah regions depend on parklands to maintain their livelihoods (FAN 2006, NPC 2006). This large and increasing population, combined with recent droughts, induces a downward spiral of land degradation, deforestation, desertification and poverty (Abubakar & Yamusa, 2013; Adeaga, 2013; Idinoba, & Ajayi, 2011).

Improving the parkland system's resilience to climate shocks requires not only straightforward area conservation measures, but also smallholder adoption of sustainable farming practices such as farmer-managed natural regeneration (FMNR) (Maisharou *et al.,* 2015). To date, government-sponsored approaches to break this spiral and mitigate the severity of drought have focused on improving the regeneration of trees, specifically through nursery propagation and encouraging semi-domestication of wildings. Whilst effective in principle however, these efforts have encountered significant problems:

(i) Tree multiplication trials have been conducted in nurseries by researchers without efficient linkages with farmers, resulting in selection of the "wrong" species in terms of farmers' preference and desirable quantitative traits (Yeboah, *et al*. 2009, Teklehaimanot, *et al*. 1996)

(ii) Poor propagation methods of parkland tree seedlings influence the composition of species and impedes mitigation efforts in recent times (Newton *et al*. 2015, Cooper *et al.* 2006, Leakey *et al*. 1999)

(iii) Semi-domestication, including the natural regeneration of wildings, inherently selects individuals that are suited to historical, rather than the present/future climate and tends to perpetuate vulnerability to drought stress rather than to select climate-adapted individuals. (Niang, *et al.,* 2014; Bouda, *et al.* 2013)

What is desperately needed is a clearer understanding of what settled farmers across the range of savannah parkland agroecosystems require, both now and under future climatic conditions, and how these needs can be met through well-targeted tree regeneration practices.

1.1 RESEARCH QUESTIONS

This study will answer the following fundamental question:

- What can Nigeria's dryland savannah communities learn from the experiences of others in locations where current climate is analogous to the future climate that the communities will likely experience?

This will be broken down into five more detailed questions:

- Which trees are most important for communities from across a North/South transect through the parkland savannahs?
- How are these trees currently managed within a parkland agricultural context?
- In what way is the climate experienced by settled farmers likely to change over the next century?
- How is changing climate likely to affect tree species suitability across the savannah systems?
- How do practices such as different propagation methods optimise tree root morphology to mitigate drought stress?

1.2 RESEARCH AIMS

The research project aims:

- To identify the most important tree species in farms across three savannah AEZ and how they are distributed
- To predict future climate for selected locations within each current agroecological zones (AEZ) of Nigeria
- To understand how predicted climatic changes might impact suitability for selected tree species
- To determine the impact of the selected trees' root morphology on seedling survival and drought resistance
- To examine the impact of propagation method on root morphology for the selected tree species

- To determine which species and practices may be transferable between locations to help settled communities adapt to shifting climate patterns

- To assess the efficacy of techniques and approaches in achieving the above research objectives

1.3 POTENTIAL KEY ACTORS AND BENEFICIARIES FROM THE RESEARCH

There are potential stakeholders benefiting from this research, either as influential landscape restoration policymakers at the regional level or as managers in sustainable forest strategies using local adaptation and mitigation to improve land-use resource. The key actors and beneficiaries from this research are outlined below:

1. Farmers: The restoration and regeneration of parkland trees will not only help store large amounts of carbon but also provide the multiple benefits of agroforestry practices for small scale farming men and women. This would reduce poverty, malnutrition and improved livelihoods. It would also increase the resilience to climate-related shocks and extreme weather events in the affected agroecological zones within Nigeria.
2. An emerging green business sector: There are many opportunities for dedicated farmers and landowners in terms of provision of seedling nurseries and tree services for parkland restoration. This would include setting up a local enterprise to earn extra income and ensure regular supply of seedlings for protection and restoration of agroecosystems. Hence, the creation of sustainable local job and plant material supply chain through local nurseries. This will also provide a niche for plant propagators, particularly the local women and vulnerable men in local communities to become experts of raising resilient seedlings.
3. Federal, States and Local Governments: This research findings would enhance land use maximization benefits and reduce trade-offs between different interests in

agriculture and forest management policy. This can be achieved if the government at different levels provide a framework for managing the multi-stakeholder challenges in achieving targets for parkland restoration and adaptation. Here, the findings revealed that connecting the climate nsure policy instruments and investments that put small-scale farmers, and especially women, at the heart. Promote that at least 10% of all existing agricultural land shall be covered by trees.

4. Development banks and Non-Governmental Organisations: This research highlights potential opportunities and investments for climate finance business and funding in agroecosystem restoration. This will include provision of business-oriented solutions to the communities affected in the agroecological zones. The solutions such as sustainable alternatives to energy crises, managing food insecurity and reversing environmental degradation.
5. The academic research community: The community would benefit through provision of independent methodological analysis and prediction of managing trees on farms, under future climate shocks. The predictions are spatial models that fill the gaps in multi-stakeholder links between policy and practice of managing tree regeneration and survival using data. This would be driven by results data from this research by identifying few key indicators that are important to tree regeneration and survival in local communities degraded parklands. The approach in this research is multidimensional. It will be useful for not only foresters but also specialists in agriculture, meteorology and other land-use managers.

The following schematic diagram shows the relationship between the components of the research, with a focus on the parameters that are essential to each of the research questions.

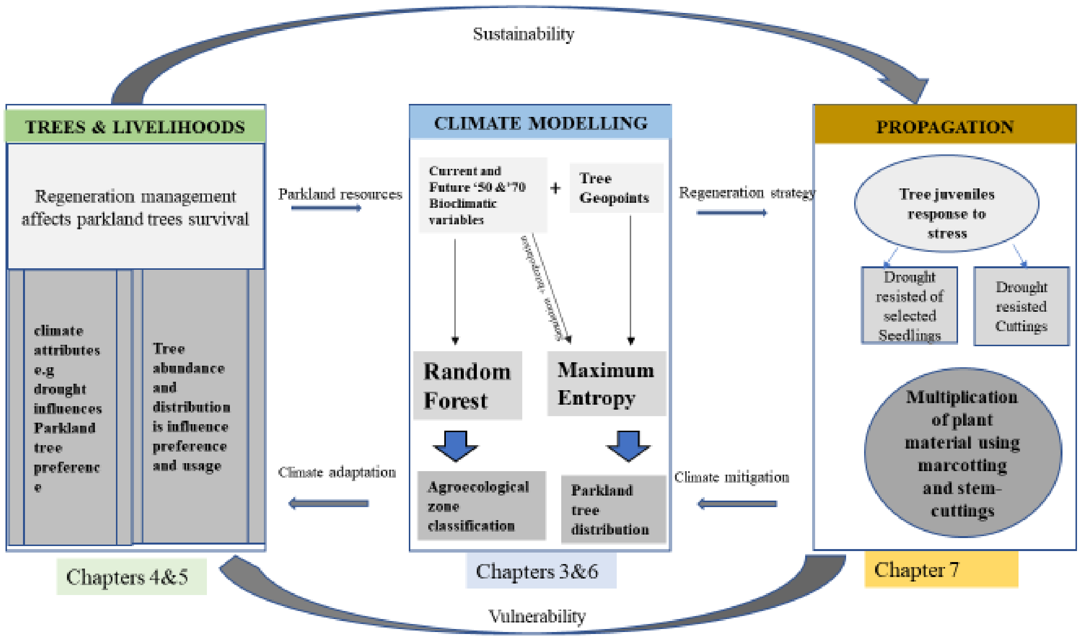

Figure 1.1: Schematic diagram showing the relationship of the research inputs in all chapters.

1.4 STUDY SITES DESCRIPTION

Nigeria, lying between latitudes 4–14°N and longitudes 2–15°E on the Gulf of Guinea occupies landmass of 923,766 km^2 (FGN, 1999) and can be divided into seven agroecological zones, namely Sahel savannah, Sudan savannah, Northern Guinea savannah, Southern Guinea savannah, Derived savannah, Mid-altitude and Humid forest (IITA, 2011). This classification is based on the similarity of climatic variables including the length of crop growth period, precipitation, temperature, farming systems and the natural vegetation (trees and shrubs distribution) (FAO, 1996; Isaiah, 2015). This project will focus on three savannah zones in Northern Nigeria, i.e. the Sudan Savannah, Northern Guinea Savannah, Southern Guinea Savannah. Figure 1.2 below is the map of Nigeria showing all the agroecological zones, where necessary, will also be used as the default map of this thesis for illustration in future references.

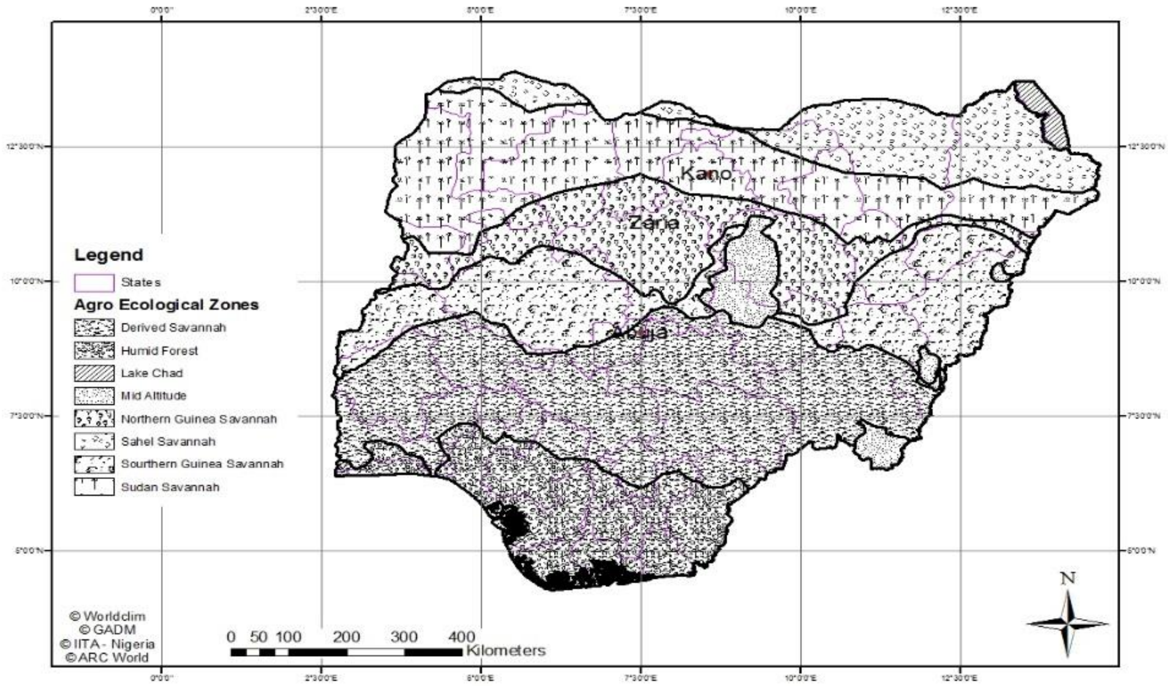

Figure 1.2: Map of Nigeria showing all the agroecological zones

1.4.1 Sudan savannah

The Sudan savannah (SS) zone is located in the Sokoto plains, covering over one-quarter of Nigeria's total area and stretching from the west, through the northern sections of the central highland bordering the Niger Republic (Plate 1). The average annual rainfall is low (less than 650mm) and the prolonged dry season (up to 9months) makes it susceptible to drought (Sowunmi and Akintola, 2010). Figure 1.3 is the graphical average annual climate data of Ringim, one of the locations of the research field study in Sudan savannah. Unlike the average summation of ten or more years data, the one-year climate data is shown to provide an insightful perspective on how precipitation and rainfall occur in specific locations under study.

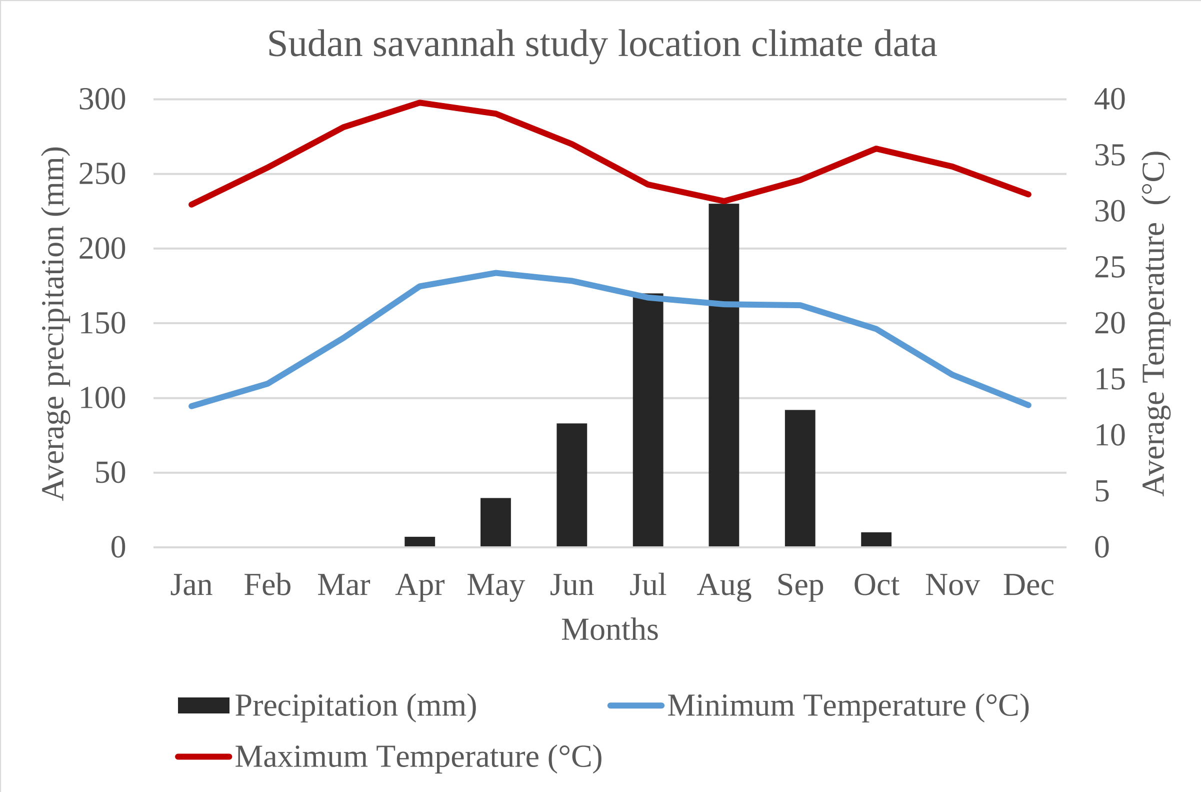

Fig. 1.3: Average annual precipitation and annual temperature of Sudan savannah. Location – Ringim (Source: Nigeria Meteorological Agency/climatedata.org-2017).

The SS is the most densely human populated zone of northern Nigeria (NPC, 2006) with about 12m tall scattered trees spread across the fields and stunt grasses of less 2m in height.The vegetation has undergone severe land degradation and desertification in the process of agricultural expansion and animal husbandry in recent times (Ja'afar-Furo, 2014). The trees of the Sudan savannah include the *Acacia senegal*, *Vitellaria paradoxa*, *Fairdehbia albida*, *Tamarindus indica*, *Adansonia digitata and Parkia biglobosa.*

Plate 1: Nigeria's Sudan Savannah parklands (Ringim, Nigeria) characterised with sparse vegetation with high temperature, high light intensity, low rainfall and low soil nutrients (Photo credit : Ibrahim Abdullahi).

1.4.2 Northern Guinea savannah

The Northern Guinea savannah (NGS) is the most extensive ecological zone in Nigeria, and when combined with the southern Guinea savannah, covers almost half of the Nigeria's land cover (Figure 1.2). The NGS belt is characterised as semi-arid and has a unimodal rainfall distribution with the average annual temperature and rainfall of 25 ºC and less than 900 mm respectively (Salako, 2003). It is characterized by the long dry period; rainfall begins at the end of April and ceases sometimes in October (Figure 1.4).

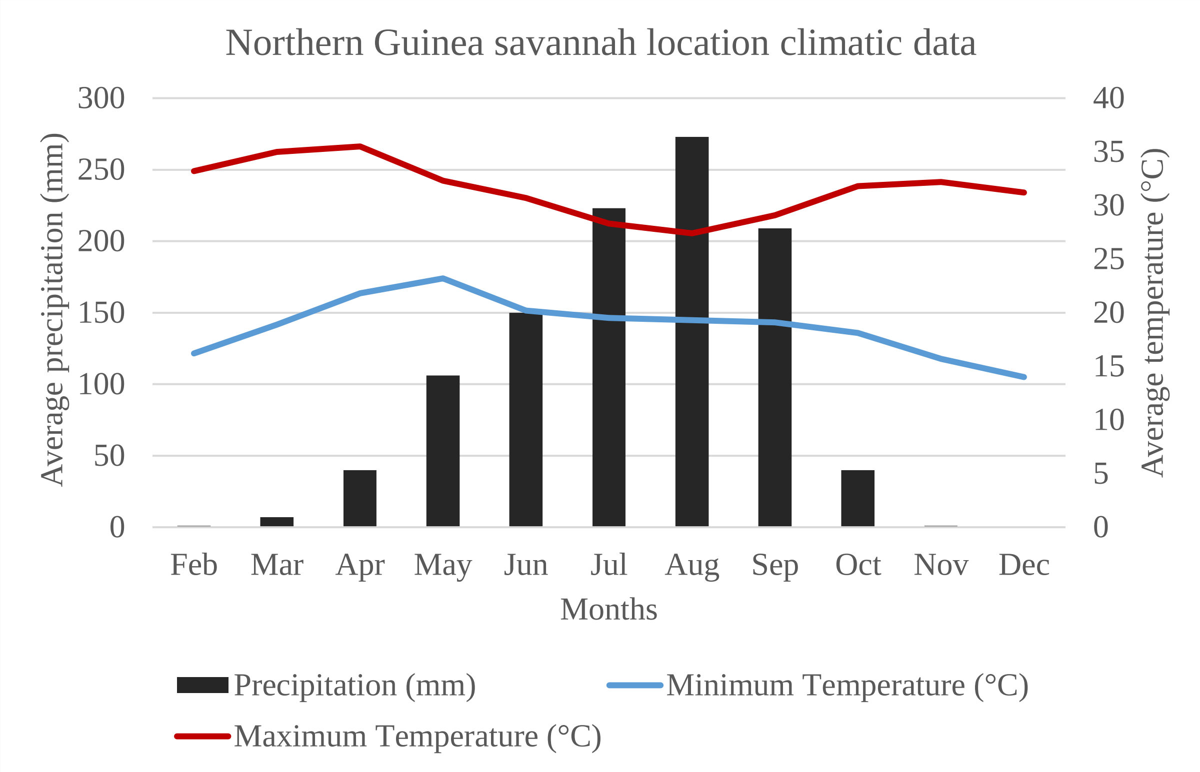

Fig. 1.4: Average annual precipitation and mean annual temperature of Northern Guinea savannah. Location – Zaria (Source: Nigeria Meteorological Agency/climatedata.org-2017)

The NGS is a mixture of shorter grasses and few trees of about 15m in height. The zone with its typically short trees and tall grasses is more luxuriant than the Sudan savannah. Species found in this zone include *Parkia biglobosa*, *Adansonia digitata*, *Vitellaria paradoxa*, *Balanites aegyptiaca.*

Plate 2: Nigeria’s Northern Guinea Savannah (Kaduna-Zaria expressway). The zone is best known for its agrisilvopastoral system on the parklands due to its potentials of combining climatic and edaphic factors of Sudan and Southern Guinea Savannah (Photo credit: Ibrahim Abdullahi).

1.4.3 Southern Guinea savannah

The Southern Guinea savannah (SGS) also has a bimodal rainfall pattern with annual precipitation at about 1300mm and a wet season that lasts for around 7- 9months. The precipitation peaks between the months of August and September, up to 250mm. Relative humidity and temperature are moderately high with an average of 70% and 28 degree Celsius respectively. The wet season is longer than the above-selected zones, Relative humidity is about 58% with medium to high evapotranspiration (Fig. 1.5)

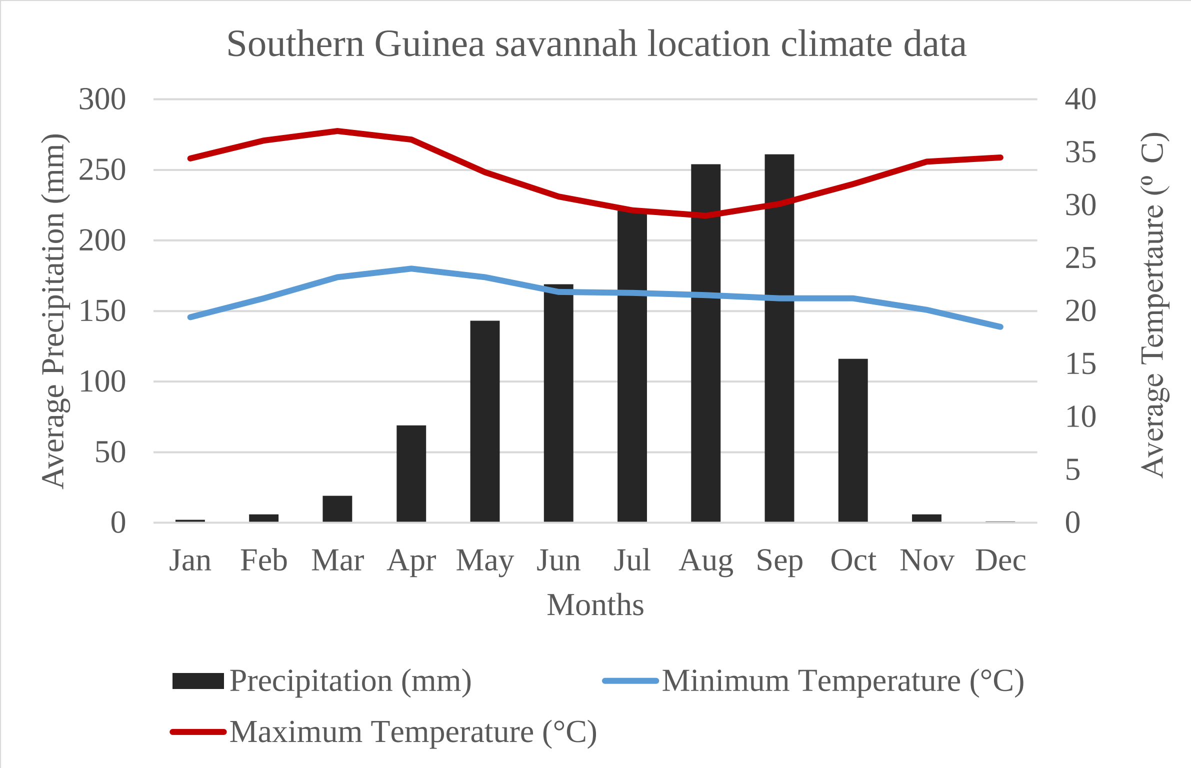

Fig. 1.5: Average annual precipitation (mm) and mean annual temperature (degree Celsius) of Southern Guinea savannah. Location – Abuja (Source: Nigeria Meteorological Agency/climatedata.org-2017)

The soils are luvisols (alfisols) with well drained sandy loam soils. Top soils in the zone are alfisols, mostly well drained brownish loamy sand soil with savannah woodland trees and shrubs forming a faint close canopy (Gbadegesin and Akinbola, 1995). The savannah zone is characterised with scattered savannah woodland trees, coppiced shoots, woody wildlings and shrubs forming a sparse canopy (Plate 3). Although the bulk of livestock found in Nigeria are distributed in the savannah zones as it transects northwards, woody vegetation and grasslands dominated the SGS landscape. The woody perennials with economic potentials include *Afzelia Africana, Parkia biglobosa, Vitellaria paradoxa, and Danillie oliveri*. Other exotic tree species dominating parklands in the zone are *Mangifera indica, Anarcadium occidentale, Moringa oleifera* and *Theobroma cacao*

Plate 3: Parkland of Southern Guinea Savannah of Nigeria (Sheda-Kwali, Nigeria). The zone is characterised with high rainfall, high temperature, dense grass vegetation and more woody regeneration. (Photo credit: Ibrahim Abdullahi).

1.5 SCOPE OF THIS RESEARCH

Time and financial constraints limited the accessibility and mobility to more than 3 locations and farms covered for each AEZ in the research. The insurgency in North-Eastern Nigeria as at the time the research was conducted, made the region no travel zone for civilians. So, it was difficult carrying out any research on the driest agroecological zone in northern Nigeria, the Sahel savannah.

1.6 THESIS OUTLINE

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CHAPTER TWO: 2.0 LITERATURE REVIEW

2.1 AGROFORESTRY PARKLANDS: PROSPECTS AND CHALLENGES IN SUB-SAHARAN AFRICA

Agroforestry parklands are landscapes in the tropical savannahs where scattered multipurpose trees are found on farmlands due to farmer's interest in selection and protection, basically for economic use (Hänke *et al.*, 2016; Leakey, 2014; Regmi, 2003). Over the years, savannah parklands have provided not only significant agricultural biodiversity and food security but also livelihoods, ecosystem resilience, cultural inheritance and aesthetic value to the landscapes for the millions living in the Sub-Saharan Africa (Djenontin *et al*. 2015, Larwanou and Saadou 2011, Faye *et al.* 2010, Regmi 2003, Boffa 2000). The significance of parklands in the savannah to improve farming systems for ecosystem services in recent times encountered setbacks. They include the restoration strategies on how to cope with the socioecological complexity of managing food security and sustaining agroecology in a changing climate (Maisharou 2015, Sinare and Gordon 2015, Schroth and Sinclair 2003). One of the major problems facing agroforestry parklands is the management of agroecosystem to withstand drought especially taking into account the adaptation and mitigation strategies for regeneration of the trees on farms (Bayala *et al.*, 2015; Ong *et al.,* 2014; Sohl and Ginkel, 2014; Nair, 2009; Schroth and Sinclair, 2003).

2.1.1 Agroecological classification of parklands

Many findings on climate change scenarios evaluate the effects on land use and agroecology change as the temperature and precipitation vary. They include local climate effects on parkland vegetation variability, particularly temperature and precipitation change on growth of field crops (Ohunakin *et al.,* 2015; Omotosho, 2008). Others are classification of agrometeorology for sustainable agricultural production at different stages using climate data suggested. For instance, Ogungbenro & Morakinyo (2014) used the rainfall characteristics and dry spell to classify the agroecology into zones I (Guinea), II (Savannah), and III (Sudan). The results showed tight and steep gradients for rainfall onset and cessation dates as well as seasonal length for zone I in Guinea savannah region. Zones II and III have spacious and scattered contours, respectively. Similarly, Bello (1995) and Odekunle *et al.,* (2005) classified agroecology of Nigeria using potential evapotranspiration and rainfall onset data for four zones from north to south; Sudan savannah, Northern Guinea savannah, Southern Guinea savannah and Forest regions but Odekunle *et al.,* (2005) further sub-divided the forest region into the rainforest and coastal regions. Furthermore, a detailed classification for sub-Saharan Africa agroecological zones using a length of growing season as the primary factor among other climatic factors by IITA (2000) was used to reclassify agroecological zones into deserts, arid zones, semi-arid zones, sub-humid zones, and humid zones in Seo (2014). In essence, rising temperatures and erratic precipitation are the major predictable factors used to model a spatial change in agroecosystems as it is affected by drought.

2.1.2 Nigeria's Agroecological zones characteristics

According to Isaiah (2015), Nigeria's agroecological zones (AEZ) are divided into eight classes. This spatial classification distribution of the agroecology is the same as shown in Nigeria agroecological zones map (figure 1.2) in Chapter 1. The climatic variables of the seven classified AEZs are briefly described, based on the climate data used as follows:

1. Sahel Savannah (SAS): Characterized with the highest annual temperature, up to 46 degrees celsius in the warmest month, lowest annual precipitation (less than 200mm), an extended dry season and the warmest quarter of the year (mostly in the 2nd quarter).
2. Sudan Savannah (SS): Sparse vegetation, scanty trees, major crops are cereals, the average annual temperature at 33°C and annual precipitation is less than 1500mm. Characterized by temperature seasonality deficiency with the lowest mean values for daily and annual temperature range. The AEZ had isothermality with the highest values, and the precipitation is low annually with a long dry season.

3. Mid Altitude (MA): Characterized by low minimum temperatures with minimum temperature seasonality on a high altitude. The zone had the lowest isothermality. The annual total precipitation is similar to SGS and has the coldest quarter of all groups and a three-four month dry season .
4. Northern Guinea Savannah (NGS): Transient between Sudan and Southern Guinea savannah vegetation, sparse trees, major crops are cereals and legumes, the average annual temperature at 30°C and annual precipitation is about 1500mm. Characterized by high temperatures except at cold month months with low temperatures. Though a long dry season is recorded in the zone, the annual total precipitation is the highest among the groups with the warmest quarter annually.
5. Southern Guinea Savannah (SGS): More grass and shrubs vegetation, densely scattered trees, major crops are cereals and tubers, average annual temperature at 27°C, annual precipitation is 1800mm. Characterized by temperature seasonality range. It had high isothermality, and very close mean values for annual temperature range. There is high annual precipitation and shorter dry season in comparison with NGS.
6. Derived Savannah (DS): Characterized with moderate tropical temperature, high annual precipitation, and very short dry season and a warmest quarter of the year.
7. Humid forest (HF): Characterized by the lowest minimum annual temperature of the coldest month but with a short dry season with the highest annual precipitation.

2.2 DROUGHT EFFECTS ON SAVANNAH PARKLANDS OF NIGERIA

Drought is the absence of moisture over a prolonged period due to lack of precipitation and high potential evapotranspiration (Adeaga 2002). Drought is known one of the most significant natural factors contributing to low soil fertility, malnutrition and poverty in the semi-arid lands of Nigeria (Olsson *et al.* 2014, Abubakar and Yamusa 2013, Farauta *et al.* 2011, Cooper *et al.* 2006). The potential impacts of drought in the region is affecting the economic and the environment. Reversing the impacts is dependent on certain factors, including tree regeneration management (Bayala *et al.* 2015, Faye *et al.* 2011, Otun & Adewumi 2009, Simons & Leakey 2004). Nigeria is in the tropical climate with variable dry and rainy seasons, warm temperature, and high evapotranspiration is depending on the local climate factors (Eludoyin *et al.* 2013, Abdulhamid 2003). However, most parts of Nigeria, like other regions of sub-Saharan African had poor record data on the trends of past annual precipitation, thereby creating an irreversible data gap and making scientific conclusions to improve ecological challenges very difficult (Otun and Adewumi 2009). Though reports available on rainfall variability (Ogungbenro and Morakinyo 2014, Oguntunde *et al.* 2011) and drought frequency and intensity (Oguntunde *et al.* 2014, Kayode and Francis 2012, Adeaga 2003, Otun and Adewumi 2009) in recent times are focusing on shortage of precipitation and increase in heat intensity. Government institutions have recognised that drought has been happening in the Sudano-sahelian zone of Nigeria for centuries, resulting from about 4% decrease in precipitation per decade over the last 100 years (FRN 2003). In 2013, Nigeria Meteorological Agency (NIMET) reported most parts of Nigeria experienced drought after a long cessation of precipitation and later, short duration but high-volume rainfall as seen in Figure 2.1 below. The map showed that the drought affected areas is spreading from semi-arid areas in the north-central region down to the hinterlands of rainforests in Southwest Nigeria. There scientific reports on the temporal and spatial occurrences of drought in Nigeria with different scenarios due to data gap., particularly the savannah zones. For instance, while most authors use a standard rainfall index that includes deviation of the cumulative precipitation from climatological average (Oguntunde *et al.* 2014, Abubakar and Yamusa 2013, Kayode and Francis 2012, Adeaga 2011, Adeaga 2003) to describe the occurrence and intensity at interval, others discussed the drought intensities and its effect (Kayode and Francis 2012, Shuaibu and Oladipo 1993) on the agroecology of Nigeria as a whole. Kayode and Francis (2012) employed the Bhalme and Mooley Drought Index

(BMDI) in Shuaibu and Oladipo (1993) to explain the classification of the degree of drought intensity using a simple descriptive method. The results of their finding showed that low intensity droughts of mild, moderate and unnoticed (1.5-2.5) are the closest index to classify the drought in the savannah regions of Nigeria, but the high intensity droughts of severe and extreme conditions might crop in to the Sudan savannah and gradually sweep downwards if control measures are not taken. Table 2.1 detailed the classification chart of drought intensity as mentioned above.

Table 2.1. Bhalme and Mooley Drought Index (BMDI) classification chart.

BMDI	Character of Anomalous Moisture Conditions
4.00 or more	Extremely wet
3.00 to 3.99	Very wet
2.00 to 2.99	Moderately wet
1.00 to 1.99	Slightly wet
0.99 to – 0.99	Near normal
- 1. 00 to – 1. 99	Mild drought
- 2.00 to – 2.99	Moderate drought
-3.00 to -3.99	Severe drought
-4.00 or less	Extreme drought

Adapted from Kayode and Francis (2012). Source: Shuaibu and Oladipo (1993).

Stakeholders from sub-Saharan Africa gathered in Namibia to focus on drought resilience and the impact of el-Nino. This led to declaring drought policy themes for Africa based on six principles – (i) Reduce exposure (ii) Reduce vulnerability (iii) Increase resilience to risk (iv) Transformation (v) Prepare, respond and recover (vi) Transfer and share of local ideas and strategies (*Windhoek Declaration* 2015). One of the above themes emphasised on the need for local knowledge on management and adaptation approaches to review the agroecological strategies of African communities at national levels.

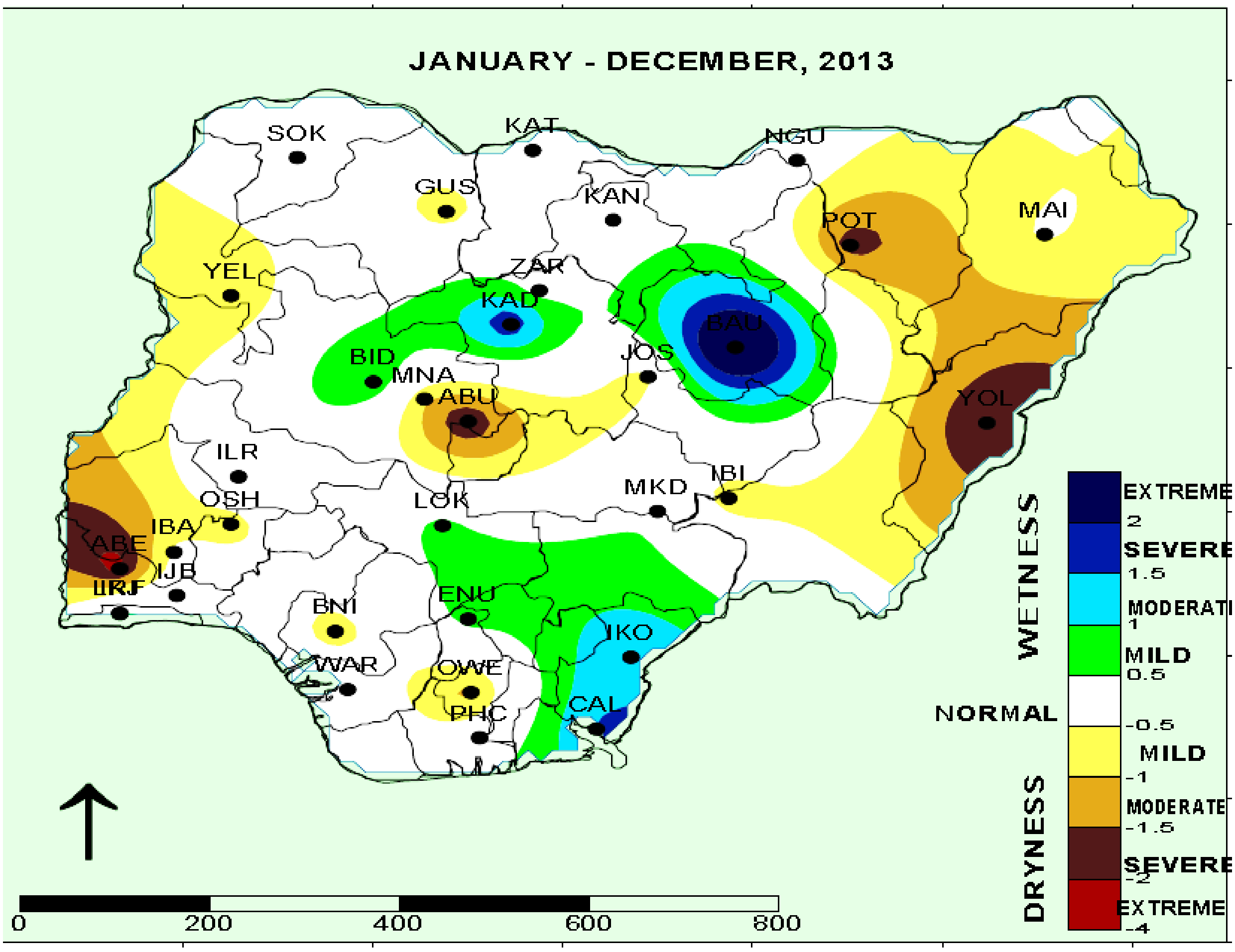


Fig. 2.1: Map of Nigeria showing 12 Months Standard Precipitation Index for groundwater drought (SOURCE: Nimet, 2013)

2.2.1 Effect of Drought on Tree Regeneration of Savannah Parklands

The ability of tree root to absorb and retain moisture from the soil is critical for their survival (Wilkinson *et al.* 2015). Tree integration into farming systems in savannah belts of Nigeria is known to increase fertility and moisture (Ogunkunle and Awotoye 2011). Research has showed that the understanding of farmers is not only limited to the management of tree utilization and regeneration to retain moisture in drought-related scenarios (Cline-Cole and Maconachie, 2016; Haglund *et al.* 2011) but also sustaining livelihoods (Amjath-Babu *et al*. 2016) and biodiversity potentials and valuation (Farnsworth *et al.* 2012, Iwu 1996).

In Nigeria, like other nations in sub-Saharan Africa, trees are regenerated and managed on farmlands using the popular approach termed Farmer Managed Natural Regeneration (FMNR) (Weston *et al*. 2015, Faye *et al.* 2010). FMNR involves the practice of active management and protection of mostly indigenous wildlings metamorphosing into trees and shrubs with the aim of adding to the quantity and value of perennials on parklands (Haglund *et al.* 2011). There are reports about how agriculture and forestry integration in the environment is improving land-use and land cover changes through FMNR (Bayala *et al.* 2015, FAO 2015, Wilhite *et al.* 2014). These include experts from FAO consulting farmers and pastoralists and concluding that trees outside forests contributes to sustainable livelihoods by over 50%, including conflict zones. The contribution is a shift towards ecologically sustainable land use management by the use of local strategies to regenerate and protect trees against drought effect on parklands in some parts of West Africa (Weston *et al*. 2015, Dile *et al.* 2013, Haglund *et al.* 2011, Clothier *et al.* 2010, Faye *et al.* 2010, Sinclair and Joshi 2000).

2.3 CLIMATE CHANGE ADAPTATION AND WHY THE FMNR APPROACH

Climate change has affected the agroecosystems in Nigeria in different ways. These range from environmental stresses leading to erratic precipitation and leaching (Oguntunde *et al.* 2011), increasing temperatures and decreasing relative humidity (Eludoyin *et al*. 2013), encroachment of desert sand dunes with desiccating winds (Akinbami *et al.* 2003), low soil fertility (Maconachie 2012), and drought susceptibility as a result of continuous cessation of rainfall over a long period of time (Oguntunde, *et al.* 2014, Badejo 1998). Together, these set producing severe limitations on tree growth and affect crop yield. Despite such stresses, local communities adaptation strategies often contain surprisingly large amounts of plant biomass by managing parkland tree species in order to sustain their livelihoods and provide functional agroecosystems (Sinare and Gordon 2014, Bouda *et al.* 2013). However, IPCC reports indicated the need for more commitment to landscape restoration through climate adaptation and mitigation requires financing in Africa (Niang *et al.,* 2014). This would include the provision of incentives for enhancement of trees outside forests for the greening of parkland landscapes, particularly in rural drylands of Nigeria (Maisharou *et al.,* 2015; Choudri *et al.,* 2013; Weston *et al.,* 2015).

FMNR as a resource-conserving approach for parkland trees is enhancing soil fertility through organic nutrient cycle and soil water retention, thus increasing yield and sometimes sustaining biodiversity (Bayala *et al.* 2014, Amonum *et al.* 2009, Teklehaimanot 2004, Hoffmann *et al.* 2001). But the increasing demand of wood and NTFPs for energy to sustain annual human population growth rate of Nigeria at 2.6% (as at July 2017) is not only unsustainable to juvenile perennial wildlings but also insufficient for curbing the deforestation and desertification rates (World Bank Report, 2017). Nigeria's forest evaluation unit estimated an average of 350,000 hectares of forest cover loss annually in the last 20 years, either through illegal logging or agricultural expansion (Ogbonnaya, 2003). The survival of young tree plants protected by farmers are impeded by pests and diseases as well as excessive heat waves in parkland landscapes (Cavers & Cottrell, 2012.; Eludoyin & Adelekan, 2013). As most important parkland trees are either classified as 'threatened' or 'endangered' and sometimes, 'vulnerable' species in the IUCN (2006) register.

2.4 PREDICTING CHANGE IN CLIMATE OF PARKLANDS USING CLIMATE MODELLING

In recent times, climate scientists have observed and predicted different climate and how the regions are changing and that trend still continues at a faster rate than 50 years ago (Pachauri *et al.* 2014). The observation has necessitated scientists to employ different statistical model, tools and software such as climate analogue (a tool developed by Walker Institute, UK to predict locations future climate in present time elsewhere), MaxEnt (popular spatial tool used in predicting species distribution using known environmental parameters) and other climatic modelling applications to predict the future of climate change (Ramírez-Villegas *et al.* 2011, Phillips *et al.* 2004). Different climate modelling approaches are important in identifying areas that have statistically similar climatic conditions, especially where extreme precipitation changes over time can lead to heavy rainfall and extended droughts. The model outcomes have been used to improve mitigation strategies for enhancing livelihoods and ecosystem resilience (Bunn *et al.* 2015, Phillips *et al.* 1997, Ramirez-Villegas *et al.* 2011). Statistical modelling tools also combine many variables such as bioclimatic data (rainfall and temperature), socio-economic data, soil characteristics, planting season time among others to provide information for researchers and other stakeholders (Mer 2012). For instance, climate analogues, just as MaxEnt, is the approach that locates a site whose climate today is similar to the given future of another location of interest (e.g where can we find today the future climate of Kano, Nigeria within the sub-region), or the other way round. However, the shift in agroecological zones in Nigeria are predictions due to changes in edaphic and socio-economic factors influenced by climate drivers requires more scientific evidence using different scenarios and approaches.

2.4.1 Observed and future projections of Nigeria climate trends

The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) explained the new scenarios that influence human and natural systems for adaptation and mitigation, after records showed up to 1 degree celsius increase in temperature globally in the last thirty years (1983-2013) (Casajus *et al.* 2016, IPCC 2015). The new scenarios are representative concentration pathways (RCPs) which are set of emissions as well as greenhouse gas concentrations designed to support the effects of potential policy responses as well as industrialization in a changing climate (IPCC 2000, IPCC 2015). The RCPs are tropical climate scenarios with four greenhouse gas concentration trajectories, namely RCPs 2.6, 4.5, 6.0, and 8.5 adopted by the IPCC for its fifth Assessment Report (AR5) in 2014. The RCPs effects are significant to land use and land use change (LULC), as shifting agroecological vegetation through anthropogenic activities is induced by climate change drivers (Matthew & Ohunakin 2017, Gonzalez 2001). RCPs effect observations and simulations can play vital roles in understanding the present and future climate change. This is because models have been reported as very powerful tool that use simulating effects of scenarios to project future climate change for any region (Dubuis *et al.* 2011, Matthew *et al.* 2015).

It is quite challenging to build a model strategy free of ambiguity from researchers' perspective to suit the projected changes in climate adaptation (Curtis *et al.* 2018, Karlson *et al.* 2015) . Though models built using mechanistic simulations were used to estimate the effects of change under multiple climate emissions scenarios in Nigeria on hydrology (Oyerinde *et al.* 2016), crop productivity (Fischer *et al.* 2005), and weather stresses (Allen *et al.* 2010, Eludoyin & Adelekan 2013), the end results targeted policy simulations for uncertain future. There is also ambiguity among global researchers regarding uncertainties based on climate models scenarios to evaluate grid versus local scale and model biases. Recently, climate scientists team from Africa in Oxford developed a process-based evaluation model that is region-specific for Africa, but the strength of coarse-resolution to simulate interannual variability of West Africa climate is still weak (James *et al.* 2018). Therefore, the model might not be closest to real scenarios application on a more extensive spatial scales for agroecological zone classifications, due to high clustering of limited spatial data.

Intergovernmental Panel on Climate Change (IPCC) in its recent report said Nigeria is expected to be highly impacted negatively by climate change and an increase in climate variability (IPCC, 2015). The climate trends in recent times which include rainfall, temperature and evapotranspiration among others have been studied and projections made on future trends are discussed below

2.4.2 Precipitation and Temperature

Nigeria's savannah region, in the last 30 years, had an average of 25% decrease in annual precipitation (Nkomo *et al.* 2006). The erratic changes in precipitation have been mild in other parts of Africa, ranging between 15-20% (Olsson *et al*. 2014). In the last five decades, sub-Saharan Africa ecological conditions have changed drastically, from the shrinking of lake Chad in the borders of Nigeria, Cameroon and Chad, to the extreme land degradation and deforestation process in wetlands of the Niger Delta (AGRA 2014). The most likely cause is anthropogenic climate change, resulting in a shift of the climate zones southward. This then leads to encroachment of the Sahara desert into the Sahelian zone of Nigeria (Badejo 1998, Herrmann *et al.* 2014, Oeba *et al.* 2018). This seems to be particularly true of West Africa where significant alterations in precipitation during the great Sahelian drought of the early 1970s and 1980s affected great parts of West Africa in terms of ecological, economic, and societal aspects. After this drought period, livestock density increased resulting in an intensification of grazing pressure (Dardel *et al.* 2014, Von Vordzogbe *et al.* 2015).

The differential pattern of occurrence of dry and wet episodes between southern and northern Nigeria was further consolidated by rainfall variability in the country on a decadal scale. Over northern Nigeria, rainfall was observed to a 33% decrease in an irregular pattern which intensified over time from 1921 to 2000 (Otun & Adewumi, 2009).

Trends in air temperature of Nigeria over three decades (1971-2000) indicated a predominance of positive anomalies (Akinsanola & Ogunjobi 2014, Ajibola 2001, Eludoyin & Adelekan 2013). For instance, Akinsanola & Ogunjobi (2014) results showed 5-12% increase in temperature between the decade (1981-1990) and the decade (1991-2000) with evidence of warming across the savannahs of Nigeria at 95% confidence level. Eludoyin & Adelekan (2013) described the comfort climate as 21-degree celsius to suit most purposes, including human physiological comfort. They also affirmed that there is an increase in temperature and evapotranspiration between 1981 and 2009, rising to about 2ºC in variability across the regions. Future trends of temeprature in Nigeria by scientists (Fick & Hijmans 2017, Gemeda & Sima 2015, Yelwa *et al.* 2013) reflects warmer climes in northern Nigeria, exhibiting drought pronness of the landscapes with low rainfall index.

2.5 ROOT MORPHOLOGY OF SAVANNAH TREES UNDER WATER STRESS

Despite the unreliability of the actual global tree mortality trends hinders model projections of future agroecosystems response to climate change based on the review of (Allen et al., 2010b). There are suggestions and evidence that trees are affected by drought impacts from a trait-based and inter-species specific perspective than intra-species specific and provenance perspectives (Anderegg, 2015; Bouda *et al.*, 2013; Polle *et al.*, 2019). For instance, the widespread and economically important Nigerian parkland tree species such as *Parkia biglobosa, Vitellaria paradoxa* and *Tamarindus indica* are projected to be negatively affected by increase in intensity and frequency of dry and hot conditions induced by drought in other Sub-Saharan nations (Bazié *et al*. 2011, Ouedraogo *et al.* 2017). Drought has been reported to have effects of water stress on the dry forest species, up to 90% of trees at first-year seedling and wildings are affected due to low precipitation (Brandt *et al.* 2016). In tropical savannahs of West Africa, annual precipitation varies from about 300 mm to >1,000 mm (Lodoun *et al.* 2013, Nicholson 2013). The seasonal changes produce extended dry spell, leading to seven months of drought regime in semi-arid regions of Nigeria (Kayode & Francis 2012, Papaioannou 2016). Drought regimes produce vivid changes in characteristics of tree seedling morphological and physiological structure, particularly on the slow death of tap root and fine roots (Poorter & Markesteijn 2007). There are numerous studies of the shoot and root survival responses sustaining growth and productivity under different drought conditions, simulating the phenological responses under a controlled environment (Brunner *et al.* 2015, Poorter & Markesteijn 2007, Saywood 2013, Schreeg *et al.* 2005). For instance, in the study of seedling survival in a tropical forest, Engelbrecht et al. (2005) worked with 28 phylogenetically different woody species across 60 plots, and classified the different stages of wilting of the leaves into 5 as follows; not wilted (1), slightly wilted (2), wilted (3), severely wilted (4). They further calculated percentage survival similar to Poorter & Markesteijn (2007) as subtraction of Number of plants at the initial stage from Number of species surviving after the final stage, then divided by Number of plants at the initial stage and multiply by 100. Although root characteristics are quite significant for predicting plant responses to resource scarcity that led to mortality. Fry *et al.*,(2018) found in a more sophisticated experiment using tomography that tap-rooted tree seedlings have lower ability to alter morphology response to small water pulses than fine roots but there is the need to discussed these findings to focus more on parkland tree seedlings.

2.5.1 Tap root system response to water stress

The development of taproot is influenced in seed grown seedlings than the cutting-grown propagules of *Eucalyptus grandis*, a savannah exotic tree species. This was reported during water-stressed regeneration experiment in Zimbabwe that compared seed germinated seedlings to cuttings propagated seedlings under same stress treatment (Saywood, 2013). Similarly, Sasse & Sands (1996) concluded in their tree seedling experiment that water stress exposure at a moderate level is not significant to preconditioning cuttings for survival, that taproot development is only affected at the extreme level of water stress. In another study, *Anacardium occidentale* seedlings showed that was seed propagated had more stable tap root systems for access to soil nutrient and moisture conditions in comparison with vegetatively propagated plants(Aliyu 2007a). Genetically, The review of knowledge compiled on tree roots adaptation to drought supports the view that they can withstand drought and maintain morphological and physiological functions for over 80% tree species tested (Brunner *et al.,* 2015). What remains unclear is to what extent farm trees in Nigeria at the juvenile stage survive extreme drought periods through changes in root morphology.

2.5.2 Fibrous root system to water stress

Tomlinson *et al,.* (2012) compared root morphology and biomass partition of tree seedlings from different species across savannahs of three continents using water gradient. The findings reflected differences across continents in few traits, particularly fine root structures, suggesting species react differently to climate pressures in savannah environments. For instance Otieno *et al.,* (2005) described *Acacia xanthophloea,* a parkland species to possess more fibrous roots system than well-defined tap root system during a greenhouse water stress experiment. The capacity of parkland species overcoming drought as an overriding factor in resisting water-stress is dependent on species specificity and root system (Agbelade *et al.* 2017, Leban *et al.* 2016, Wartenberg *et al.* 2018, Weston *et al.* 2015). This means survivability of different parkland species across different agroecological zones in Nigeria needs to be examined at the development stage. This is important for improving agroforestry adaptation through local farmers' viewpoint and enhancing sustainable tree resources on drought-threatened landscapes.

2.6 MACROPROPAGATION OF PARKLAND SEEDLINGS TO IMPROVE GREEN LANDSCAPE

Prance (1994) observed tropical tree species overexploitation is leading to severe reduction of species abundance and subsequent extinction of species. With the alarming forest exploitation and destruction in Nigeria in the last 20 years as seen in Bainbridge (2017) and FAO (2018), the future of trees is on farms. There are reports on the need to improve domestication, outside seed propagation of useful Nigerian forest trees species to agroecosystems in order to prevent their extinction via macropropagation (Akinyele 2019, Dunsin *et al.* 2016, Leakey 2018). Macropropagation involves the process of vegetative regeneration, either using cuttings as plant materials or developing cultivars on trees through modified air layering, also called marcotting (Simons & Leakey 2004). Teklehaimanot *et al.* (2000) confirmed that stem cuttings and air layering are two propagating techniques multiplied *Parkia biglobosa* cultivars, up to 35% success rate. Aliyu (2007) had more than 50% success rate from propagating cashew cuttings in Ibadan, Nigeria using vegetative propagation. However, there is the need for more extensive studies on the importance of stock plant management and the stock plant environment, particularly the popular parkland species such as *Parkia biglobosa, Vitellaria paradoxa, Anacardium occidentale, Diospyrous mespilliformis* juvenile growth study on land productivity and food security and as affected by climate drivers on drylands as suggested by (Leakey 2018). The propagation of the species must conform with the farmers vision of maximum productity and soil improvement. In a dryland tree experiment review, Schroth (1995) discussed how tree roots are considered by farmers during the propagation and management of trees on farms. They include

1. Tree species selection with minimal root competition, by shoot pruning.

2. Tree identification using root distribution network effect on annual crops.

3. The reduction of tree root length density by tillage.

4. Adopting agroforestry rotations over tree-crop associations.

These factors are essential for improving parkland management and regeneration research under extreme climate conditions. These will not only aim at the different methods of propagating parkland trees for food security and soil fertility but also to support the government afforestation programs and reduce poverty and malnutrition in the savannah zones. Hence, the need to fill that knowledge gap on local trees that have scanty information on seedling survival and further investigate the suitability of presumably more drought-tolerant species from within to ensure the survival of tree seedlings, promote future ecological stability and productivity of agricultural landscapes in Northern Nigeria.

CHAPTER THREE: CLASSIFICATION OF AGROECOLOGICAL ZONES FOR PARKLAND TREE SUITABILITY IN NIGERIA: AN ASSESSMENT OF CLIMATE CHANGE IMPACT ON SAVANNAH LANDSCAPES USING RANDOM FOREST

3.1 BACKGROUND OF THE STUDY

Climate predictions for Nigeria suggest that the interior of the country will become generally warmer, more arid, and with increased seasonal changes of precipitation (Ayanlade *et al.*, 2018; Eludoyin & Adelekan, 2013; Odenkunle, 2004; Oguntunde *et al.*, 2012; Omonijo, 2017). The high demand for land use to feed over 200 million human population living in Nigeria across the agroecological zones is making agroecosystems management and sustainability difficult (Abdullahi & Anyaegbu 2017, Adesina & Chianu 2002, Ehirim & Osuji 2017, Okpoho 2018, NPC 2016). This is because changing climate effects on agroecosystems resulting from intensive cultivation, overgrazing, seasonal bush burning, and deforestation is degrading savannah forests and parklands across Nigeria landscapes (Abubakar & Yamusa, 2013; Adeaga, 2013). These landscapes have significant impact on local people's land-based livelihoods and parkland productivity thereby forming distinct zones of agroecology (Koko & Abdullahi, 2013). The livelihoods of about 90 million rural dwellers, mostly peasant farmers in northern Nigeria depend on the regeneration of agroecological landscapes known as parklands, to grow annual crops and manage trees (Ayanlade *et al.*, 2017). Meanwhile, parklands require specific climate range within the region to flourish but affected by the decrease in both yield and quality as the climate changes. Studies on the future prediction of Nigeria climate showed increase in temperature and decrease in precipitation volume, thereby inducing land degradation and desertification, as well as mounting pressure on irrigated crops and power generation below economic by 2030, if unchecked (Ndegwa *et al.*, 2017; Oyerinde *et al.*, 2016; Wezel *et al.*, 2006).

Currently, sub-Saharan Africa region harbours savannah agroecological zones (AEZs) which is home to over 700 million hectares of parklands sustaining livelihoods of about 350 million people. One-third of the human population in the region are within drylands of Nigeria and depends on only one-tenth of the parkland landscapes for food security and livelihoods (WFP, 2018). To achieve the aim of restoring the degraded landscapes of sub-Saharan Africa, such as the popular Green Wall project, intensive research that includes spatiotemporal patterns of future climate extreme events is needed. In this chapter, the spatiotemporal approach was developed to predict the impacts of climate change using AEZs climate data across Nigeria and how it can affect tree restoration on parklands.

Several researchers used different model methods that involved spatiotemporal data and measured the impact of future climate change on sub-Saharan Africa and the tropics agricultural crop landscapes. These include specific agroforestry crop and landscape simulation model and interpolation to examine the direct effect of climate change (Ahmad *et al.,* 2018; Arowolo & Deng, 2017; Bunn *et al.,* 2015; Kala *et al.*, 2017; Oeba *et al.*, 2012). For instance, (Arowolo & Deng, 2017) arrived at land conversion rate 5% per year using the spatial calculating analysis model in national land-use change drivers study. The study focused on broader cover changes employing different source of climate data from the global climate free data. In another study, the lumped parameterised rainfall-runoff model was used to predict high potential evapotranspiration on Northern Nigeria water reservoir by to over 20% in 2030 (Oyerinde *et al*., 2016). The results also showed the yield of major agroecology productivity would decrease precipitously with warming. Although these findings are primarily driven by higher temperatures and erratic rainfall, they are limited by the number of parameters used. However, these studies focused on specific crops and/or broader land use cover changes. Studies focusing on agroecological zones changes driven by climate change for tree suitability in Nigeria did not focus on climatic factors. This is creating a challenge to develop farmer-focused restoration strategies to adapt to the projected changes in climate. Though an earlier evaluation by Kala *et al.*, (2012) of how changing climate impacts altered the economic distribution of Africa's AEZs confirmed drier zones southwards, it is rather regionally focused. Hence, the need to model at the local country level on changes of the AEZs to measure climate change effects on tree plant survival. The random forest model which is a classification method of fitting the modes of individual trees from multitude of decision trees of bioclimatic information to predict outputs is used to classify the AEZ of Nigeria. This model approach allowed identification in the potential shift of AEZ according to the expected climate change using climate data input. In order to focus on precipitation and temperature effects, the model predictions input was limited to only bioclimatic information. Bioclimatic information variables are biologically relevant annual seasonality trends derived from the analysis of monthly precipitation and temperature data. The free global climate data consisting of climate layers called bioclimatic variables in gridded data at different spatial resolutions are employed as independent input for different climate prediction research (Fick & Hijmans 2017). These include higher spatial resolution area of up to 1 km^2 grid used to analyse, describe and model maps of sub-Saharan Africa, Mediterranean and tropical landscapes using several approaches to achieve different objectives (Akpan *et al.,* 2018; Bunn *et al.,* 2015; Gislason *et al.*, 2006; Heiskanen *et al.*, 2017). In this research, topographical conditions were assumed to have a negligible effect on the general climate of Nigeria's agricultural landscapes. To identify the future of AEZs in Nigeria using the model for improved identification of bioclimatic characteristics of all regions in Nigeria is necessary. There is also the need to distinguish local AEZs in a systemic measure through classification to improve climate adaptation and mitigation. So, the following were asked questions asked:

3.2 RESEARCH QUESTIONS

- Can Nigeria's current agroecological zones be predicted from current bioclimatic variables?
- How are predicted climate scenarios likely to impact agroecological zone distribution over time, particularly on tree suitability?

3.3 RESEARCH OBJECTIVES

The primary goal of this research is to project the biophysical change through classification of present and future climate data of agroecological zones (AEZ) in Nigeria under various climate change scenarios and use these to classify the distribution of savannah agroecosystems. By employing a random forest modelling classification tool, we;

- classify the current distribution of Nigeria's agroecological zones (AEZ) using current climate data
- predict future distribution of agroecological zones using predicted future climate under four different RCP scenarios
- suggest analogous AEZ locations to inform future adaptation strategies.

Here, the emphasis is on changes in temperature and precipitation variation because simulating the trends using the bioclimatic future data under different climate scenario can predict changes in vegetation over time. The Random forest classification analysis model is also aiming at suggesting analogous locations for future adaptation purposes. This is because it will facilitate local knowledge transfer from farmers and improve afforestation and reforestation project management. Hence, the need to predict shifts in agroecological classification distribution under future climates of different agroecosystems in Nigeria as influenced by climatic factors. Where migration to more favourable locations is not possible, adaptation to new climatic conditions will be necessary, which may mean adopting agroecosystem practices used currently in other areas. It would allow reliable identification of respective AEZ potential vegetation that are likely transiting due to changing climate in the future. It would also improve classification accuracy of agroecological zoning using the climatic characteristics of the impacted zones. Furthermore, in AEZs that remain the same, systemic or incremental adaptation measure is required to enhance the suitability of tree species in future.

Projections of climate change by Global Circulation Models (GCMs) are uncertain. To estimate this uncertainty involves the use of multiple scenarios in climate change projections from multiple GCMs. However, the approach here is limited to a non-hydrostatic model projection with advanced atmospheric resolution extending up to 85 km in vertical levels and considered good for tropical climate scenarios (Hardiman *et al.*, 2017; Hardiman *et al.,* 2008). Hence, the Random Forest model classified only Hadley Global Environment Model 2 - Earth System model (see section 3.4.1.2) in this study.

3.4 METHODOLOGICAL FRAMEWORK

3.4.1 Random Forest modelling

The Random Forest (RF) model is a package in R with a collection of numerous individual decision trees from climate data that operate as an ensemble, spitting into prediction classes and the class with the highest votes becomes the model's prediction through bootstrapping sample. The sample is then split randomly into two subsets, for training (70%) and for testing (30%, out-of-bag sample, OOB). Each of the splitted bootstrap sample was fitted to a classification tree by a random subset selection of environmental variables (No. of variables for splitting at each tree node – mtry, set to 4) for each node created within a tree (Strobl *et al.,* 2008). The collection of all data, including bioclimatic variables at four different scenarios described below:

3.4.1.1 Climate scenarios and projections

The Representative Concentration Pathways (RCPs) are tropical climate scenarios from the Global Circulation Model (GCM) with four greenhouse gas concentration trajectories, namely RCPs 2.6, 4.5, 6.0, and 8.5 adopted by the IPCC for its fifth Assessment Report (AR5) (Niang *et al*., 2014). One of the advantages of using RCPs to describe uncertainty is that these pathways are more informative in atmospheric concentrations, with a wide range of possible changes in future anthropogenic greenhouse gas (GHG) emissions. Thus, the climate change projections of temperature and precipitation using bioclimatic variables determined by HadGEM3-ES in the IPCC AR5 are obtained for the present and future classification analysis. The classification model is applied to all seven agroecological zones within the borders of Nigeria, the focus area of study for shift in agroecosystem as induced by bioclimatic conditions. Other features like land use drivers, topographical characteristics and socio-economic dynamics are assumed to have negligible effect on the climate of the landscapes.

3.4.1.2 The bioclimatic data for the agroecological zones

A total of 774 geo-referenced locations were extrapolated from google earth covering all the seven AEZs. Each location is a simulated farmland per local council. There are 774 local administrative councils in Nigeria. The use of councils location representation is too reduce spatial bias due to proximity and improve coverage, as high as 95% AEZ cover (Figure 3.1). The geo-referenced points were reduced to individual points in a shapefile format scattered across Nigeria AEZ on a 30-second arc-minute grid interpolation map in ArcMap 10.6 GIS software. All maps and locations were created using the WGS-84 coordinate system in ArcMap and subsequently employed for interpolation of models using RF package in R programming.

The 19 bioclimatic variables used in analysing the changes in AEZ is summarized in table 3.1 below. The table described all the 19 GCMs used in the classification. The scenarios chosen were the representative concentrations pathway (RCP) of 2.6, 4.5, 6.0 and 8.5 of Hadley Global Environment Model 2 - Earth System (HadGEM2-ES), ranging from mild to extreme. The

HadGEM2-ES is a climate model comprising of an atmospheric GCM with earth system components. The components include vegetation and carbon balance as represented by the dynamic global vegetation model that simulates different vegetation types such as broadleaf tree, needle leaf tree, C3 grass, C4 grass and shrub (Chong-hai & Ying 2012, Ladle *et al.* 2017). For emphasis, the current and future bioclimatic variables of the most recent WorldClim version2 gridded climate data was used (Fick & Hijmans, 2017). RF package used the current (1970-2000) data extrapolated using shapefile from all location points consisting the 19 variables to classify all raster map layers and then stacked for interpolation of the site pixels for AEZ modelling. The same method was applied for the climate prediction of AEZ in the period 2040 to 2069 (2050) and 2071 to 2080 (2070). The data extracted from the WorldClim data was interpolated under 30 seconds arc-minutes (1 km^2 grid) resolution for the current climate as well as future bioclimatic variables datasets. The resolution employed for predicting the spatial trend in the agroecology distribution of Nigeria landscape is the most refined available global climate data.

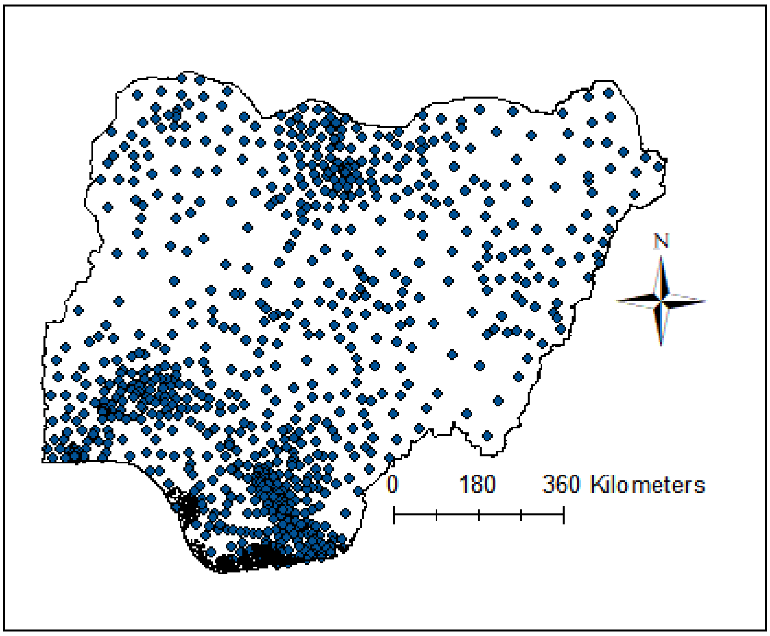


Fig 3.1: Map of Nigeria showing the 774 location points used in bioclimatic variables extrapolation

Table 3.1: The Bioclimatic variables

Label	Variables	Units
Bio1	Annual mean temperature	ºC
Bio2	Mean diurnal range (mean of monthly (max temp-min temp.)	ºC
Bio3	Isothermality (p2/p7) (100)	ºC
Bio4	Temperature seasonality [standard deviation 100]	ºC
Bio5	Maximum temperature of warmest month	ºC
Bio6	Minimum temperature of coldest month)	ºC
Bio7	Temperature annual range (P5-P6)	ºC
Bio8	Mean temperature of wettest quarter	ºC
Bio9	Mean temperature of driest quarter	ºC
Bio10	Mean temperature of warmest quarter	ºC
Bio11	Mean temperature of coldest quarter	mm
Bio12	Annual precipitation	mm
Bio13	Precipitation of wettest month	mm
Bio14	Precipitation of driest month	mm
Bio15	Precipitation seasonality [coefficient of variation]	mm
Bio16	Precipitation of wettest quarter	mm
Bio17	Precipitation of driest quarter	mm
Bio18	Precipitation of warmest quarter	mm
Bio19	Precipitation of coldest quarter	mm

Abbreviation: mm = millimetre, ºC = Degree Celsius

3.4.1.3 The model classification of the Agroecological zones (AEZs)

Random forest, like its name implies, is a group made up of number of individual decision trees that operate as an ensemble. In this case, the individual trees is the data points that splits out as nodes forming a class prediction and the class with the highest votes is employed as the model prediction. Here, the Random Forest model (see 3.4.1) package in R was used to classify the data extrapolated from bioclimatic variables for 774 data points shown in Figure 3.1. The extrapolated data are the modal value results of the data points from each bioclimatic variable, and each data point is a farmland site. The spatial distribution of the dependent AEZs was then used to assess the climate of all farmland sites, and for years 2050 and 2070 evaluation of how changing climate influences shift in the AEZs. For each Random Forest model, up to 500 decision trees with seven variables got selected at each node and replicated four times for each RCP scenario. The decision trees with the most votes became the predicted AEZ classification. Each AEZ classification obtained in the maps reported are background locations, where different agroecology is likely to be found based on the climate data variables, for the years 2050 and 2070 bioclimatic variable data for each RCP scenarios. The most likely analogues location for AEZ classification in the future was extrapolated for each pixel using the mode results for the 19 GCMs for RCPs 2.0, 4.5, 6.0 and 8.5 respectively.

To evaluate the prediction and improved estimates of node error rates of the random forest decision trees as reported by Breiman (2010), each tree was grown until the last node and used to predict the observations of Out-Of-Bag (OOB) classes. The OOB error estimate computation is calculated from the corresponding bootstrap sample for each tree data split and before averaging the estimate. This is because the training of the trees do not include OOB observations, but estimates of cross-validated accuracy within each classification run (Evans *et al*. 2011). The RF package also provided variable importance measurement. This measurement is based on the mean decrease in classification accuracy to determine the magnitude of the decision tree nodes. According to Gaal *et al.* (2012) and Strobl *et al.* (2008), variable importance measures comparison or interpretation and is dependent on the predictor variables descriptive ranking, rather than the absolute values. The decrease is a normalized variable difference for the out-of-bag observed variable data, just as the out-of-bag data is randomly permuted. The sampling ratio is the trade-off between the dependent AEZ classification in multiple categories and the classification into suitable classes and unsuitable locations.

3.5 RESULTS

3.5.1 Calibration and validation of Random Forest model for the Agroecological zones of Nigeria

The R programming package, Random Forest (RF) identified the zones suitable for each agroecological zone in Nigeria map scale by selecting the same number of points that falls with the shape file of each AEZ. A validation process performance for the training set was calibrated to classify the raster values in agreement with the point values. The Random Forest (RF) validation resulted internally into a satisfactory OOB error (8.87%) for the current model, where the classification error (mtry = 4) is within the range of about 11-38% for Guinea savannahs and Sudan savannah zones (Figure 3.2). The trend in the graph showed number of trees for all the variability in the classified zones do not exceed 500 decisions, with all number of variable at each split at 4. The error lines is required to maintain the steady trend before 500 trees to obtain premium classification decisions for the nodes in RF model (Gislason *et al.* 2006).

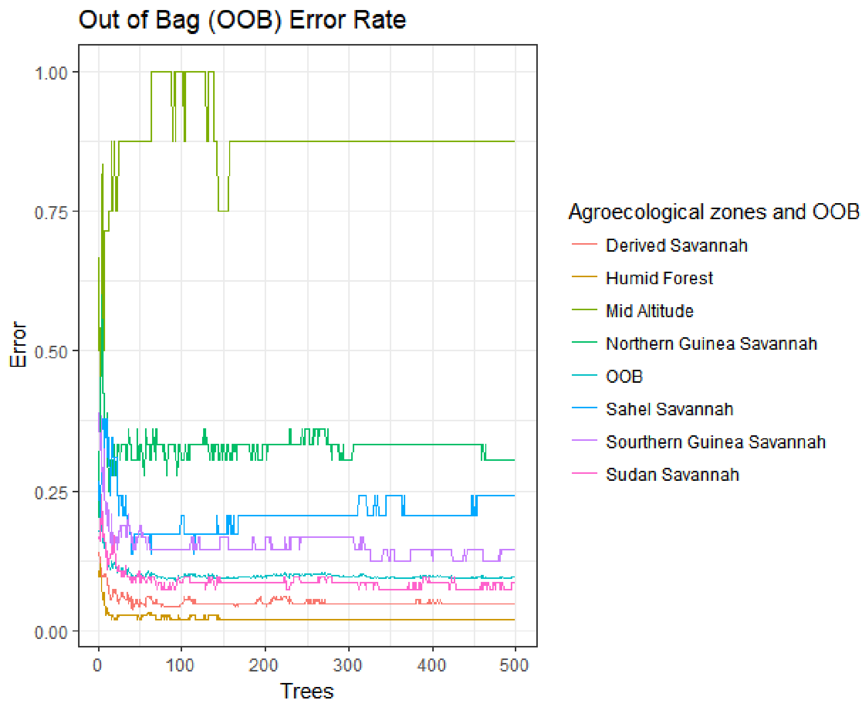


Figure 3.2: Out-Of-Bag error rate to estimate measured prediction error for each agroecological zone in order.

In the training data, top variable parameters having the primary importance to predict the presence of current AEZ include Bio07w2 (Temperature annual range), Bio04w2 (Temperature seasonality), and Bio15w2 (Precipitation seasonality), while the lowest prediction variable impact was recorded among Bio10w2 (Mean temperature of warmest quarter), Bio08w2 (Mean temperature of wettest quarter), and Bio01w2 (Annual mean temperature) (Fig. 3.3). Hence, important variable parameters that included temperature and temperature seasonality range are the top predictors used as model classifiers for years 2050 and 2070 AEZ in Nigeria. The precipitation of warmest quarter (Bio18w2), mean temperature of coldest quarter (Bio11w2) and mean temperature of driest quarter (Bio09w2) are also important values but with low ranks in the prediction of all the random samples. The model prediction variable importance is supported by pixel classification matrix discussed in the next section with the current AEZs ranging between 53 and 60% prediction accuracy.

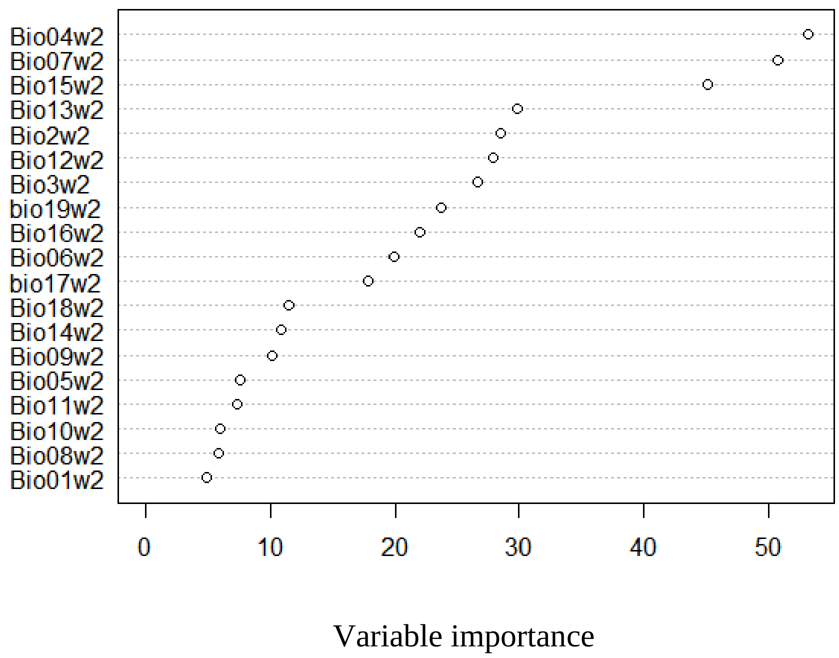


Figure 3.3: Variable importance based on the bioclimatic Variable mean decrease accuracy of current, 2050s and 2070s across all agroecological zones in Nigeria.

3.5.2 Agroecological classification confusion matrix

Nigeria's current AEZ is spatially defined using overlay maps developed by the International Institute for Tropical Agriculture through multiple clustering analysis of local climate and other socio-ecological variables in Nigeria (IITA 2000). The application was employed at a local scale for analysis of how changes in modified temperature and precipitation, length of growth and evapotranspiration effects agroecosystem landscape sustainability overtime. Table 3.2 is a confusion matrix of Random Forest (RF) classification with 500 decision trees, and 4 variables split at each node. The data used are for training and test accuracies for the agroecological classes, respectively. In using bioclimatic data, agroecological zones matrix were represented with ratio of predicted class over the actual class via algorithm in RF package. Although, similar and close variables of the bordering classes made the algorithm difficult for modelling processing. Mid Altitude AEZ had the highest classification error (87%) with 6 pixels misidentified (3 in Southern Guinea savannah, 2 each in Humid forest and Derived savannah) and only 1 pixel correctly identified as Mid Altitude. Derived savannah had the lowest classification error rate (5.5%) with 154 pixels correctly identified and 9 pixels misidentified as Southern guinea savannah and Humid forest. More also, Sudan savannah, Northern and Southern Guinea savannahs had error rates 8.5%, 33.3% and 14.6%, respectively. Figure 3.3 shows the current AEZ map of Nigeria modelled using the confusion matrix in the table below, while figure 3.4 is the masking of original spatial AEZ map of Nigeria as an overlap on figure 3.3 for comparison.

Table 3.2: confusion matrix for current bioclimatic data in Random Forest classification of Nigeria Agroecological zones (AEZ) (using 500 trees and testing 4 variables at each node)

AEZ	Derived Savannah	Humid Forest	Mid Altitude	Northern Guinea Savannah	Sahel Savannah	Southern Guinea Savannah	Sudan Savannah	Classification Error
Derived savannah	154	5	0	0	0	4	0	0.055
Humid forest	3	148	0	0	0	0	0	0.020
Mid Altitude	2	2	1	0	0	3	0	0.875
Northern G. savannah	0	0	0	24	0	3	9	0.333
Sahel savannah	0	0	0	0	22	0	7	0.241
Sourthern G. savannah	4	0	0	3	0	41	0	0.146
Sudan savannah	0	0	0	7	1	0	86	0.085

3.5.3 Current Agroecological Zones (AEZ) prediction

The classification of agroecological zones by random forest package was broadly correct on a national scale, considering that simulation of the model to the accepted agroecological mapped area (refer to fig. 1) and that the predicted layers included are within the limits of agroecological regions. In addition, the RF model calibration and validation process confirmed the classification errors to be minimal for all the variables used. The RF classification provided current AEZ distribution maps (Fig 3.3) and then used the classifier to forecast the shifts by the 19 GCMs in the year 2050 and 2070, respectively (Fig 3.6). The AEZ classifications currently in Nigeria is mostly in parklands, farmlands and plantations all over the landscapes within the territory: Sahel, Sudan, Northern Guinea and Southern Guinea Savannahs (over 70% landcover), as well as Mid Altitude, are in the northern region, while Derived savannah and Humid forest dominated the southern region of Nigeria. The northern region towards the central area is characterized by temperature and rainfall variability. Masking the conventional AEZ map on the current classification, there is a relative similarity with the predicted classifier, except at the Mid-altitude laying outside the conventional plateau area of North-Central region. In the classification using bioclimatic variables as seen in figure 3.3b, Sahel savannah prediction aligned with the conventional AEZs at the northwestern region with minor extension overlapping Sudan savannah. The Sudan and the Northern Guinea savannahs spread from east to west in the current AEZ prediction, with the former opening eastwards and the latter closely following the conventional AEZ trends. The southern Guinea savannah prediction showed a strong relationship with the conventional AEZ, with over 90% accuracy as confirmed in the confusion matrix in table 1 above. Modelled Derived savannah and Humid forest also had up 95% match with the mapped agroecology version.

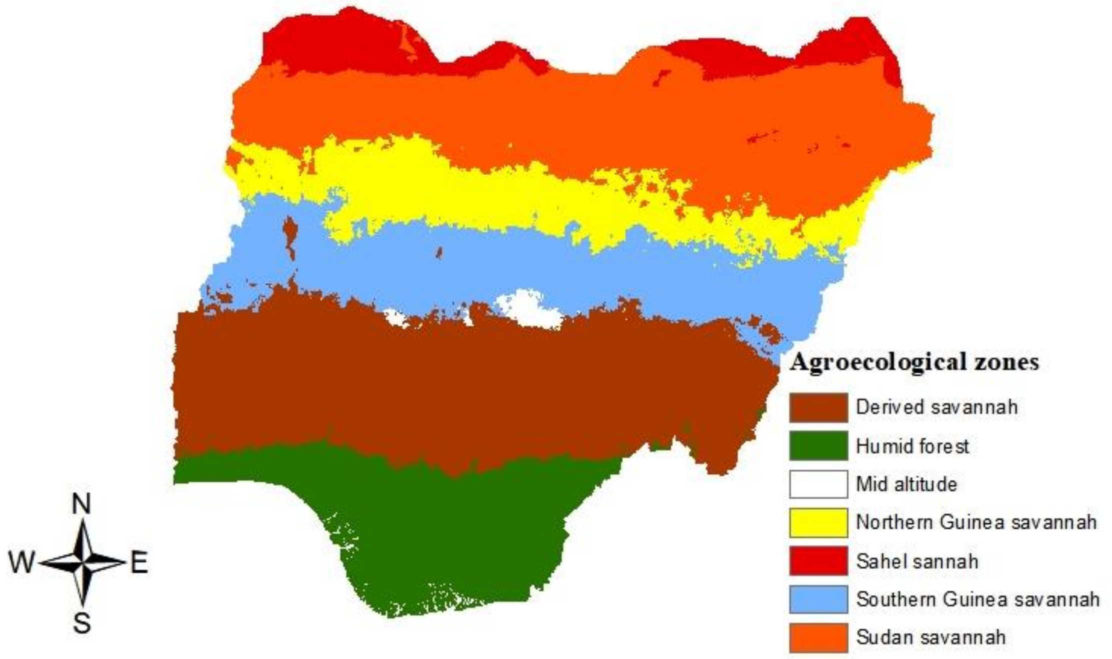


Fig 3.3: Modelled version on conventional Agroecological zones of Nigeria using current 19 GCMs of new bioclimatic variables

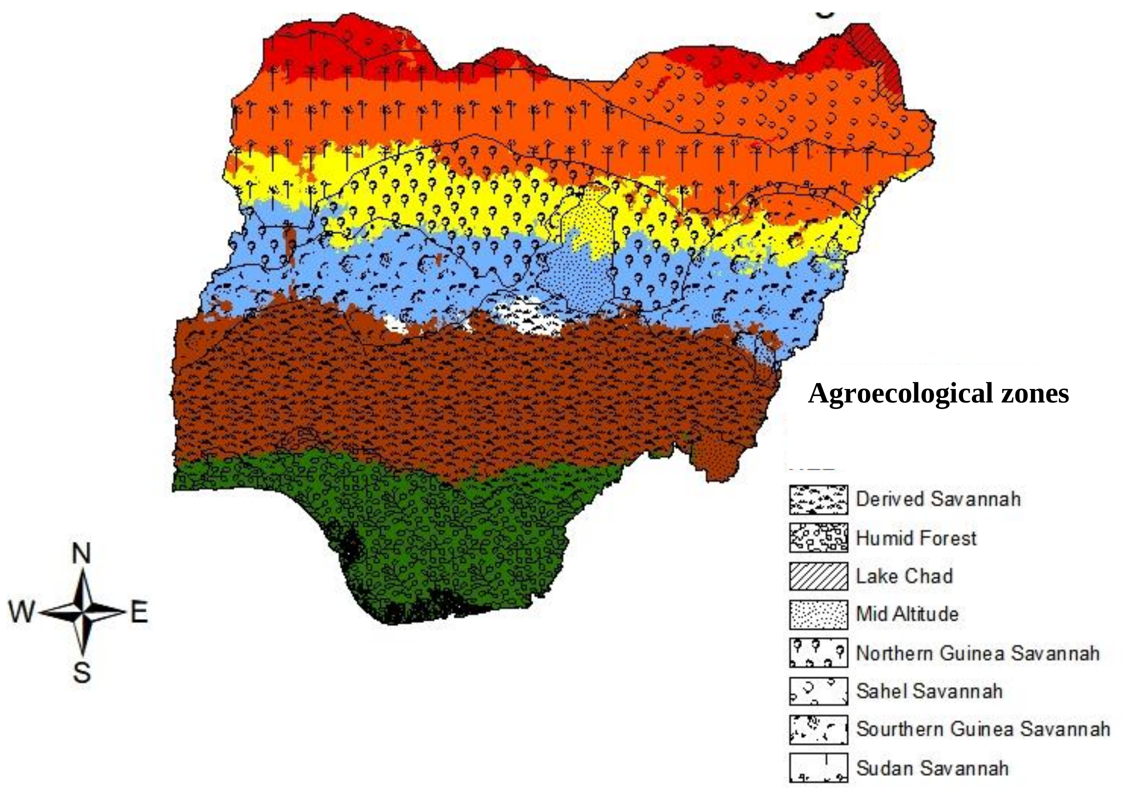
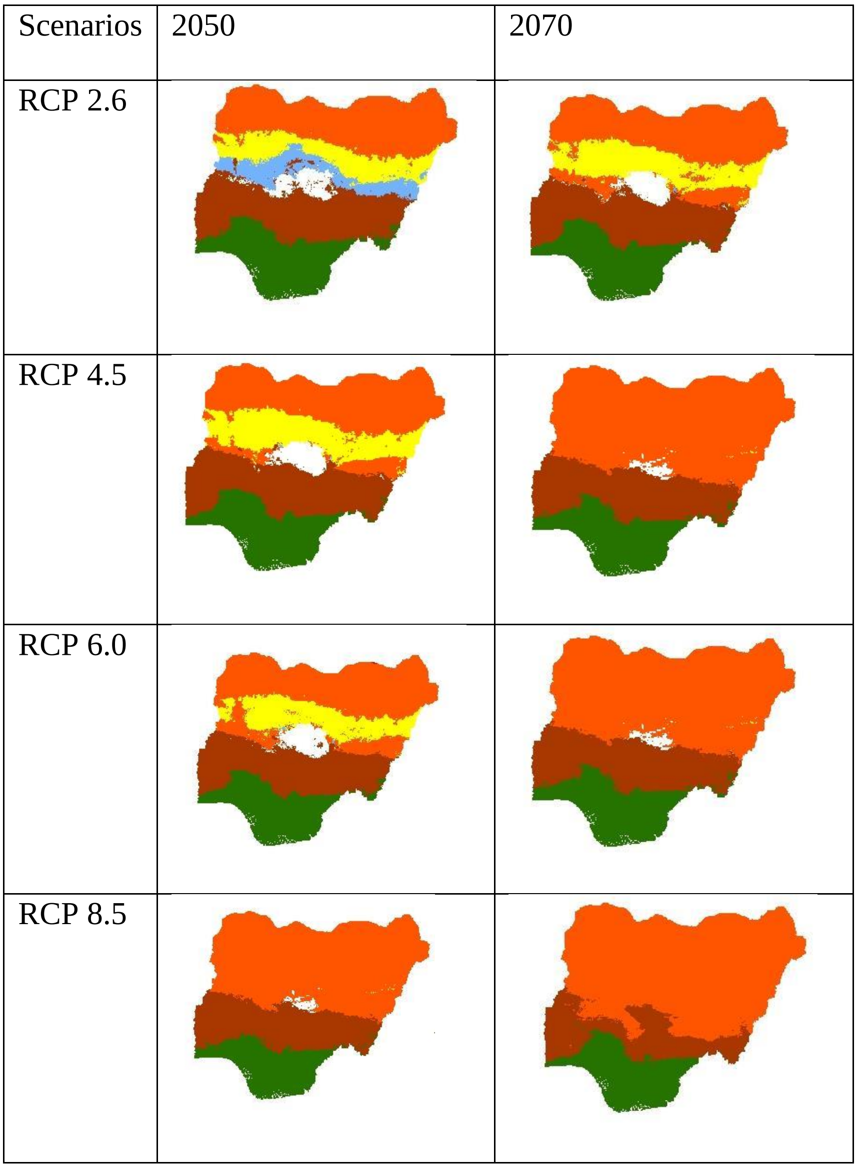


Fig 3.4: Modelled version on conventional Agroecological zones of Nigeria using current 19 GCMs of new bioclimatic variables

3.5.4 Projected Agroecological zone changes under the RCP scenarios

Models predict general southwards shift in dry agroecological zones from the north to south of Nigeria. The prediction for the first modelled future (2050) showed a shift towards the southern region (North-South). By 2050, there is a change in the spatial distribution of AEZs across all the RCP scenarios, except the Southern Guinea savannah (SGS) maintaining the AEZ classification only at RCP 4.5. The spatial extent of the SGS is however reduced by 18 % (see figure 5). Under extreme climate scenarios (RCP 8.5) the present climatic conditions experienced currently in northern regions can be expected in a greater part of the country in the future (2050-2070). In a moderate climate scenario (RCP 6.0, the Northern Guinea savannah is lost by 2070, and under extreme climate scenarios (RCP 8.5) by 2050. Under moderate climate scenarios (RCP 6.0) the Southern Guinea savannah is lost by 2050. The result in this period did not show any similarity in the simulation with the present conditions in the northern region, e.g. the Mid Altitude zone is getting warmer with more precipitation. These areas can be found only in the northern part of the country, just as reported in climatological shifts of the landscape ecology due to global warming (Hänke *et al.*, 2016). Migration of agroecology to the south is witnessed in all scenarios but at a significant rate in most extreme scenarios of year 2070 model. Changes in Northern Guinea savannah zone for extreme climate scenarios is similar to the Sudan savannah with long dry spells. Other AEZs in the southern region (Derived savannah and Humid forest) resists climate variable effect to some extent in both 2050 and 2070 model with variability less than 5.2 – 13.7% range for the raster (AEZ) layers (Fig 3.5). The figure also showed that majority of the predicted zones had converted bordering zones of the current AEZ map in 2070 model with Sudan savannah region occupying over 35% and 47% of Northern Guinea Savannah and Mid Altitude, respectively. Sahel savannah at the border of the northern region did not reflect in the shifts across all scenarios. Southern Guinea savannah faded out after RCP 4.5 scenarios. This implies that Southern Guinea savannah precipitation pattern is changing. The model is predicting for both 2050 and 2070 delay that will cause first annual rain to begin in the last week of May of beginning of June, unlike the usual Mid-March rain for early planting at present. The Northern Guinea savannah prediction showed that critical months of 2070 at extreme scenarios is between June and September, where beginning and cessation of precipitation would be very close. This will cause an extended drought in the zone, leading to disappearance of the agroecology and replaced by drier Sudan savannah as seen below (Fig 3.4 and 3.5).



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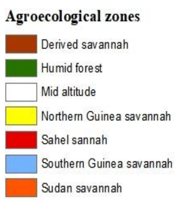


Figure 3.4: Shifts observed in 3 agroecological zones shifts modelled for dryland Nigeria four different bioclimatic variables scenarios.

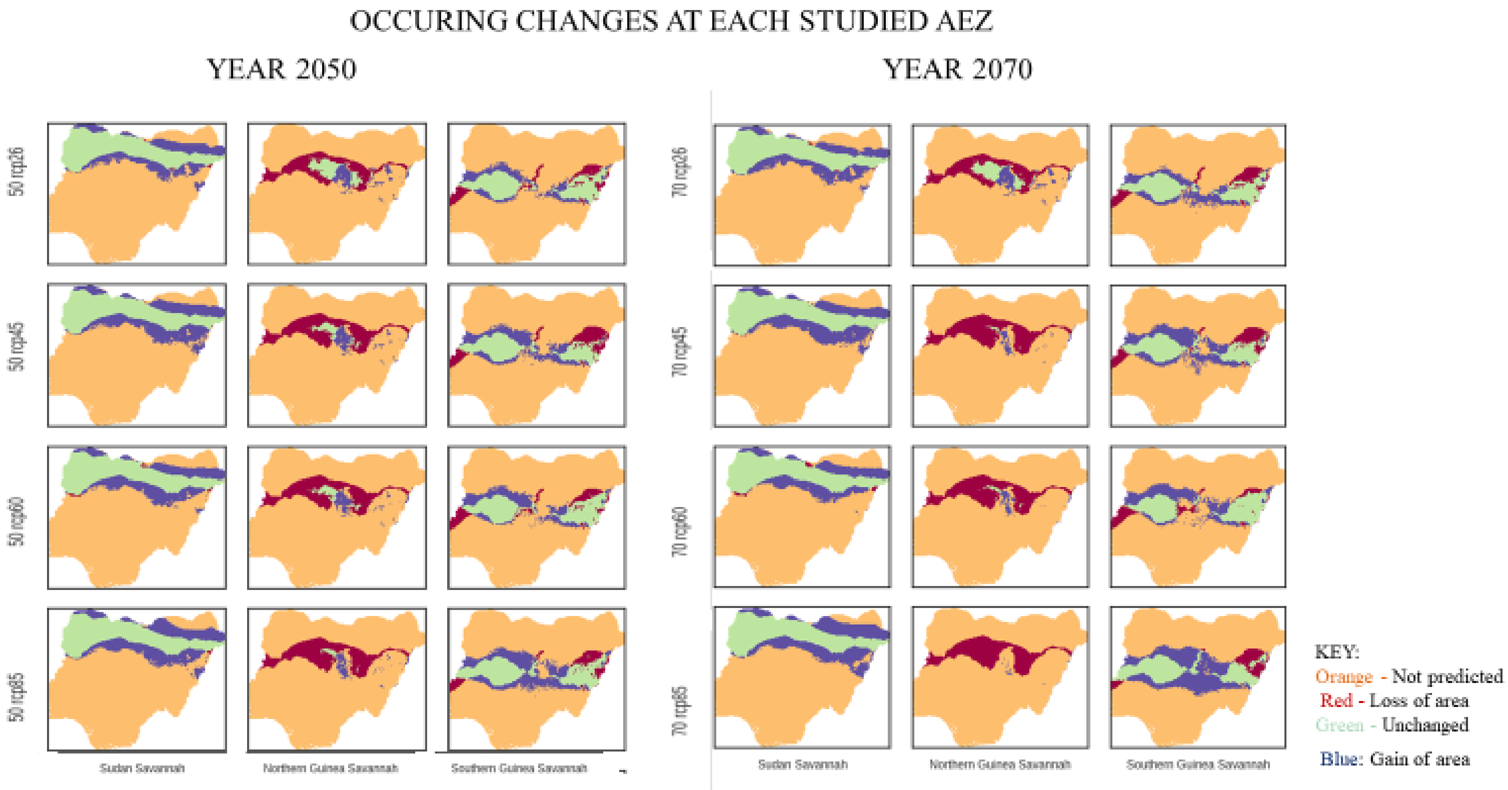


Figure 3.5: Changes observed in the three agroecological zones under this study of dryland Nigeria using four different bioclimatic variables scenarios.

3.6 DISCUSSION

Based on the predictions through classification, communities in the central part of Nigeria are the most affected by climate change with most localities experiencing drought-threatened conditions in future. The modelling of agroecological zones classification is to provide more insight on changing climate impacts on the land-use change in Nigeria with attention on livelihoods and farming systems. The local approach used in AEZ is more refined than the regional AEZ model as it offers more demonstration of how different AEZs will be affected at the national level, to allow policymakers and farmers improve adaptation and mitigation to climate change impact (Seo, 2014). The projected local impacts of all the climate scenarios did not disagree with previous findings on the impacts magnitude of change in climate shifting agroecology globally, up to 50% from the 2050s in sub-saharan Africa (Bunn *et al.*, 2015; Gaal et al., 2012; Kala *et al.,* 2017; Seo, 2014). The zones that are suitable for cereals and tuber production now will in the future now have climates with higher temperatures and long dry seasons. These mean a total shift or possible disappearance of current AEZ characteristics in Northern Guinea savannah, Southern Guinea savannah and MidAltitude zones as well as in most parts of the driest Sahel savannah. Furthermore, substantial landscapes across the northern region of Nigeria that currently lies within the Sahel and Northern Guinea Savannahs are to be replaced by Sudan savannahs in the future. Just as modelled in (Kala *et al.,* 2017; Seo, 2012), these scenarios will offer great consequences for decision-makers and landowners in sustainable livelihoods strategies that involves forest management, particularly in the semi-arid regions. Parkland landscapes areas productivity will struggle for sustainability while the forested parts of Nigeria may become more productive. Research to adapt agricultural productivity to mitigate climate change impact will thus have to make agroecosystems better adapted to heat and drought stress. Thus, the need for regions to change their agronomic and plantation practices to remain productive and sustainable, for example, by learning from Sudan savannah farmers what trees are planted, and when they are planted in their locality. Other climate change induced problems like the low yield in agricultural produce, and the disappearance of dryland resources, especially parkland trees on large hectares affect food security and livelihoods. The dryland tree disappearance is observed across different savannahs within the predicted changing agroecological zones locations in Nigeria (See chapter 5). On the other hand, classification of climate change induces AEZs shift was studied by (Kala et al., 2017) and (Seo, 2014) for sub-Saharan Africa. While the former used the generalised linear model for predicting farmers decision impact on future AEZ shift using climate scenarios, the latter focused on how to evaluate the future behavioural decisions impact on land suitability. The results are useful but could not focused on the integration of ecological and climate sciences among regional states. Other studies used land cover datasets from Chinese GlobeLand30 land cover to predict the spatial land use change of cultivated landscapes between 2000-2010 (Arowolo & Deng, 2017). Although seasonal length was relegated among the factors, precipitation pattern skewed to May-August across all AZ. The month range coincides with the months of modal rainfall in volume and frequency. The model estimated the current drivers of land-use change and the spatiotemporal intensity effect on agroecosystems distribution of Nigeria. More also, co-kriging interpolation was used to study the changing climate in Northern Nigeria after obtaining 1981 to 2010 temperature and rainfall variables from NIMET. The interpolated results showed a prediction map high variability in Vegetation index (NDVI) and precipitation across the period. In Bunn *et al.* (2015), global multiclass classification of coffee plantation suitability for future climates into agroecological zones was projected using the Random Forest (RF) model. FAO-guided AEZ method approach was used to redefine future classification of the coffee plantation climate suitability migration, upwards up to 500m increase in elevation. Meanwhile, Nigeria's current AEZ is defined using overlay maps developed by the International Institute for Tropical Agriculture through multiple clustering analysis of local climate and other socio-ecological variables in Nigeria (IITA 2000).

The use of machine learning techniques such as the RF algorithm have been debated to be vulnerable to overfitting specific variables, depending on the scenarios (Bunn *et al.* 2015, Hand & Till 2001). In order to meet the objectives, variables with lowest levels of out of bag error to produced high classification accuracy shown above. Lastly, this prediction confirms the impact of changing climate scenarios projects the vulnerability of parklands to drought as the AEZ moves southwards (Bunn *et al.* 2015, Gislason *et al.* 2006, Kala *et al.* 2017, Seo 2014). The severity of parklands suitability to tree vegetation as illustrated by the models under extreme emission scenarios provides a considerable data for different adaptation approach as agroecological zones shifts.

3.7 CONCLUSION

This chapter uses the random forest classification method to predict the impacts of climate change on agroecological zones (AEZs) of Nigeria with observed and future bioclimatic variables. It was concluded that the classification of AEZs using climatic data is a major step for parametrisation of agroecosystems in Nigeria, with a focus on parklands in the drylands of Northern region. The AEZ classification predicted the gradual disappearance of three of the four current AEZs to favour the expansion of Sudan savannah zone under different scenarios, by over 62%. This established a connection between climate data and agroecosystems, reaffirming that drought-induced climate is reducing agrobiodiversity landscapes. The adaptation strategy of shifting agricultural and/or forest management of present north-eastern states to north-central states if the future climate is altered for instance, requires spatially simulated model of current the AEZ classification. Therefore, stakeholders can use different trials of farming management strategies involving trees of AEZs with future conditions, consider changing Northern Guinea savannah (Zaria region) and Southern Guinea savannah

(Abuja region) by planting more Sudan savannah (Kano region) valuable tree species for future mitigation purposes. Moreover, additional research should expand the climatic variable limits to include environmental factors such as land cover (with land-use productivity index), topographical data and socio-economic index when predicting the worst impacts of climate change on the agroecological zones of Nigeria.

CHAPTER FOUR: RURAL FARMERS' PREFERENCE AND KNOWLEDGE OF PARKLAND TREE MANAGEMENT AND REGENERATION IN DRY AGROECOLOGICAL ZONES OF NORTHERN NIGERIA

4.1 INTRODUCTION

The natural resource depletion in sub-Saharan Africa is affecting livelihoods more in drier agricultural landscapes as the agroecological zones transect upwards, particularly in the savannah parklands of Northern Nigeria (Fasona *et al.* 2013, Odihi 2003). The agroecological zoning classification of Nigeria is based on the agricultural productivity potentials, socio-economic factors, climate factors (rainfall pattern) and landscape vegetation, including parkland trees (FAO 1996, Isaiah 2015, Leakey 2014, Seo 2014). Parkland trees are characterized as woody perennials selected and managed traditionally by farmers for certain functions while cultivating staple food crops (and sometimes, rearing animals) on same field (Bayala *et al.* 2014, Faye *et al.* 2010, Boffa 2000). The parkland trees are not only essential providers of products and services for different communities but also important to agroecology functions of sub-Saharan Africa agricultural landscapes, including Nigeria (Sinare and Gordon 2015). The trees economic and nutritional values include providing wood fuel and combating malnutrition among local population, either as leafy vegetables and condiments or as fruits to challenge malnutrition (Amjath-Babu *et al.* 2016, Boffa 2000, Jones & Rayment 2016, Leakey 2014). Hence, West Africa parkland trees contribute significantly to ecosystem management, landscape resilience, sustainable livelihoods and food security across the agroecological zones (Bayala *et al.* 2015, Larwanou and Saadou 2011, Faye *et al.* 2011, Sanon *et al.* 2007).

The number of people living in Nigeria is estimated at 198 million as at 2018, and rural communities that constituted 55% of the total population currently relies on fast declining renewable resources, particularly forests for survival, especially fuelwood, and fruits (Amiebenomo 2002, WPP 2019). Nigeria's deforestation rate is one of the highest in the world, estimated at 5% per annum (losing over 400,000ha of forest area between 2010 and 2015) with agricultural land, urbanisation and drought leading as the drivers and it is more apparent on the drylands (FAO 2016). However, parklands are managed and protected under Farmer-Managed tree Natural Regeneration (FMNR) across West African drylands (Lovett & Haq 2000). FMNR is a traditional farming systems involving protecting and nurturing young tree wildings and matured trees outside forests with potential benefits to farmers (mostly in rural areas) on agricultural fields. This system provided protection to few trees in dry forest regions through subjective and preferential treatment to sustain them on agricultural landcapes, based on the product and services renderred (Maisharou *et al.* 2015; Choudri *et al.* 2013; Weston *et al.* 2015).

Literature on the preference of parklands species to support livelihoods in Nigeria's savannah communities is scanty but tree preference has documented for neighboring West African nations is mainly based on its functions to sustain livelihoods either as energy or as food and medicine (Haglund *et al.* 2011, Faye *et al.,* 2011, Weston *et al.,* 2015). More also, reports on evidence of deforestation (Mfon *et al*., 2014; Odihi 2003), poor and weak policy framework of afforestation programmes (Ibrahim & Muhammad, 2015), corruption and lack of coherence of government agencies in relation to forest management (Popoola, 2015; NFP, 2006; Onyekwelu *et al.,* 2006; Odihi, 2003) and extended drought regimes affecting farming and vegetation (Adeaga 2013, Kayode & Francis 2012) did not highlight specific trees management to improve the the local agroecosystems. For instance, Nigeria Forest Policy (NFP 2006) documented that over 75% of the rural population depend on fuelwood as domestic energy supply, resulting in the loss of about 70 million m^3 of wood from forests as fuelwood annually to farmers and rural women collecting trees outside farmlands. The policy document provided general estimate but did not indicate how specific tree species loss affected agroecosystems. So, what remains unclear locally is the extent of understanding the tree-crop interactions in a parkland system to optimise the potential for farmers living in northern Nigeria. For example, does farmers' tree preference influence the propagation and retention of tree juveniles in dry agroecological zones? The following are the research questions:

- Does parkland trees species preference on farms differ among the three studied agroecological zones?
- Are there differences in the local management of parkland trees with crops among the sampled agroecological zones?

An integrated approach in understanding the change in savannah parkland current and predicted climate will help in increasing its adaptive capacity if farmers' knowledge is documented (Onyekuru & Marchant 2016, Urama *et al.* 2017). This research is not only valuable to restoration and conservation of parkland trees as a sustainable dryland resource but also in provision of information to stakeholders on regions suscetible to changing climate at the local level. In this chapter, the study aims to evaluate the local knowledge on identification and regeneration of most important tree species in parklands for enhancing agricultural productivity and livelihoods. This was done through the assessment of local regeneration management methods for the preferred tree species in water-stress situation with focus on roots adaptation to drought. The potential utilization and problems of parkland trees in the respective agroecological zones will also be enumerated.

4.2 MATERIALS AND METHODS

4.2.1 Study Location

Field study was conducted in Northern Nigeria, transecting through three out of the seven agroecological zones as seen in figure 1.1 (Chapter 1). The locations are four different field points each in **Sudan savannah, Northern Guinea savannah, and Southern Guinea savannah** agroecological zones, all located within Northern Nigeria explained in table 4.1. These study locations are communities that were predicted in the modelled AEZ, identified as drought-prone areas based on the random forest classification of future using 2050 and 2070 bioclimatic variables (Refer to Chapter 3 result section). The location coordinates, among others, were further employed in chapter 6 for modelling distribution of two parkland trees using maximum entropy distribution.

4.2.2 Data Collection and Statistical Analysis

The local knowledge management of parkland trees was evaluated through survey using simple but extensive mobile tool software called Open Data Kit (ODK) for data collection and sorting (See appendix 1.1). ODK is a software application tool for collection of field information on android mobile platform in a simple and flexible format using forms (Hartung *et al.* 2010). ODK has three major steps – Build, Collect and Aggregate which enhances the process of data information, including coordinates and multimedia, collected electronically through mobile phones or tablets. The format in Signore (2016) was employed in designing the questionnaire (with major changes). Data collected from the field was exported imported into ODK aggregate build, an offline platform for organizing ODK data on computer for further analyses (Anokwa *et al.* 2011). The questionnaire comprised open and closed-ended questions. In the open-ended questions, responses were categorized for the respondents in order to simplify data analysis.

Using a purposive random sampling method, a minimum of five key informants per village were identified through the village-heads after consultation for interview and collection of information. A total number of 96 respondents (92 individuals and 4 groups) were sampled in four villages per zone zone during the study (See Table 4.1 for agroecological zone description). Individual interview was the main method of collection. More also, focused group meetings were held at the community public centres (mosques and village chief's compounds) in three villages (one for each zone) sampled.

Information obtained focused on two major themes;

(1) Farmers' preference on savannah farm tree species and the relationship among the agroecological zones. i.e. the ranking of most prioritised species on their farms was done using order scale (1st to 5th), then applied priority sorting technique to rank 10 most frequent species among the three zones

(2) Management and status of propagation of savannah farm trees including respondents' perception on growth rate, root spread, response of roots to stress and other regeneration techniques. In order to reduce ambiguity on specific information about tree management and interaction with crops, visual illustrations were applied to facilitate respondents' answers.

Non-parametric statistical test, Kruskal–Wallis one-way ANOVA and Wilcoxon signed-rank test were used to compare growth indices and relationships among three agroecological zones unequal data for management and usage responses. This is because the data was not normally distributed (Fagerland, 2012). Different R packages (agricolae, ggplot2) on R 3.4.2 version were used.

(3) On general constraints of regenerating trees on farmlands, statistical analyses were simply in frequency and percentages to describe the differences among farmers in the three sampled agroecological zones.

Plate 1.3: Interview session with a farmer on his farm plot using ODK collect on an android tablet in Sheda (Southern Guinea Savannah), Nigeria.

Table 4.1: Agroecological locations characteristics

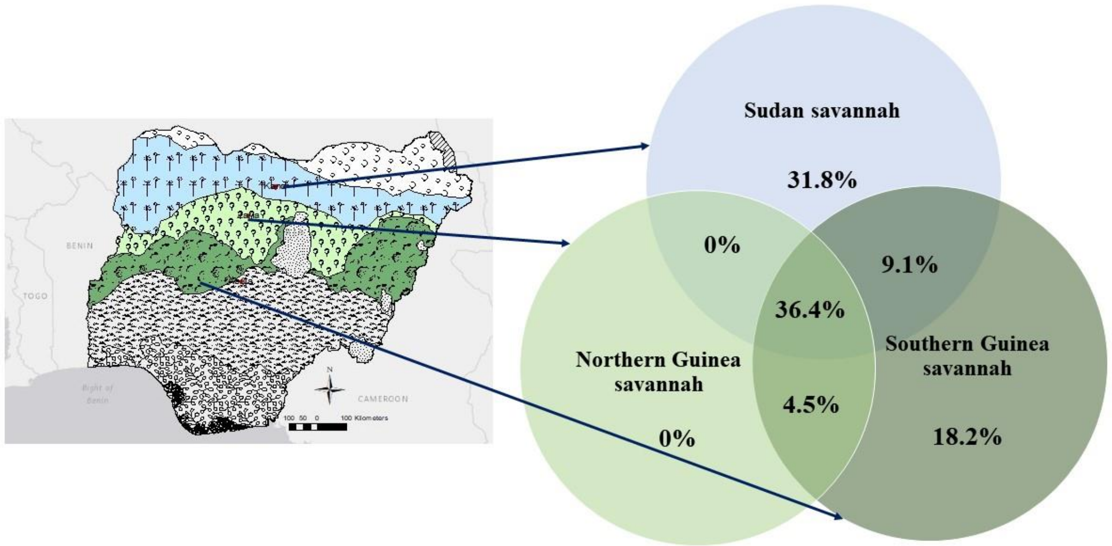
Agroecological zones	NR.	AAR (mm)	AAT. (°C)	LGP (days/yr.)	Major City (Field points -Villages)
Sudan Savannah	30	800-900	33-35	138	Kano (Mallama, Ringim, Tambrawa, and Zango)
Northern Guinea Savannah	25	1000-1200	28-30	165	Zaria (Bela, Farakwai, Jaji, and Kargo)
Southern Guinea Savannah	41	> 1500	25-27	198	Abuja (Gigbe, Gwako, Sheda, and Giri)

ABBREVIATIONS: NR (No. of Respondents), AAR (Average Annual Rainfall), AAT (Average Annual Temperature), LGP (Length of Growing Period).

4.3 RESULTS

4.3.1 Top ranked parkland species across the agroecological zones

Native and exotic tree species were listed as priority species by the farmers in the three savannah agroecological zones sampled. The Venn diagram (Fig 4.1) showed the distribution and relationship (based on agroecological zones) of all the important species as mentioned by respondents on their respective farmlands. All respondents affirmed that the species mentioned by them are left undisturbed and sometimes protected, if found as wilding within the farm plot. Across all locations, farmers mentioned a total of 23 tree species. Out of which nine species were listed as present in all the three zones. The intersections between the agroecological zones showed the species preference relationship except between the Southern Guinea (SGS) and Sudan Savannah (SS) where no species were listed. The diagram also indicated that the Northern Guinea savannah (NGS) zone had no distinctive species mentioned within its zone, unlike the other two sampled zones. The NGS spreads latitudinal/horizontally between the SGS and SS as the transect zone (refer Fig. 4.1).



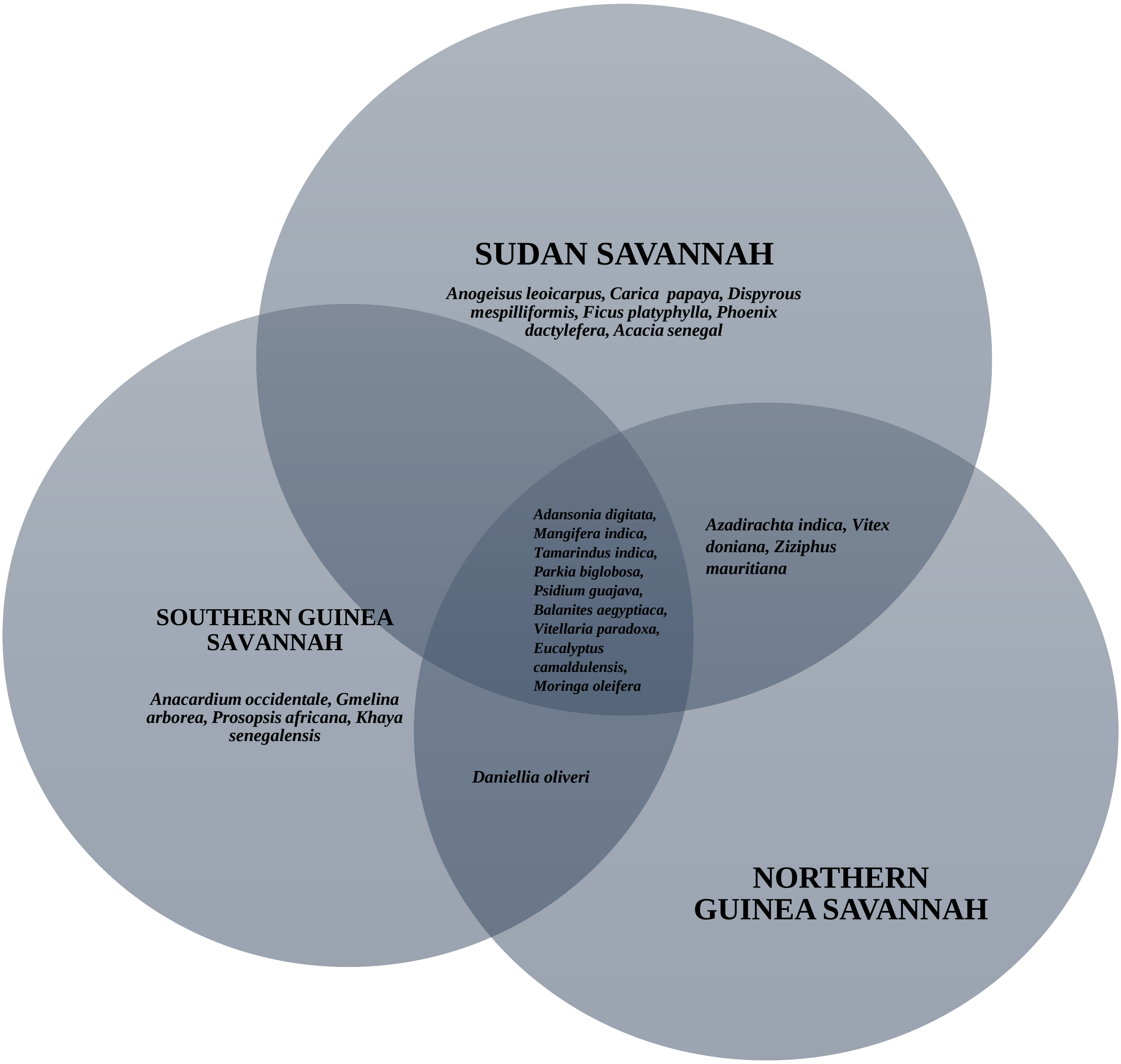


Figure 4.1: Venn diagram showing the relationship of tree species mentioned per agroecological zone by percentage and by preferred trees.

Sudan savannah has over 65% of the total tree species mentioned, the zone with greatest species richness, including the exclusive species to that zone. The exclusive lists in SS (except C. *papaya*) are peculiar drought tolerant species that covered West African landscapes *(*Hänke *et* *al.*, 2016). The SGS exclusive species (*Anarcadium occidentale, Gmelina arborea, Prososis africana, Khaya senegalensis)* are native and exotic woody parkland trees found mostly across Guinean savannahs. Unlike the SGS, NGS had no exclusive species within the zone but the intersection between NGS and SS showed two different slender-bole and tiny leaf parkland trees. The SGS and SS not sharing trees is not unconnected to the differences between the two extremes of the savannah climate characteristics found in the zone. The NGS zone had 11 parkland species mentioned at different times by the respondents. SGS zone had more slightly woody and larger trees than the other two zones. The farmers in the zone kept repeating *P.biglobosa* as well as *A. occidentale* and *M. indica* as their most valuable trees. SGS had four unique parkland species within its zone. The large trunk and broad leaf leguminous tree *D. oliveri* is the only tree shared between SGS and NGS. A sub-total of 13 tree species were mentioned by respondents in the zone.

The three studied AEZs top favourite ten species* are selected from 17 species out of the 23 different trees recorded across the zones. The ordinal method involves transformation of respondents' responses (ranked ordinal values) by replacing highest frequency in a ranking order; 1-10 (Table 4.2). This means about 77% of the total species sampled are ranked as the 10 most prioritised species across the AEZ. Furthermore, six, eight and seven out of the ten parkland species were found in SS, NGS and SGS zones, respectively. *Parkia biglobosa* tree led as topmost preferred by the respondents, except in Southern Guinea savannah. *Mangifera indica* is an exotic fruit tree species on top of the table list in SGS for based on farmers' preference and the species is within the top five listed in other zones. But the trend showed a reduced preference ranking for this species further north from SGS to SS. *Parkia biglobosa* and *Adansonia digitata* are the two native tree species found in most preferred parkland species list across the zones sampled, as mentioned by the respondents. The Baobab tree (*Adansonia digitata*) is ranked at 10^{th} position in the SS zone, while it maintained a higher rank of 8^{th} and

6th in the SGS and NGS respectively. Others parkland trees at top-ranked in all the sampled zones are exotic tree species - *Psidium guajava, Moringa oleifera* and *Eucalyptus camaldulensis*, commonly planted and survived in dry tropical landscapes. *Eucalyptus camaldulensis* relevance as a plant species on parklands increases as the agroecological zone shifts towards drier zones. The upward movement from a 10th position in the SGS through 7th in NGS to 5th position in SS is clear evidence of the drought-tolerant species popularity among farmers. *Vitellaria paradoxa* is another essential native woody parkland species on the list and among the top 5 but limited to two guinea savannahs only. *Ziziphus mauritiana* and *Tamarindus indica* are two native dryland species that are significant to livelihoods of farmers in NGS and SS. The two species are between 7th and 10th postion for both zones. In the SGS, *Anarcadium occidentale* (Cashew) and *Prosopis africana* are two solely trees in the zone to be among the preferred species, as they maintain 4th and 5th psitions, respectively. Other native parkland species include *Vitex doniana*, maintaining 7th position in the ranking and *Diospyros mespilliformis* listed as 2nd most preferred by famrers in SS. The trees listed are highly valuable mutipurpose species and the uses are explained in the next section.

* Using the ordinal method of ranking, a list of ten most essential species were sorted for each agroecological zone as seen in table 2 below. The list was limited to ten due to time and resources constraint faced in the research. It was further trimmed to three species during propagation trial.

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Table 4.2: The ten most preferred species in each study agroecological zones based on respondents' ranking preference

Rank	Southern Guinea savannah	Northern Guinea savannah	Sudan savannah
1	*Mangifera indica* (129)	*Parkia biglobosa* (111)	*Parkia biglobosa* (77)
2	*Parkia biglobosa* (111)	*Vitellaria paradoxa* (76)	*Azadirachta indica* (70)
3	*Vitellaria paradoxa* (95)	*Mangifera indica* (58)	*Diospyros mespilliformis* (49)
4	*Anacardium occidentale* (66)	*Psidium guajava* (32)	*Mangifera indica* (45)
5	*Prosopsis africana* (53)	*Moringa oleifera* (20)	*Eucalyptus camaldulensis* (36)
6	*Psidium guajava* (47)	*Adansonia digitata* (15)	*Moringa oleifera* (30)
7	*Moringa oleifera* (29)	*Vitex doniana* (15)	*Tamarindus indica* (29)
8	*Adansonia digitata* (12)	*Eucalyptus camaldulensis* (9)	*Ziziphus mauritiana* (18)
9	*Daniellie oliveri* (10)	*Ziziphus mauritiana* (9)	*Psidium guajava* (16)
10	*Eucalyptus camaldulensis* (9)	*Tamarindus indica* (9)	*Adansonia digitata* (15)

Notes: Species ranking is based on the sum of function (ranking scores i.e 1st to 5th) of tree species according to the respondents from all the zones. Ranking score of the topmost species in each zone are in bracket.

4.3.2 Importance of parklands trees to farmers in savannahs of Nigeria

There is the need to include what parkland trees listed in table 2 above offer as different environmental and product services to the farmers. These products and services ranging from nuts and seeds and traditional medicine to soil amelioration and reducing erosion influenced the choice of the species as reported in the next section. Meanwhile, figures 3a-c below outlined that the top parkland trees offer multipurpose services that improve livelihoods among the respondents in the Sudan savannah (SS), Northern Guinea savannah (NGS) and Southern Guinea savannah (SGS), respectively.

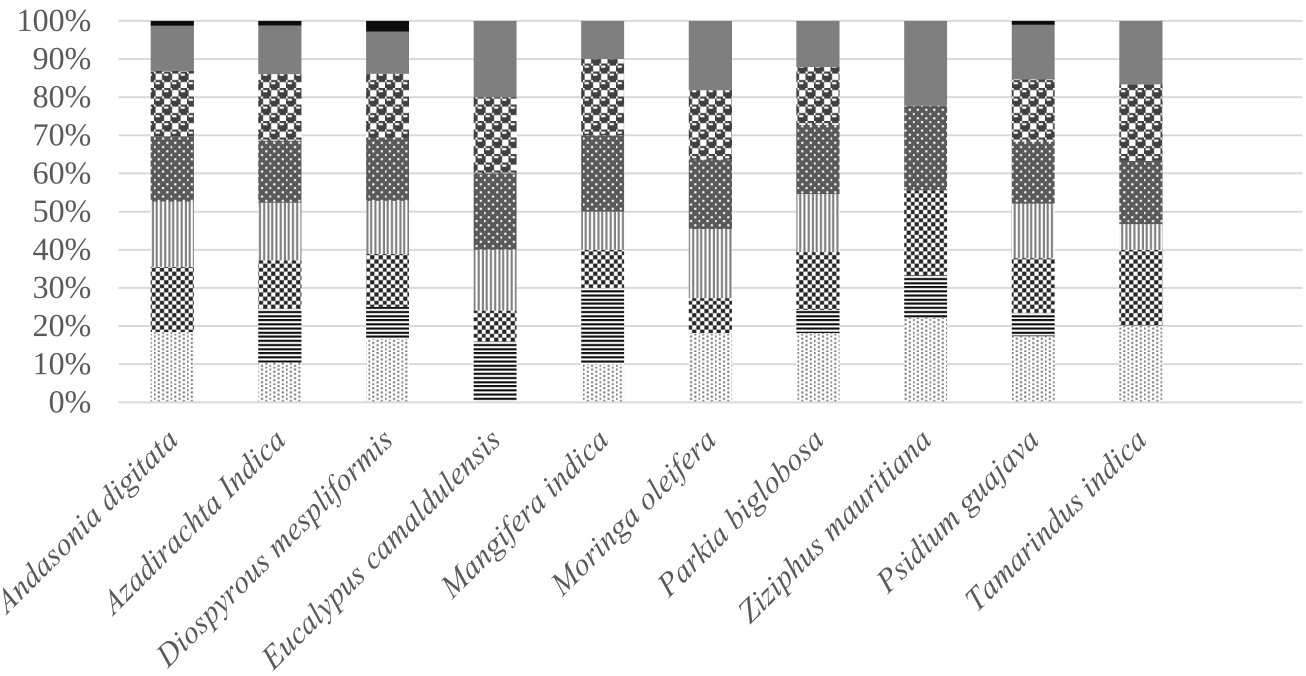


Fig 4.2a: Top 10 most preferred parkland tree species in Sudan savannah

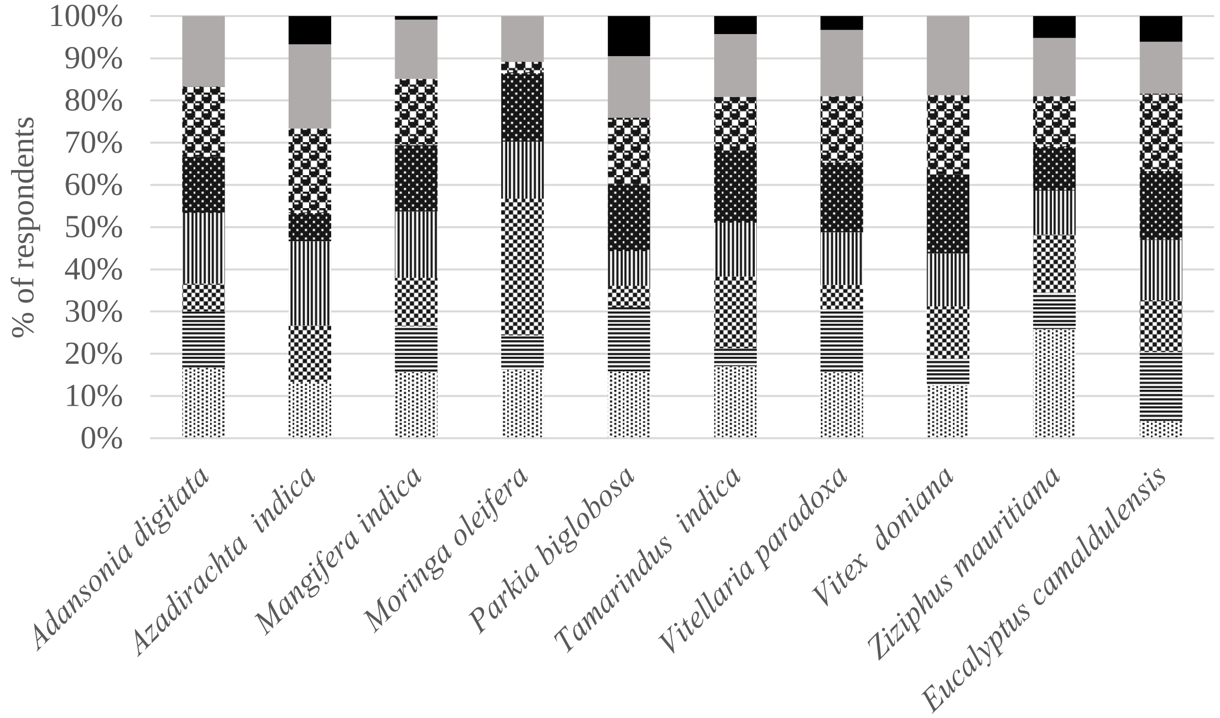


Fig. 4.2b: Top 10 most preferred parkland tree species in Northern Guinea savannah

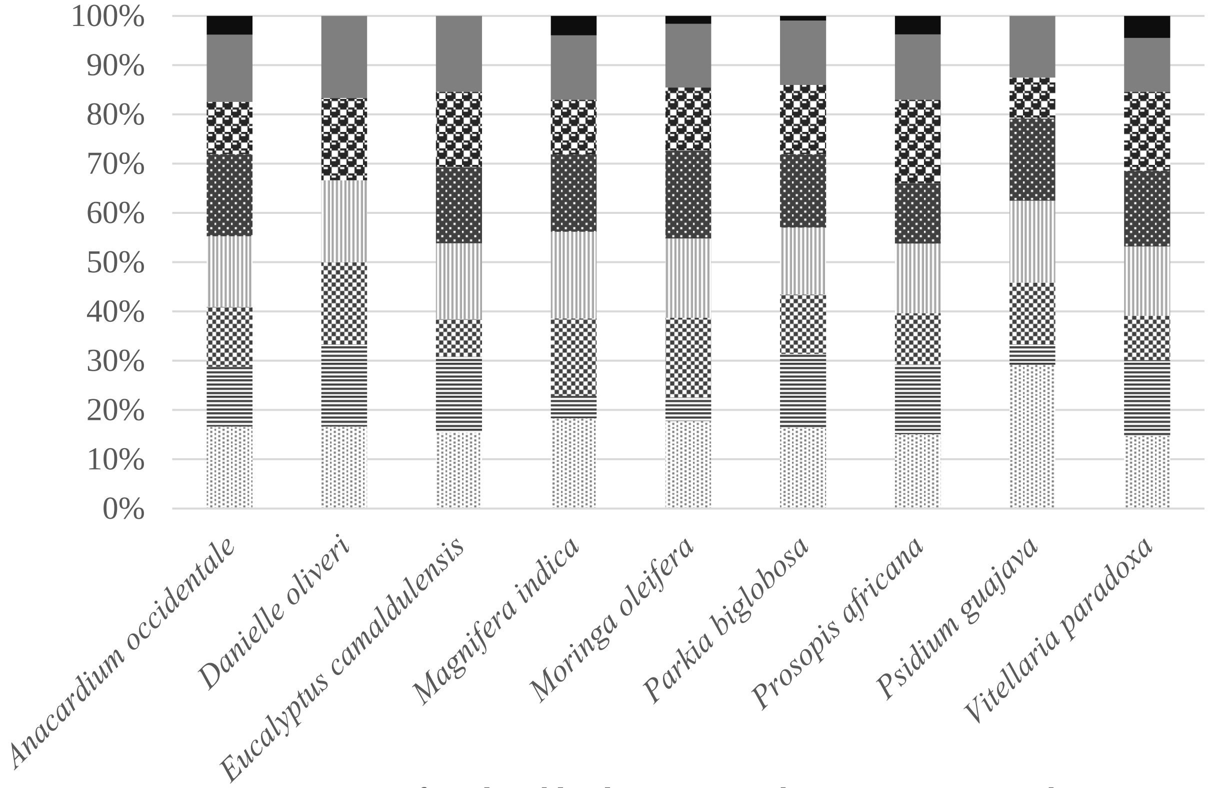


Fig. 4.2c: Top 10 most preferred parkland trees in Southern Guinea savannah

In the graphs, the bars showed top species listed by farmers namely, *Parkia biglobosa*, *Mangifera indica* and *Vitellaria paradoxa* had equal percentage distribution range (10-20%) for each usage as a multipurpose species across the zones (Fig. 4.2a–c). On the respective zones, only popular Sudan savannah species (SS), *D. mespilliformis* had 10% more use for the farmers in the zone classified as others in the graph. The species unique performance for all functions, just like *Adansonia digitata* and *Moringa oleifera* is one among many alternatives in the top-listed parkland species with high commercial value. *Adansonia digitata* is another age-old species with multipurpose uses, over 70% are environmental functions, including improving soil fertility and water retention during extreme drought to support crops, such as millet. The Sudan savannah respondents also reported a slightly higher percentage rate (over 5%) for the other nine species to provision of medicine and nuts for food or seeds for planting on farms than other zones.

The respondents in Northern Guinea savannah have multipurpose use for all their best farm tree species mentioned as seen in figure 3b. For instance, in the environmental function of parkland trees, no Northern Guinea savannah species scored less than 15% for erosion control except *M. oleifera.* Shade is another significant aesthetic value to farmers and workers that scored high percentage rate range (10-20%) for NGS species. Native species with the highest scores such as *Tamarindus indica, Vitex doniana* and *Parkia biglobosa* were considered as favourite resting place during breaks. The demand for fodder for livestock is imminent in NGS. *Moringa oleifera* species over 20% rate in fodder, making it the highest leaf material used, not only in NGS but also across the zones.

The Southern Guinea Savannah *Anarcadium occidentale* (Cashew) is an exotic fruit tree, now a parkland species in the dry tropical landscapes of Nigeria. It is offering a wide range of services as reported by the respondents. The species contributes on an average (10-15% of all uses mentioned) but the focus is on nut and fruits for its high commercial value. Other species in the SGS with great multipurpose uses had other uses except for *Eucalyptus camaludensis, Daniellia oliveri* and *Psidum guajava*. In general, four species were outstanding in their multiple usage; namely *Parkia biglobosa, Vitellaria paradoxa, Diospyros mespiliformis* and *Anarcadium occidentale*. The species scored between 15-20% for all functions in any zone they are listed as top species. Hence, the focus on the potential regeneration management of the four species using seeds in the glasshouse discussed in Chapter 7.

4.3.3 Regeneration of parkland tree species as observed by the respondents

The regeneration and growth rate status of parkland species in all the zones studied is shown in figure 4a-c. The bars show percentage responses of farmers for each species mentioned in an AEZ. There are three categories of regeneration by seeds; sporadic, prolific and slow/little growth. For clarity, sporadic growth in this context refers to having an established and transferable seedling from seeds after planting, on or before 10 days and can grow up to 15 cm height. Similar description applies to prolific and slow but the days extend to 10-20 days and 30 days or more, respectively. This is significant to parkland tree management on farms (*P.biglobosa* in particular) as the categorisation would enhance the understanding of what species do best at the juvenile stage. In SS, only two species (*A. digitata* and *P.guajava*) are recorded not to be sporadic in growth. The species had more than 60% of the respondents classifying the trees as slow in growth. The NGS on the other hand, had only *A. digitata* as the species with no sporadic growth at all. Out of the top 10 species ranked by the respondents, 7 of them had more than 50 % of the respondents agreeing that the species grow very fast (sporadic) at the juvenile stage. Parkland trees in the SGS recorded only four species as having more than 50% of the respondents agreeing that the growth is sporadic. The respondents mentioned the growth to be prolific, about six species out of the top ten had over 40% of the respondents. Only A.digitata had 100% recorded as slow by respondents. Generally, top species like *P, biglobosa, M. indica* and *V.paradoxa* are classified as fast growing species by the majority of the respondents across the zones. NGS had more species considered as fast growing than the other two AEZs.

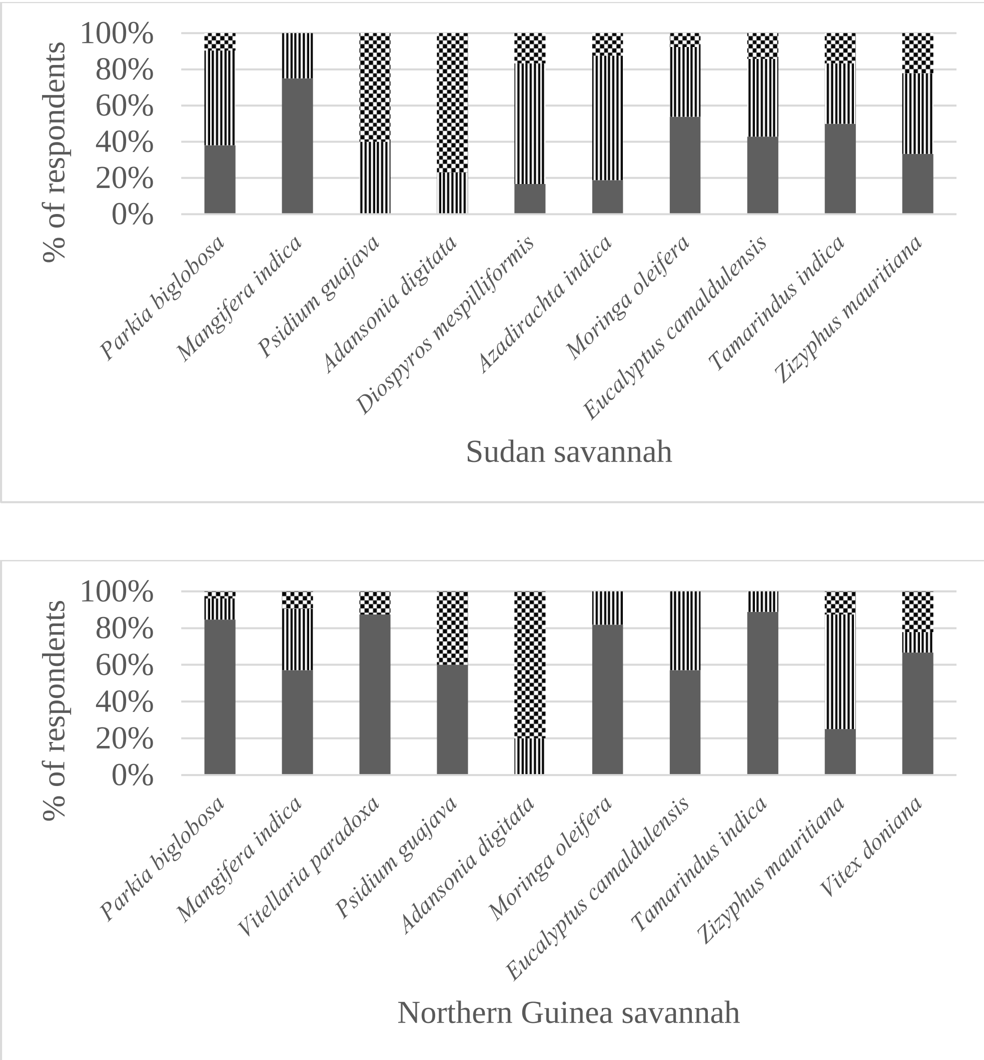


Fig. 4.3: Bar chart of farmers' responses on parkland species growth rate of (a) Sudan savannah (b) Northern Guinea savannah

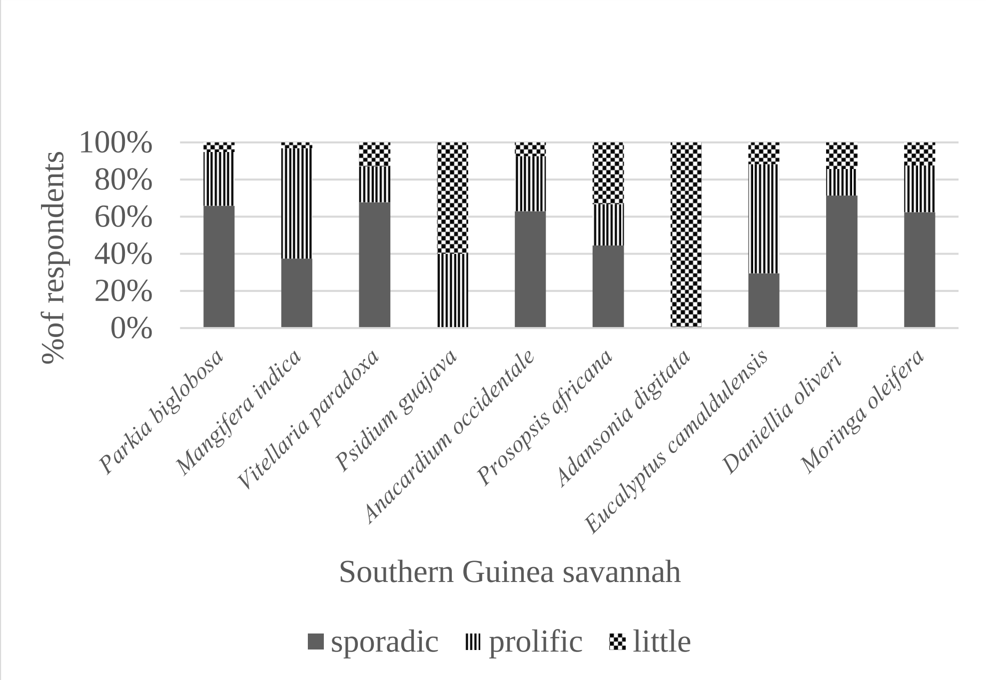


Fig. 4.3: Bar chart of farmers' responses on parkland species growth rate of Southern Guinea savannah

On the leaf abscission, farmers in SS zone responded that 66% of the ten species shed their leaves during the dry season as shown in pie charts below (Fig. 5). Evergreen trees are 30% of the trees mentioned. The trees never shed leaves either in rainy (wet) season or dry season, according to the respondents. The NGS had the least (2%) wet season leaf shedding parkland trees. The species mentioned was *Azadirachta indica*. Farmers said the tree shed little leaves in order to enhance water retention at the end of rainy season for dry spells. NGS also had the highest percentage rate (74%) of species shedding leaves during the dry spells, while the SGS had the lowest (65%) percentage rate. farmers recognised the Leaf shedding importance through production of non-toxic organic fertilizer to cash crops grown on same plots after decompostion, therby enriching soil nutrients and reversing degradation.

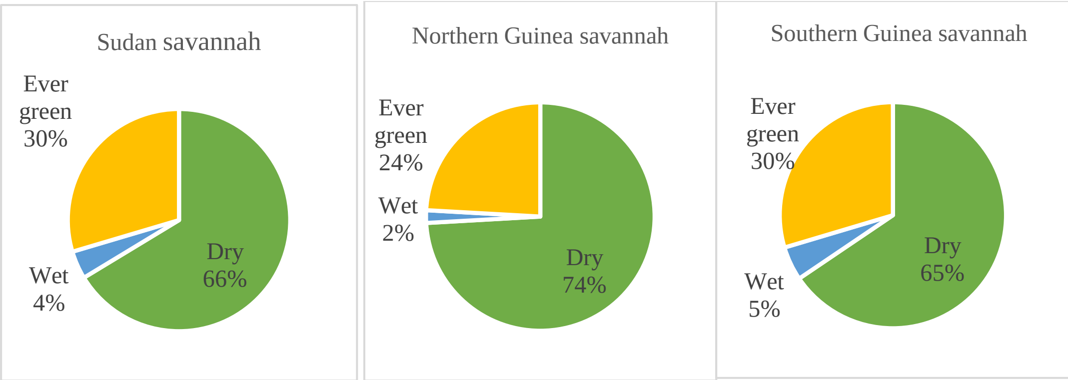


Figure 4.4: Farmers' perception of leaf shed across the three AEZs for all the species

4.3.4 Relationship between respondents' parkland species preference and regeneration perception as well as the uses

In the table 4.3 below, using spearman rank correlation, positive relationship between specific AEZ farmers' parkland tree preference and the multiple uses of the species as well as the regeneration potentials increase from north to south. For instance, the Sudan savannah (SS) correlation coefficient shows high positive relationship, ranging from 71.8% in the SS to 83.9% in the Southern Guinea savannah (SGS). The regeneration potential correlation with tree preference shows positive correlation but the gap between SS and Northern Guinea savannah (NGS) is slightly over 20%. Therefore, the respondents' preference is dependent on the uses as the linear relationship suggests in the graphs for the agroecological zones.

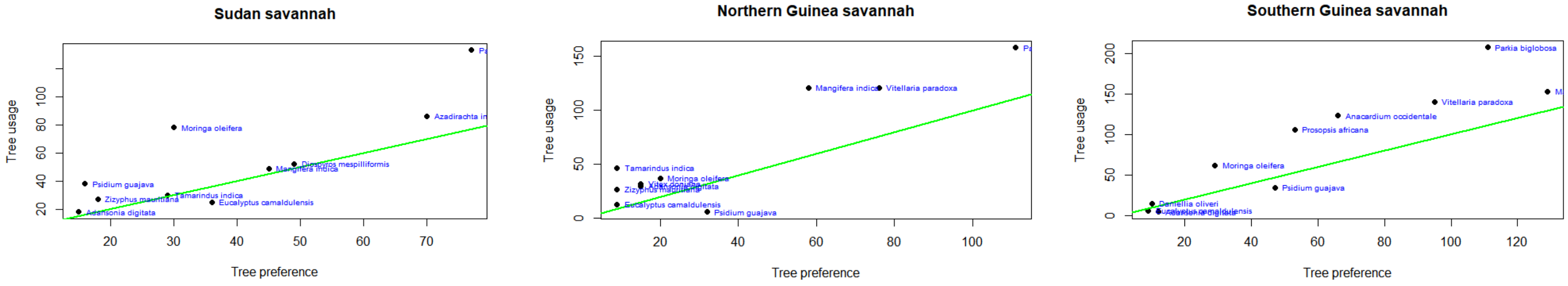
Table 4.3: The Spearman rank of correlation between tree species preference, uses and regeneration potentials

Coefficient	TREE SPECIES PREFERENCE		
	SS	NGS	SGS
Regeneration	0.461	0.611	0.681
Uses	0.718	0.731	0.839

The graphs below provided a visual representation of the linear relationship between the species preference using ranked values against the sum of frequency of all uses. Using the top ten species per zone, the results showed a stronger relationship between preference and uses of parkland trees across the three savannah AEZ than the regeneration potential. Fitting a regression line to the scatter plots showed the positive closeness of uses against preference. In the SS zone, *D. mespilliformis, T. indica* and 0*M. oleifera* are seen to trend with the regression line to ascertain the dependence of species preference on usage, just as correlated in table 3. Same applied to the other two zones, there is a close relationship between the species and their uses. Across the zones, there is a consensus on *Parkia biglobosa* and *Vitellaria paradoxa* as the best tree species on the farmed lands for its great diversity as a parkland (except SS zone for *V.paradoxa*). This is because the species high scores is confirmed in all the zones studied.

The scattered plots also showed the relationships between the regeneration potentials and species preference. The relationship is generally positive (46.1 % to 68.1 from SS to SGS) as seen in the above table. However, it is not enough to define that farmers depend on the growth rate of any species across the zones to rate the respective species as one of the favourites on any farmland. The positivity of the relationship increases as the AEZ shift southwards. Generally, the farmers understanding of tree growth rate differs as seen above in the response of farmers understanding of tree growth rate during regeneration of farms. Hence, farmers' consensus is that species preference is dependent on the multidimensional value of that species to the local community.

(a)


Sudan savannah
Tree usage
Tree preference
Moringa oleifera
Azadirachta in
Psidium guajava
Zizyphus mauritiana
Tamarindus indica
Adansonia digitata
Eucalyptus camaldulensis
Mangifera indica
Diospyros mespilliformis
Northern Guinea savannah
Mangifera indica
Vitellaria paradoxa
Tamarindus indica
Moringa oleifera
Eucalyptus camaldulensis
Psidium guajava
Southern Guinea savannah
Parkia biglobosa
Vitellaria paradoxa
Anacardium occidentale
Prosopsis africana
Moringa oleifera
Psidium guajava
Daniellia oliveri

(b)

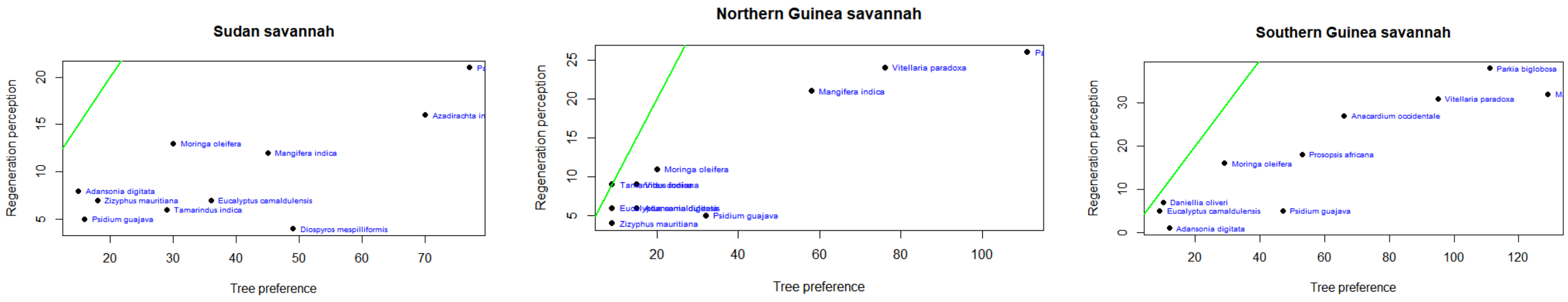

Sudan savannah
Regeneration perception
Tree preference
Moringa oleifera
Mangifera indica
Azadirachta in
Adansonia digitata
Zizyphus mauritiana
Eucalyptus camaldulensis
Tamarindus indica
Psidium guajava
Diospyros mespilliformis
Northern Guinea savannah
Vitellaria paradoxa
Mangifera indica
Moringa oleifera
Psidium guajava
Zizyphus mauritiana
Southern Guinea savannah
Parkia biglobosa
Vitellaria paradoxa
Anacardium occidentale
Prosopsis africana
Moringa oleifera
Daniellia oliveri
Eucalyptus camaldulensis
Psidium guajava
Adansonia digitata

Figure 4.5: (a) The number of respondents relationship between ranked parkland species preference and the usage of the species. (b) The number of respondents relationship between mean of ranked parkland species preference and the regeneration perception. The green line in the graph indicates the line of best fit, showing positivity of the correlation coefficient

.

4.3.5 Challenges in parkland landscapes

In the parkland communities of the three studied zones, low fertility is reported as the most challenging problem with Northern Guinea savannah farmers having over 40% responses compared to the other two zones with about 30% each (Figure 2). In farmers' term, soil fertility is considered low when soil is not lumping together when gripped tightly under human fist and light brown. Soil organic manure and high moisture content are considered locally to be fertile using colour (dark brown) and texture (sticky loamy clay type of soil). In this context, the soils were dry, coarse and light in colour with no lump when gripped under human fist. Other tree-soil related problems encountered in the farmlands, according to the interviewed farmers were as follows; i. Erosion & flood ii. Pest and diseases, iii. Drought and landscape degradation. In all the zones, deposition of sand dunes, sheet and gully erosion and unwanted floods are climate-change induced drivers affecting the zones with ranges between 18 - 30%, 16 - 25% and 8 - 15%, respectively. These factors are causing parkland savannah ecosystems more drought and degradation and poor seed among others, according to the respondents.

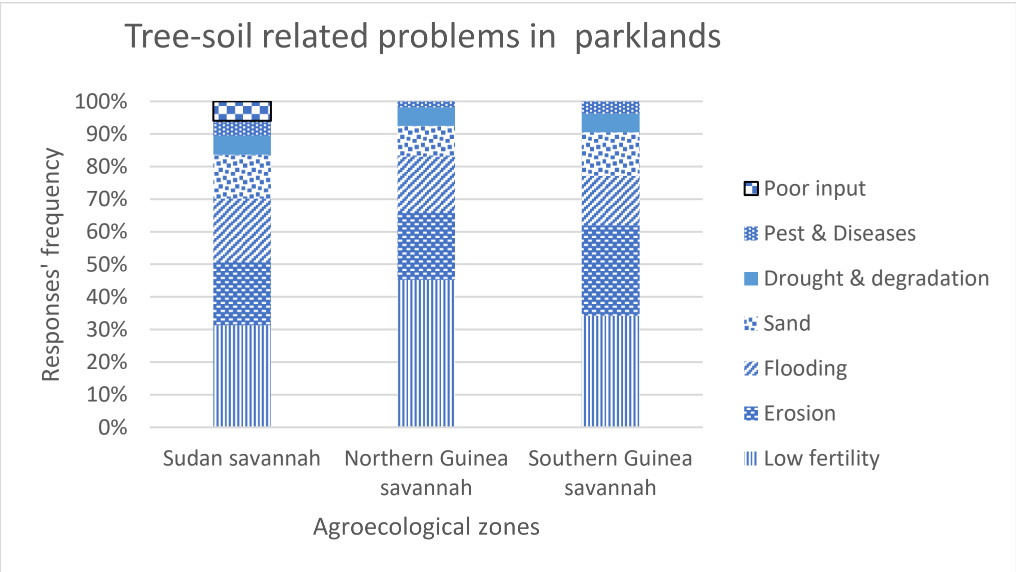


Figure 4.6: Tree-Soil related problems encountered in the farmlands according to interviewed farmers (N=96)

4.3.6 Local knowledge on ethnobotany and management of four parkland species based on their dominance across zones

The following sections are responses of farmers to how tree roots interact with crops based on their perception. The analysis was done using Kruskal-Wallis H rank sum test. The Kruskal-Wallis H test is a rank-based nonparametric test used to determine if statistically significant differences exist between two or more groups or treatments of an independent variable on an ordinal dependent variable. The agroecological zones formed the three groups tested using independent responses for this research.

4.3.6.1 Local knowledge of suckers sprouts on parkland tree roots

The sprouting of suckers from root stems beneath the ground surface of savannah parklands is common trait among tropical trees. As sprouting in trees improves their survival ability under different stressful conditions, including drought (Del Tredici, 2001), this improves their resilience. Root suckers are often rare in savannah landscapes, except under anthropogenic disturbances (Mwavu & Witkowski, 2008) but when it occurs, the sprouting of seedlings from the tree roots can be located either within the tree canopy area or outside the tree canopy area and sometimes both. The existence of suckers sprouting on the damaged and undamaged protruding roots had no statistically significant differences (Fig 5) when compared among the three zones. Although, among different species across the zones, respondents' information on sprouting suggests finding suckers outside the canopy is a rare occurrence, except in leguminous tree, *P.biglobosa.* The sucker's position is classified in the study for illustration purposes (see appendix 1.1) as thus; i. under canopy area, ii. outside canopy area, iii. Both areas, iv. None of the areas (No suckers).

Plate 2: Illustration of tree suckers during interviewing session with community members at the village square meeting in Giri (Southern Guinea Savannah), Nigeria. (Photo – Abdullahi Salihu, 2017)

Majority of the respondents constituting over half the total number had reported non-sprouting of suckers from the tree roots for all the most important species selected. This is indicated in the boxplots below (Fig. 4.7) showing quartile range of the respondents to be above 50% for NGS and SGS. The boxplot is a graphical summary of median range using percent quartiles. Although the boxplots had outliers at the outside and the both canopy graphs for SGS respondents, Sudan savannah respondents (with less than 25% quartile) are unsure about seedling sprouting from tree root. Using the Kruskal-Wallis non-parametric test of significance, no differences among all the sampled zones with seedlings sprouting under canopy area (χ^2 [N = 96, df = 2] = 0.94785, p-value = 0.6226) and outside canopy area (χ^2 [N = 96, df = 2] = 3.806, p-value = 0.1491) (see appendix 1.3). The Kruskal-Wallis test was applied because the observed trees are independent, and the data did not meet test of normality condition. Hence, significance difference was assessed by testing the differences among the three zones sampled. It was observed that respondents' ethnobotanical knowledge of tree suckers enhances the contribution of trees on farms to replenishing soil fertility or inhibiting cash crop growth via completion for nutrient and light. However, farmers in the studied zones are not keen on using collecting materials from suckers for multiplication or regeneration but protect suckers only if the species is desired and survive the dry spells as wildlings. Sudan savannah farmers had the least idea on sprouting seedlings and coppicing as it is the zone with precipitation of shortest regime and volume in this study.

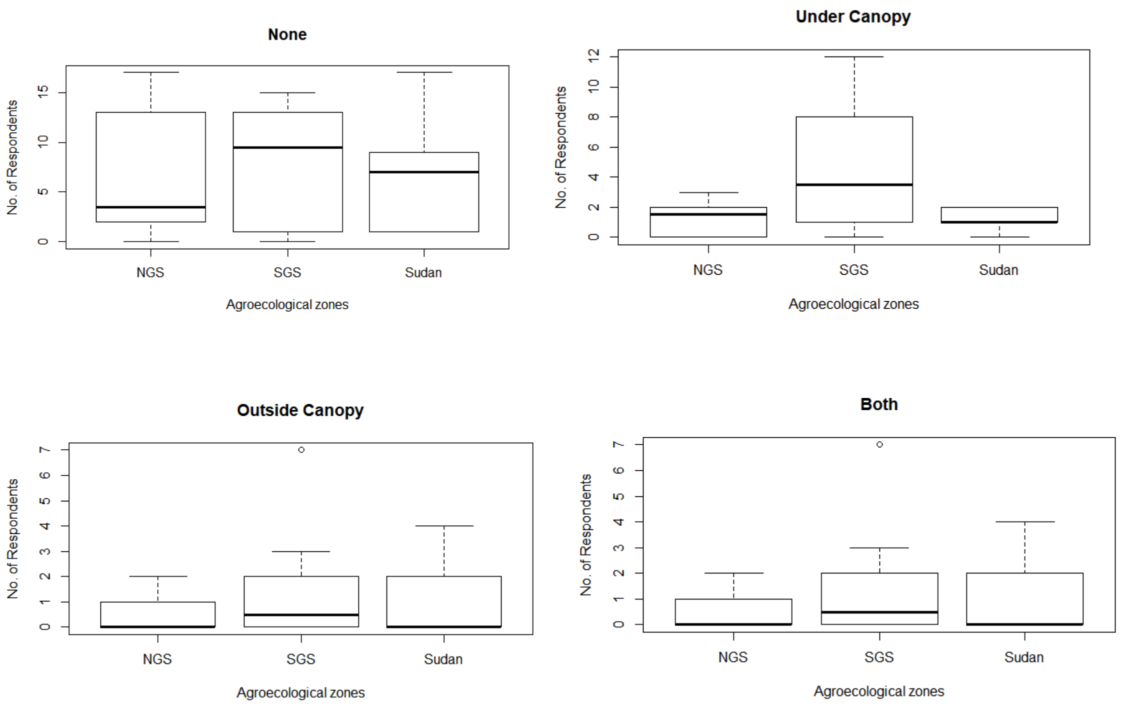


Fig. 4.7: Differences in local perception on the growth of Suckers from the roots of top 5 parkland trees in the selected agroecological zones. Abbreviation: SGS- Southern Guinea savannah, NGS - Northern Guinea savannah, Sudan – Sudan savannah

4.3.6.2 Local knowledge on parkland tree root spread

Tree roots grow predominantly below the soil surface (up to 100 cm in depth) and extends beyond the tree height or the canopy area, based on scientific reports (Guerrero-Campo *et al.* 2006, Persson & Baitulin 1996, Ranganathan *et al.* 1996). The ethnobotanical knowledge of farmers in Nigeria on roots morphology is significant to tree-crop interaction to improve agroforestry productivity. Regarding the root spread, they were classified into above, equal and below. This was illustrated to farmers that the extension of root morphological length could be longer, same and smaller respectively in relation to tree canopy cover (appendix 1.1). In this research, perception of farmers' on root spread for the three studied zones (Fig. 4.8) as presented in the boxplot had outliers in NGS for equal spread as well as SS and SGS for below the canopy spread. In the three graphs, SGS had between 50-75% quartile range, indicating the highest number of respondents with understanding of root spread of trees on their farms. The above canopy spread graph had upper whiskers in all the zones, resulting in high 3rd quartile values. On the the Kruskas-Wallis test of differences among the zones, there is no difference in the mean of all respondents. This is because the mean distribution for all the tree spread types were less than the Kruskas-Wallis chi-square values. (appendix 1.3). All root spread responses were distribution for the 10 preferred parkland trees of each agroecological zones are statistically same for above, below and equal spread of roots with tree canopy perception (Fig. 4.8).

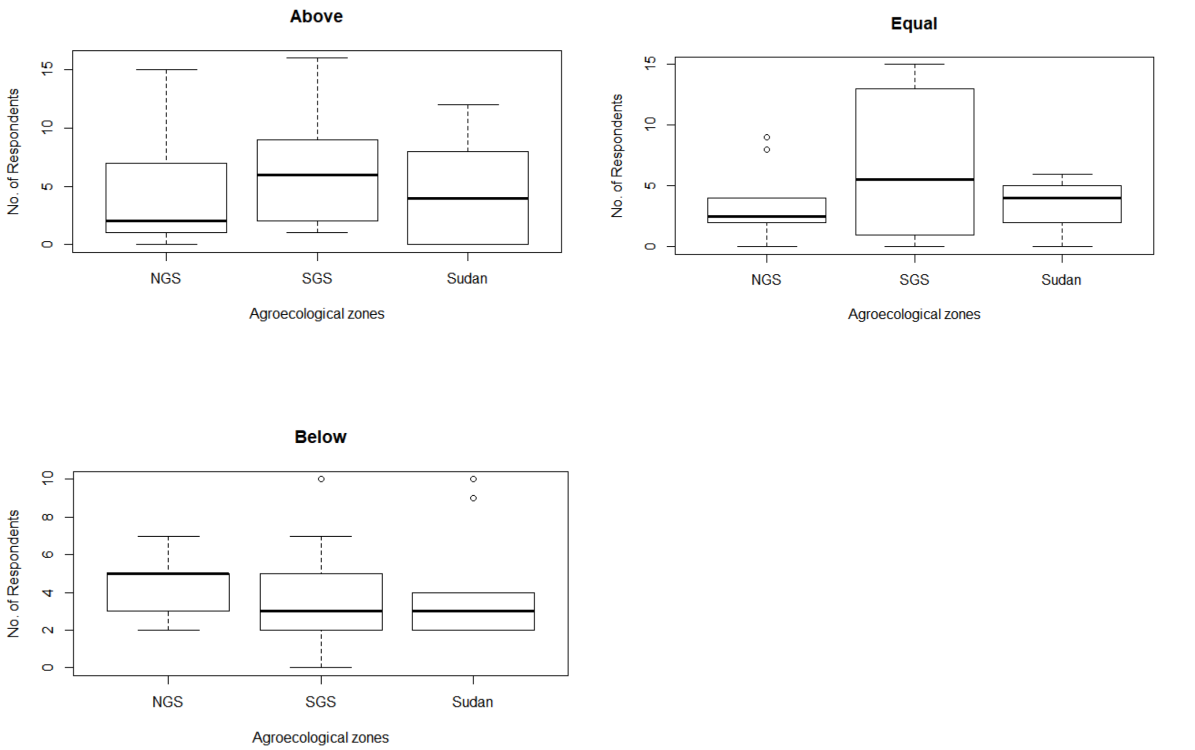


Fig. 4.8: Respondents knowledge on root spread of 4 valuable parkland species across the zones (Fieldwork, 2016). Abbreviation: SGS- Southern Guinea savannah, NGS - Northern Guinea savannah, Sudan – Sudan savannah.

4.3.6.3 Respondents' opinions on farming around the parkland trees

The coexistence of managed woody perennials and agricultural crops and grasses in savannah ecosystems is what made up parklands. A simplified diagram (see appendix 1.1) of trees relationship with agricultural crops was used for illustrations to allow farmers, in the three studied zones, select the planting status of the annual crops in and around the tree on their respective farmlands. The current interest is the closeness at which relative tree abundance cover is cropped when found in parklands. The farmers' responded to three patterns around the tree canopy – Outside, Under and Within. Results indicated that there were statistically significant differences in the perception of cropping 'outside' tree cover by farmers in SS, NGS and SGS, chi-squared ($N= 96$, $df = 2$) $=7.7736$, p-value $= 0.02051$ using Kruskal-Wallis One-Way ANOVA at 5%. Dunn's Multiple comparison test showed the difference ($p<0.01$) between SGS and Sudan savannah (0.014). The planting of food crops under and within tree covers in parklands showed no significant differences according to the respondents (Fig 4.8). Over half of the respondents, mostly grandparents, across the SGS zones selected the outside tree canopy cover as the extent of the root spread in all the important native species. Though, an exotic parkland fruit tree species, *A. occidentale* had more respondents (over 50%) agreeing that the root extension below ground is the same as the tree cover. There was also a strong association between respondents that selected under the tree canopy cover are young farmers with less than 2ha of farmland size. Cropping around the tree edge expresses the differences in quality and/or structure between the agricultural crops and affected trees planted in savannah forest and arid zones as it relates to soil carbon (Bayala *et al.* 2006). This is because *Parkia biglobosa* and *Vitellaria paradoxa* were reported to have influenced carbon and nitrogen content by over 10% more than open field with planted cereals (Oyebamiji 2016). It also confirmed that tree response to the annual crop effect was species-specific (Bourgeois *et al.* 2016, Oyebamiji 2016). Agricultural intensification on an optimum scale alley cropping design is dependent not only on soil fertility but also on fixed land size management (Ranganathan *et al.* 1996)

Plate 3: Meeting session with community members, including the Imam (spiritual leader) at the village mosque after ceremonial Friday prayer service in Kargo (Northern Guinea Savannah), Nigeria. The mosque is one of the most important centres to circulate information and settle disputes among farmers in Northern Nigeria. (Photo – Abdullahi Salihu, 2017)

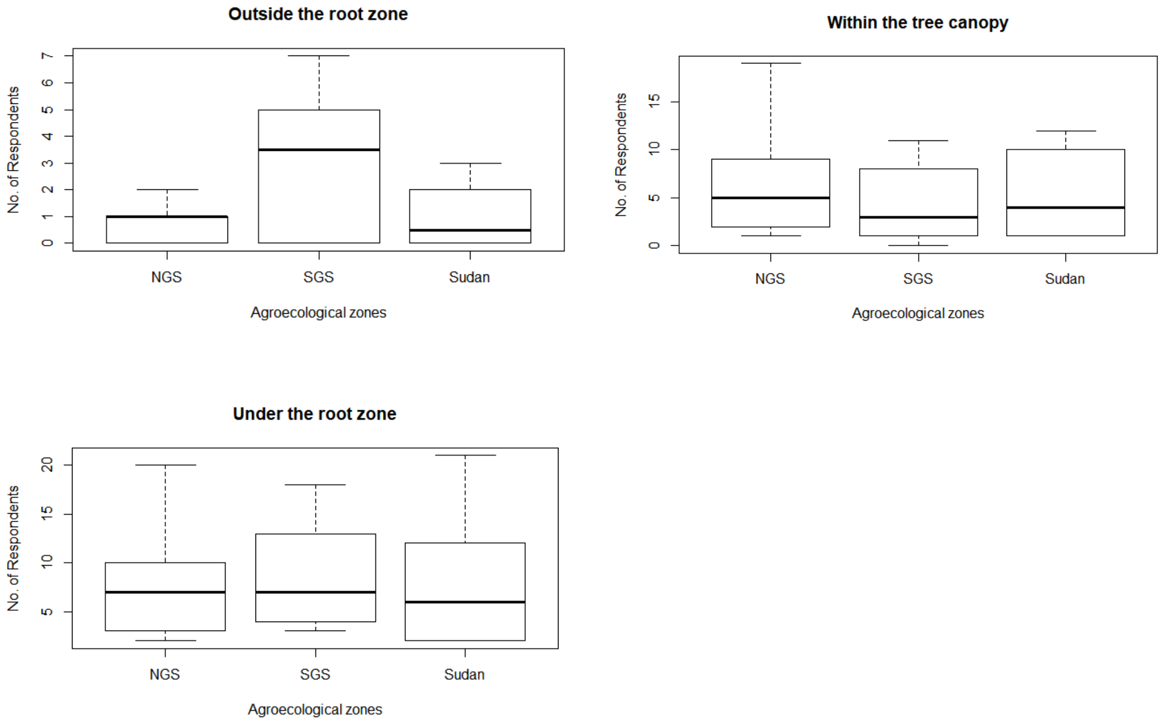


Fig. 4.9: Cropping around trees on farms according to respondents across the zones

Table 4.5: Mean and standard deviation of Root spread and suckers as perceived by farmers

	SS	**NGS**	**SGS**
Root Spread	MEAN±SD	MEAN±SD	MEAN±SD
Under Canopy	4.1±2.96	4.4±1.58	3.7±2.98
Equal Canopy	3.8±1.93	3.3±3.02	7.2±5.99
Above Canopy	4.3±4.27	4.4±5.27	6.6±4.50
Root Suckers	MEAN±SD	MEAN±SD	MEAN±SD
None	6.6±5.64	6.3±6.73	7.5±5.94
Under	1.2±0.79	1.4±1.17	4.5±4.14
Outer	0.9±1.37	0.6±0.84	1.4±2.22
BOTH	1.9±1.79	1.8±2.09	0.3±0.48

4.3.6.4 Farmers' perception of tree root and local knowledge in propagation methods

Across the savannah zones, the intensity of drought on the farmlands is increasing, just as soil fertility declines based on the results in section 4.3.2, particularly the Southern Guinea

Savannah zones (SGS). On average, 35 % of the respondents in all the zones had no idea on the physiological forms of parkland tree roots during drought (Figure 7). Farmers from SGS zone also had the highest number of respondents (51%) reporting dryness and corky texture on the outer layers of the exposed or dug out roots. On the other hand, 75% of the farmers in NGS mentioned leaf abscission as a mechanism of survival for the parkland trees during drought. There were less than 18% each of the respondents in the other two zones confirming desiccation during drought. About 63% of the responses in SGS discussed that the trees adaption measure include root extension through deeper tap and fibrous root system supports soil compaction and reduces sheet erosion.

Plate 3: Interactive session with farmers at the village market in Ringim (Sudan Savannah), Nigeria. (Photo –Abdullahi Salihu, 2017)

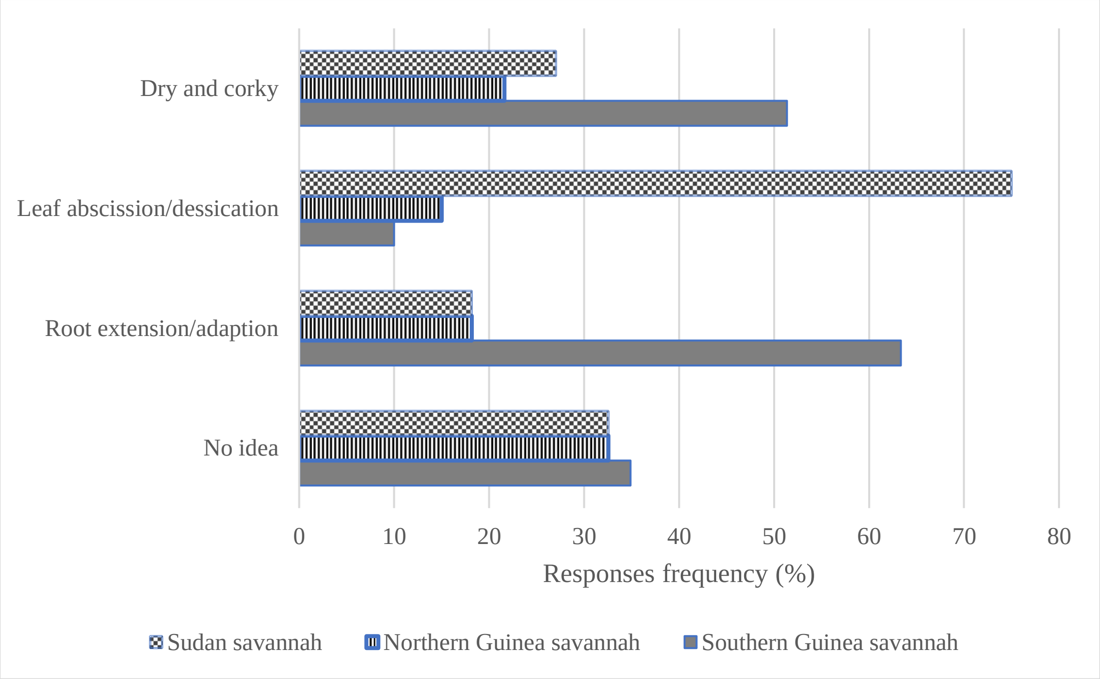


Figure 4.10: Perception of farmers on tree root response to drought across the AEZ

Figure 8 graph showed that the two studied Guinea savannah agroecological zones have fewer than 15% of respondents that mentioned coppicing in their regeneration management strategy On the other hand, over 40% of Sudan savannah farmers focused mainly on vegetative propagation through cutting to regenerate fast-growing species (mostly wind breakers) mainly as shelter belts against Sahara Desert encroachment in the northern region. This is according to discussions in one of the focused group meetings in Sudan savannah. Seeds and wildlings management are the most common methods of propagating tree species across the zones, based on respondents' feedbacks.

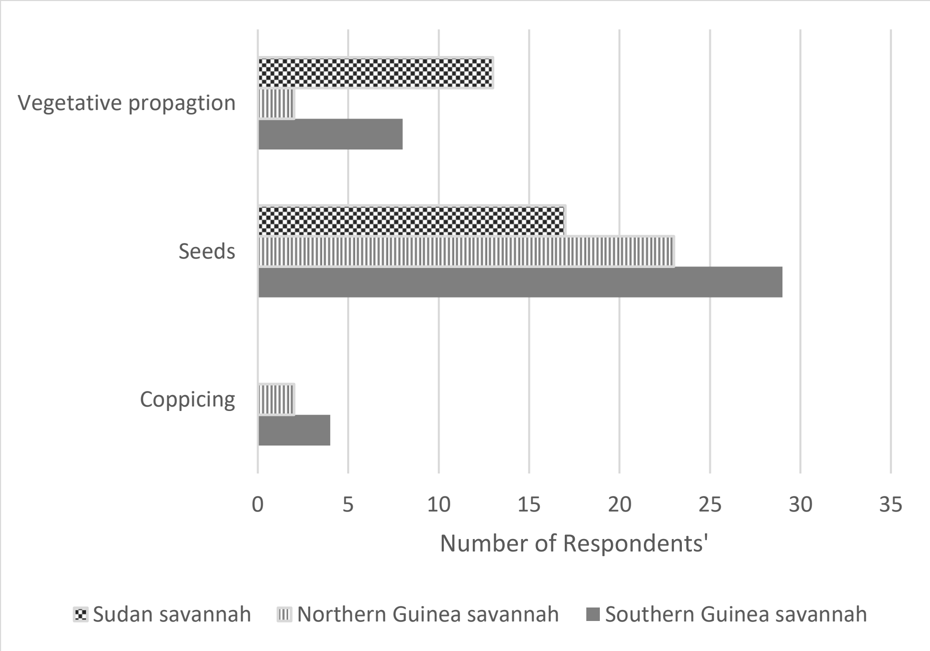


Figure 4.11: Propagation methods used in regenerating parkland trees according to the respondents

However, one of the respondents claimed most farmers in the zone rely on coppiced shoots of *D. mespiliformis* due to demand of the species among the locals as provider of high nutritional supplement during the dry season when food is scarce. *D. mespiliformis* is proven to have more than four times (25-50 mg per 100 grams) vitamin C on the apple skin and interestingly, a significant carotenoids content found in tomatoes called lycopene (NAS 2008). Table 4.5 below details the species found in parklands of Northern Nigeria that have been confirmed to be vegetatively propagated. The potential to regenerate easily through cuttings in the semi-arid areas was reported for the species in the table. The skills of propagating using cuttings is limited to agricultural extension workers and they are not willing to share the skills with the farmers. This is because extension workers make profit from plant materials, according to the respondents (not documented during the field research for confidential reasons).

Table 4.5: Propagation methods

Agroecological zones	Vegetative Propagation (Cuttings)	Coppicing
Sudan Savannah	*Mangifera indica, Eucalyptus camaldulensis, Azadirachta indica, Moringa oleifera,*	*Diospyros mespiliformis*
Northern Guinea Savannah	*Mangifera indica*	*Vitellaria paradoxa, Mangifera indica, Parkia biglobosa*
Southern Guinea Savannah	*Anacardium occidentale, Prosopis africana,*	*Vitellaria paradoxa, Parkia biglobosa*

4.3.6.5 Propagating parkland trees: Challenges and opportunities

Respondents across the studied AEZ emphasised on drought as one of the leading challenges in parkland regeneration. The effect of climate change is visible to the farmers in all the zones on the farm plots, evidence is on the next chapter during farm visits and field sampling measurement. Sudan Savannah is the most affected drought threatened AEZ with predation and pests as problem among others (Table 4.6). Predation involves the children (and sometimes, women) in the community fetching fruits and wood from the trees without owner's consent. This leads to loss of revenue and sometimes conflict. For instance, during one of the field trips, three young boys (8-12years) sneaked in to the farm with cashew fruits ready for harvest (Plate 3). It is difficult to check the culprits because addressing the issue is observed as a threat to the social fabrics of the communities affected. The culprits are mostly wives and children of close-relations and friends living in same community with farmers.

All the farmers agreed that growing trees with annual crops needs improvement and opportunities exist in the practice.

Plate 3: A young boy was caught on camera quietly climbing a cashew tree to steal from its fruit during one of the field visits in Gwako village near Abuja (Southern Guinea savannah), Nigeria. (Photo – Ibrahim Abdullahi, 2017).

Table 4.6: Challenges and Opportunities for Improvement

AGROECOLOGICAL ZONES	Challenges	Improvement
SOUTHERN GUINEA SAVANNAH	Predation, pests, low rainfall, Poor propagation techniques, poor tree form	Pruning, Improved germplasm and practices and propagation
NORTHERN GUINEA SAVANNAH	Predation, pests, drought, Poor propagation techniques, poor tree form	Alternative energy source for cooking, Improved germplasm, Tree spacing
SUDAN SAVANNAH	Predation, pests, juvenile mortality, drought, Poor propagation techniques	Improved germplasm, pest control and spacing, and better agricultural practices, alternative energy source

4.4 DISCUSSION

4.4.1 The respondents

Across the villages sampled, male farmers dominated the three agroecological zones and the female farmers were found only in the Southern Guinea Savannah (Table 5). Male dominance in farmland ownership rights is a cultural trend in sub-Saharan Africa. Reports on gender productivity differences indicated that female farmers are more productive in terms of yield, with a slight increase up to 2.8% (Mukasa and Salami, 2015). The women in Nigeria made up to 7 in every 10 labour-force in agricultural activities, with services provided mostly as unpaid family labour but are sometimes rewarded with fruits and nuts, fuelwood from trees from parkland trees within the farms as incentives (Adamu and Idisi, 2014).

Plate 6: Interview session with a woman farmer (Village chief wife) in Kilankwa village (Southern Guinea savannah), Nigeria. Women are not landowners, but work on the family farm as lease until they acquire community recognised status, such as Chief's wife as seen in the picture.

This is because access to land is still challenging to women in the savannah areas due to cultural barriers, making acquisition of large expanse of land very difficult, particularly for women that aspire to be land owners (Ogunlela and Mukhtar, 2006). Nevertheless, less than 20% of women with high social status can acquire land, e.g Community chief wives and women leaders (plate 6). Poor and ineffective land tenure system is another problem hampering land ownership and trees management in the savannahs of Nigeria. Other challenges include, but not limited to gender inequality, cultural barriers, lack of access to farm inputs, as well as credit facilities (Adamu and Idisi 2014, Ogunlela and Mukhtar 2006). Faye *et al.* (2011) & Miller *et al.* (2016)

acknowledged the challenges of farm sizes to tree preference and availability in their report. The average farm size in Nigeria is influenced by availability of resources, including farmers' socio-economic status, land availability, credit loan facilities as well as favourable government policies to irrigation and fertilizer (Onogwu *et al.,* 2013)

Table 5: Respondents information summary

Agroecological Zone	Gender (%)		Tenure (%)		Farm size (/ha)
	M	F	L	H	
Sudan savannah	100	0	76.7	23.3	3.83
Northern Guinea savannah	100	0	90.5	9.5	5.5
Southern Guinea savannah	83	17	80.5	19.5	2.84

Key: M-Male, F-Female, L-Landowner, H-Homeowner

4.4.2 The significance of parkland tree preference in a changing climate

The preference for a parkland tree species was dependent on the location and availability as confirmed in the reports of Faye *et al.* (2011) that relative significance of a species differ among West African ecological regions, as there are positive and negative associations. For instance, *Adansonia digitata*, *Parkia biglobosa* and *Vitellaria paradoxa* are all parkland trees widely preferred and attributed with multipurpose potentials for food and non-food products as well as services, including traditional religious rites and are propagated across all zones. (Kamatou *et al.* 2011, Teklehaimanot *et al.* 1996, Venter & Witkowski 2013). However, the priority for product and services of these species across Nigeria's agroecological landscapes slightly differ but not significant as confirmed by most farmers in the respective zones studied.

The lack of relationship between the SS and SGS, in terms of tree species preference is an indication of the degree of variability in the climatic features that sustain biodiversity in the respective zones (Eludoyin & Adelekan, 2013). The exotic species introduced as a plantation species became successful across Nigerian agroecological zones, particularly in the Guinea savannahs, overtime due to high potential value as fuelwood for the locals and its phenotypic traits of drought tolerance mechanism in a fast-growing soft woody stem (Otegbeye, 1992; Otegbeye & Samarawira, 1991). *Eucalyptus camaldulensis* has spread across the landscapes of Northern Nigeria either as an ornamental plants in schools and government building surroundings or as fuelwood and shelterbelts on parklands (Watanabe *et al.,* 2009). Another highly rated exotic tree species *Mangifera indica* and *Anarcadium occidentale* in Southern Guinea savannah (SGS) became parkland species due to their adaptability and economic importance in West African tropical savannahs (Gonzalez, 2001; Thimmappaiah *et al.,* 2008). The adaptability is attributed to the species response to fast growth, easy propagation as well as desirable fruits and highly valued nuts (Aliyu, 2007; Chipojola *et al.,* 2009). In short, the preference for species is not only dependent on the ecological functions, including aesthetic value on savannah landscapes but also improving livelihoods of the people via income/incentives and nutrition. *Parkia biglobosa* that appeared as top-ranked have been reported as species with products of commercial and nutritional value among the locals, with great energy potentials (Faye *et al.,* 2011; Faye *et al.,* 2010; Simons & Leakey, 2004; Von *et al.,* 2015). Other parkland species like *Vitellaria paradoxa*, *Tamarindus indica* and *Ziziphus mauritiana* that topped the rank of species mentioned between two more AEZ are local species that are abundant on farms and are protected for highly valuable end products (Further discussion on abundance in chapter 5). The products include fruits with high vitamins, oil, local juice extract, gum, fodder and fuelwood (Lovett & Haq 2000, Miller *et al.* 2016b, Ouedraogo *et al.* 2017). Hence, the local knowledge on the usage of parkland trees is a significant component in the process of conservation and sustainability of agrobiodiversity. This is because all the trees on farmlands form vital part of the economic, social, and cultural life of the communities they are found (Ong and Huxley 2003, Boffa 2000).

4.4.3 How tree products and services influence species choice

The composition of trees under parkland management is dominated by three common species, *Parkia biglobosa, Mangifera indica*, and *Vitellaria paradoxa* all three of which are mentioned by 87 out of 96 respondents. *Vitellaria paradoxa* as a parkland tree offers some great products and services to the rural economy, producing highly valued fuelwood, fodder and nuts due to its potential to survive drought and competition among other species (Jensen 2017). Although, pressure on the *V. paradoxa* in Sudan savannah caused conflict in the communities as reported, resulting in difficulty to get information on its services. *Diospyros mespilliformis* is a native species that is gradually replacing *V. paradoxa* with prospects to optimize as dryland species and preferred by the locals in Sudan savannah for its wide range of services. *Parkia biglobosa* had over 50% of the respondents confirming all the functions on the table. The green and leafy fodder from dominant *Mangifera indica*, an exotic fruit tree on the other hand had provided incentives to farmers through its fruits as products in addition to other services (Faye 2012).

Over 90% of the most preferred species are edible tree fruits with potentials for optimizing as dryland resource to supplement much-needed nutrients, provide fuelwood, generate extra income for the poor farmers as well as manure thorough litter fall over time as confirmed in the reports of Maisharou et al. (2015) and Faye *et al.* (2010). Hence, the preference for parkland species, including exotic species such as *Eucalyptus camaldulensis* across the agroecological zones (despite its non-edible fruit feature). The species is one of the success stories of British colonial days afforestation programmes in Nigeria (Otegbeye & Samarawira, 1991). The species was introduced due to its drought tolerance mechanisms, particularly for poor soils, coupled with fast growing stems known for quality fuelwood. The species is also highly valued for shelterbelts and energy in the two densely populated zones in Nigeria (Watanabe *et al.*, 2009). *Daniellia oliveri*, one of the species transecting between the two Guinea savannahs is one of the largest in terms of size. The species preference is related to the leguminous potential of fixing nitrogen and providing fodder to farmers, all year round (Olafadehan & Okunade 2018). *Azadirachta indica* and *Vitex doniana* are other trees covering the two Guinea savannah landscapes. While the former, an exotic species introduced to act as shelter belts and provide fuelwood, the latter is a native tree sustaining livelihoods as condiments and desserts in the country's semi-arid region. The two Guinea savannah zones occupied the largest vegetation belts in Nigeria, extending from the Northern region into the edges of the southern region. The vegetation is characterised with heavy grasslands, exotic and native trees that are mostly significant to livelihoods as well as cultivation of tuber, cereals and legumes by farmers all year round (Foli 2012).

4.4.4 Tree-crop interaction on savannah parklands

Cultural management of parklands enhances the physiological interaction among the tree-crop relationship thereby influencing the parkland tree species to withstand drought below ground (Philips *et al.* 2015, Ong and Huxley 1999, Schroth and Sinclair 2003, Faye *et al.* 2011). This is seen in the relationship between tree species and crops grown 'outside the root zone' differences among the zones. Shorter precipitation regime favoured cereal and legume crops on farmers' field over tubers in SS zone (Lawry *et al.* 2015, Maisharou *et al.* 2015).

Most parkland tree species are regenerated through Farmer-managed Natural Regeneration technique (Bayala *et al.* 2012). These include the protection of wildlings, mostly regenerating as coppiced, seeding or even suckers on parklands and sharing water and nutrient resources with annual crops grown by farmers via root systems, even during the dry spell (Rao *et al.* 1997). The farmers ranking of parkland trees can not only be attributed to product and services but also on the ecological influence on annual crops. This is because farmers' choice of planting close to certain tree canopies and maintaining low density through pruning is a confirmation of species specific for farm sites. This is confirmed in the report of Bayala *et al.* (2019) on the role of regenerated trees influence on soil carbon and nitrogen in 300 farm sites across West Africa. Meanwhile, a better understanding of how mature but unorganized parkland trees on farms distribution of root change with extreme climatic conditions, particularly during water-stress is still under research (Guerrero-Campo, *et al.,* 2006; Schreeg *et al.,* 2005; Xiong *et al.,* 2017). However, the findings that rooting depths are proportional to the infiltration depths is not the view of most farmers as they lack insight of root structure beneath the soil (Laio *et al.,* 2006). More also, farmers' knowledge on natural regeneration by suckers from protruding roots on soil surface and on how roots can further affect crops did not differ based on AEZ. This corresponds with the findings that the role of suckers in *Acacia* spp. plantation to cover open pasture overtime through restoration, despite the low disturbance of the landscapes but do not affect tree cover or pasture (Scowcroft & Yeh, 2013).

4.4.5 Challenges and opportunities of parkland tree management in Northern Nigeria

Gautier *et al.* (2006) reported savannah landscapes are shrinking in size and farmers are attempting to compensate increasing tree density but not without challenges. The challenges are hindering the realisation of sustainability in agroecosystem ecology and the potential of optimizing dryland resources in Nigeria. Extreme drought event is one big challenge in sub-Saharan Africa, associated with el-Niño, contributes to drier conditions resulting from lower than annual average precipitation and shorter growing periods leading to stunting growth of crop plants (WFP 2015).

The search for woodfuel is impacting on the timber resources as very little or no alternative energy sources are available for the rural poor, despite the oil and gas potentials in Nigeria (Cline-Cole & Maconachie 2016). The over-dependence on fuelwood is another challenge that has caused depletion, specifically parkland trees on farms. This loss has resulted to persistent increase in pastoral-farmer conflicts over limited land and water resources for over two decades

(Papaioannou 2016). For instance, experts have associated farmers and herders conflicts over use of land and water resources to changing climate. The conflicts are poorly managed by the authorities and in some occasions end in violent clashes and political rivalry in north-central Nigeria (Dimelu *et al.* 2017, Ibrahim 2019). These conflicts affect parkland trees as one of the most important land resources contributing to rural livelihoods in Nigeria (Madueke, 2018). Hence, this study further confirmed previous reports in other west African nations that share the regional agroecology that over-exploitation of the parkland resource is imminent and inducing local conflicts, especially in the Sudan savannah zone, the driest agroecology area in Nigeria (Boffa, 2000; Faye, 2010; Hänke et al., 2016; Ogbonnaya, 2003). Furthermore, massive pressure on demand for tree products and services such as *Vitellaria paradoxa* and *Parkia biglobosa* (particularly by women) due to their high commercial value, medicinal properties, and succulent fodder across the zones, without considering ownership rights is worrying (Elias 2015, Abdullahi *et al.* 2013). Other issues facing parkland tree management on farms include predation (theft), excessive branching and poor tree forms. All over the AEZs, communities agreed that tree products are stolen but no consensus is reached to accept it as problem. This is because the stealing of fruits from trees is mostly done by children and fruit gatherers.

In order to reduce the conflicts resuting sometimes in loss of lives, some communities in Sudan savannah came up with an informal but ‘environmentally unfriendly’ solutions that include cutting down tree species (specifically the Shea nut tree) on parklands’ as a strategy to manage conflict in the region. This is because governance at the rural level is almost non-existence and communities leaders are left with very little choice to resolve stiff competition over biological resource, despite afforestation and reforestation program intervention (M. Abdullahi, 2018)

Opportunities exist for regeneration through coppice and wildlings grown from dispersed seeds. Across the zones, the spatiotemporal variation in climate risks made an adaptation of vegetative propagation in Sudan Savannah thrive over coppicing methods as farmer-managed tree regeneration is not sufficient to sustain the parkland systems (Bayala *et al.*, 2014). Farmer-managed tree natural regeneration had a very significant effect on the regeneration of parklands, especially in managing coppiced shoots in the Guinea Savannahs but the survival of saplings is still at a very minimal rate in the Sudano-sahelian regions (Larawnou & Saadou 2011). The saplings from the seeds and protected wildings on farmlands are exposed to risks due to recurrent drought and splash floods in the Savannahs leading to ecological degradation as a result of excessive agricultural practices to sustain the high population density in the region (Phillips *et al.,* 2016, Fasona *et al.,* 2013).

4.5 CONCLUSION

Local knowledge of farmers on trees management and regeneration through tree-crop interaction in managing regional climate risks is important, and as come of age for location-based and species-specific adaptation as argued in Brook and Pagella (2016) and Coe *et al.,* (2014). Tree species preferences differed slightly but not significantly across the zones, the drier zones had more varieties of tree species covering their landscapes just as confirmed in Faye *et al.,* (2011). The positive relationship between tree uses and preference with the parkland problem affirmed that local awareness of agroforestry to curb climate change drivers through adaption and mitigation is strong. It is clear that respondents manage exotic and indigenous tree and shrub species for several products services alongside the farm crops across the three agroecological zones. The services are functions of the provisioning and the environmental services.

The most outstanding species improving livelihoods and landscapes of rural northern Nigeria is *Parkia biglobosa* due to its potential as highly valued tree resource in and outside farm plus its desirability and adaptability. In addition, more management techniques of regenerating tree through vegetative propagation is required through community participatory research approach. The potential optimization of few dryland resources to improve the parkland tree cover may not only significantly increase the landscape resilience and nutritional supplements of the communities, but also would also provide options for afforestation programmes to mitigate the effect of drought and desert encroachment in Northern Nigeria. Finally, the need for more investment in low cost innovation technologies and simple vegetative propagation skills to increase resilience and sustainability of parkland trees, in the face of changing climate.

CHAPTER FIVE: ASSESSMENT OF PARKLAND TREE SPECIES DIVERSITY AND ABUNDANCE ACROSS THE DRYLAND AGROECOLOGICAL ZONES OF NIGERIA

5.1 BACKGROUND TO THE STUDY

The West African region land cover loss between 1975 – 2000 is one of the highest in the world. Each year, land use and land-use change caused the loss of about 50,000 square kilometeres of natural vegetation(Cotillon, 2017; Eva *et al.*, 2000; FAO, 2018) . According to Arowolo & Deng, (2017) between 2000 and 2010, cultivated land use was the main driver of Land-use change process in Nigeria. The conversion rate increased significantly to about 5% of the total land area of Nigeria per year and conversion to agricultural land is the leading cause of forest and grassland loss. This is more intensified in the northern region, home to over half of the country's human population (World Bank Report, 2017). The adverse effect of cultivated land expansion includes threat to forest ecosystem, plant biodiversity and carbon emission (Zomer *et al.,* 2016). Land-use change in sub-Saharan countries is still on the increase, resulting in community conflicts such as farmers-herdsmen struggle in some parts of Northern Nigeria over resources on parklands (Dimelu *et al.*, 2017; Lubeck, 2014; Tenuche *et al.*, 2009). In the previous chapter, parklands providing essential ecosystem services to sustain communities livelihoods across agroecological zones of Nigeria was discussed.

The sustainable management of parkland is significant to maintaining biodiversity and improving the productivity of Sahelian agroecosystems of West Africa (Bayala *et al.,* 2015). The agricultural landscapes of Nigeria's dryland is part of the vast parklands cutting across West Africa and generally believed to be rich in economic woody perennial plant species, despite the soil low fertility (Aleza *et al.,* 2015; Bayala *et al.,* 2006). These parklands possess significant features of different tropical agroecosystems in the region (R. R. B. Leakey, 2014). They also host some threatened tree species, such as *Vitellaria paradoxa* that are important to sustainable agroecological services optimization (Amiebenomo, 2002).

Trees establishment in parkland systems is either by seed planting or natural regeneration of seedlings (Teklehaimanot *et al.*,1996). Coppicing is another method which trees regenerate from cut stumps, commonly from deforestation remnants for agricultural purposes (Fentahun & Hager, 2010). The most common method is the management and protection of regenerating natural trees commonly referred to as Farmer Managed Natural Regeneration (FMNR) (Haglund *et al*,. 2011). Tree planting is a common practice in Nigeria's agroecological landscapes, and more pronounced in northern region due to intensive land use and drought (Ebenezer, 2015; Kayode & Francis, 2012).

Faye *et al.,* (2011) reported that parkland tree species have traits of drought-resistant and nutritional supplement potentials among others. They also confirmed that the trees can equally grow food and cash crops for sustainable livelihoods and food security. Parkland trees have been used to reduce the challenges posed by food insecurity, malnutrition, energy shortage, high temperatures, soil fertility as well as sheet erosions (Bayala *et al.,* 2006; Miller *et al.,* 2016). Although the biodiversity of Nigeria is relatively well quantified in terms of species and ecosystem diversity of the dense forest and mangrove regions (Kayode and Ogunleye, 2008; Edet *et al.,* 2011; Adeyemi *et al.,* 2013; Bello *et al.,* 2013), the parklands in the savannah agroecological zones mostly affected by anthropogenic forces are poorly documented in terms of tree species diversity and abundance on farms. This chapter is important for identification of valuable savannah parkland trees on farm plots in the studied agroecological zones. It would also confirm the status of the respondents' most preferred trees on farms detailed in chapter 4. Hence, the need to ascertain tree species diversity and status across three agroecological zones in the northern region to enhancing arable biodiversity through sustainable agroforestry parkland systems. This study therefore evaluates tree species richness and diversity across three agroecological zones in the dry and vast savannahs in northern Nigeria.

5.2 MATERIALS AND METHODS

5.2.1 Location of Study Area

The field study was conducted across three agroecological zones lying in the dry tropical and semi-arid landscapes of Nigeria, namely Sudan Savannah, Northern Guinea Savannah, and Southern Guinea Savannah. The field points are farm plots from communities across the three studied agroecological zones in chapter 4. Figure 1 is a map below showing an inset picture of agricultural landscape for respective locations in studied agroeclogical zone. Ethical permission to sample the trees on farms was sought from traditional community chiefs before the field procedure. The sampled farms belonged to respondents interviewed in Chapter 3. The characteristics of all the field points in the study were also described in table 1 of same Chapter.

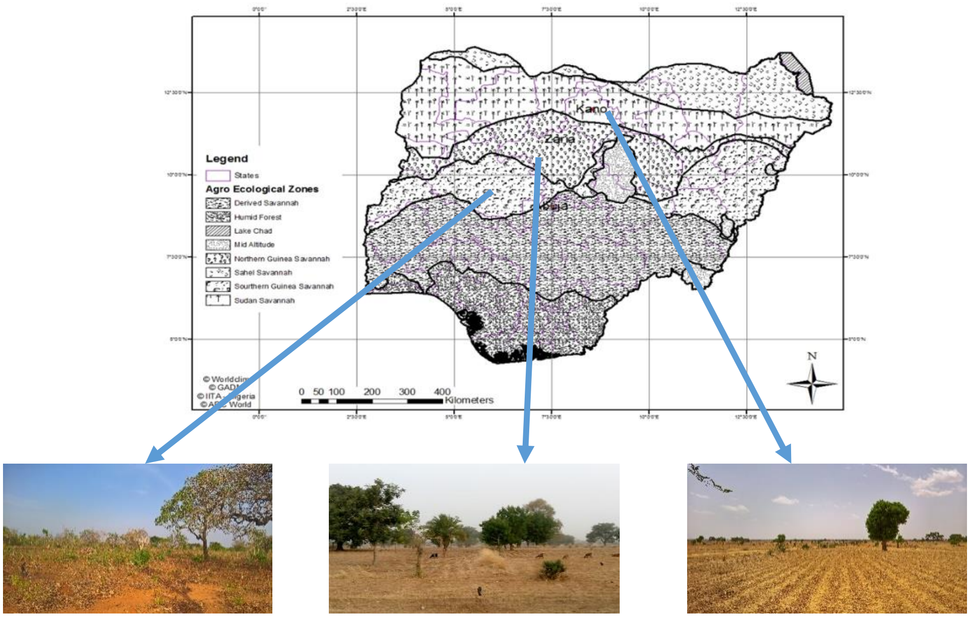


Figure 1: Images of parklands used as field points in the three agroecological zones of Nigeria for this research

5.2.2 Data Collection

The sample plot selection of the parklands was done adopting systematic sampling technique used in (Adeyemi & Okedimma, 2015) with modifications. Three (3) transects of 1000 m long separated at 1000m distance intervals were evenly distributed in each agroecological zone farm plots. Along each transect, four plots of 1.0 ha were laid at 200 m intervals (Fig.2). In each of the plots all trees with diameter at breast height (DBH) ≥ 10 cm were sampled. The trees were identified to species level. A total of 36 sample plots (36 ha) were used for all the field study (Plate 1).

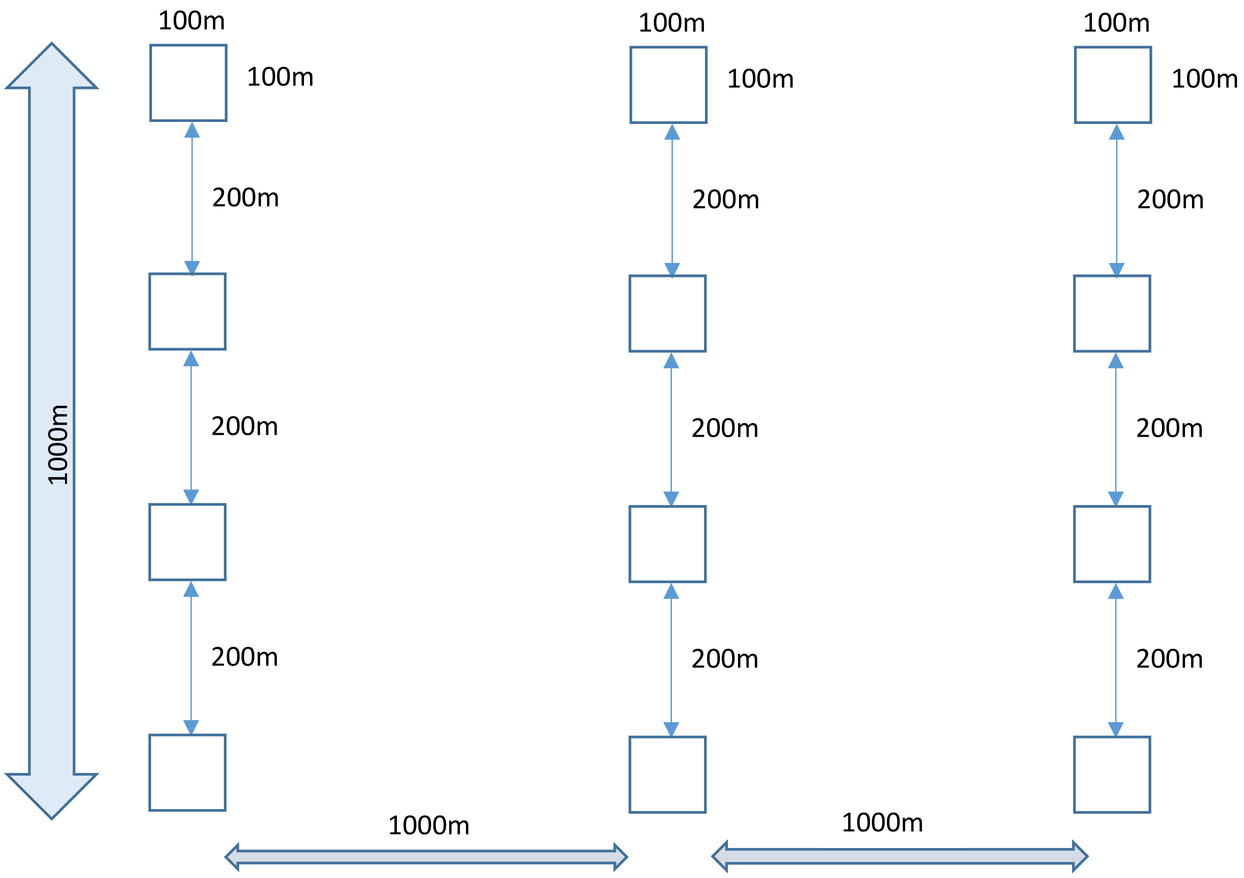


Figure 2: Field plot layout using line-transect technique in a vertical orientation

At each agroecological zone, soil sample was randomly collected only in 1 plot per transect in a triangular manner and at three points (50 m apart) in the depth of 0-15 cm and 16-30 cm using an auger in the sampled plots. The soil samples were air-dried, then taken to NRM laboratories, UK for analysis of physico-chemical parameters, except Nitrogen. For UK laboratory ethical issues, foreign soils outside Europe were not accepted for Nitrogen extraction analysis by the laboratory (See appendix 1.2)

Plate 1: The researcher (left) and his assistant (right) during one of the field plots sampling in Zaria area (Northern Guinea savannah zone), Nigeria.

5.2.3 Data Processing and Analysis

The coordinates of location points were collected using Open Data Kit (ODK) software tool on a mobile phone then geo-referenced (with the tree attribute data collected from the field) using google earth and ArcMap. Refer to chapter 3 for more on ODK. The following include the computation of all the parameters.

5.3 GROWTH PARAMETERS AND BIODIVERSITY INDICES ANALYSIS

The following biodiversity indices and growth parameters computations were undertaken.

5.3.1. Basal Area

It is the diameter of the tree at 1.37m off the ground. The trees basal area in the three zones were calculated using

$BA = \frac{\pi \ dbh^2}{4}$ BA = basal area (m^2), DBH = diameter at breast height (cm), and pi = 3.142. The total BA for each zone was computed by adding all trees BA in the sampled parkland sites.

5.3.2. Species Relative Density (RD)

Species relative density is an index for species relative distribution assessment, and calculated as thus; $RD = t_i/T \times 100$

RD (%) = species relative density t = is the number of individuals of species i. T is the total number of all individual trees of all species in the entire community. The tree species are classified based on the relative densities (RD) using the methods in Edet *et al.,* (2011) and Adeyemi *et al.*, (2015) as follows:

abundant = RD ≥ 5.00,

frequent = 4.00 ≤ RD ≤ 4.99,

occasional = 3.00 ≤ RD ≤ 3.99,

rare = 1.00 ≤ RD ≤ 2.99 and

threatened/endangered = RD < 1.00.

5.3.3. Species Relative Dominance

Species Relative Dominance (RD_0 (%)), is the assessment of relative space occupancy of a tree in a given area. The formula used for estimating is

$$RD_0 = Ba_i / Ba_n \ X \ 100.$$

Ba_i = sum of basal area of all specific trees in each zone, Ba_n = Total sum of basal area of all trees for each zone.

5.3.4. Importance Value Index

Importance Value Index involves the measure of how dominant a species is in a specified area. The tree species Importance Value Index (IVI) was calculated for each agroecological zone using the following equation:

$$IVI=(RDo+RD) / 2.$$

Where RD = Relative density, RDo = Relative dominance as seen in sections 5.3.2 and 5.3.3

5.3.5. Species Diversity Index

The Shannon-Wiener diversity index (H') is the measure of diversity combination of tree species richness in a given area and their relative abundance. It involves characterization of species diversity in a community (Ifo *et al.,* 2016). The index is employed to compute the Species diversity index in the following equation:

$$H' = -\sum_{i=1}^{R} p_i \ln p_i$$

where H'= Shannon-Wiener diversity index, t = total number of tree species in the plots, P_i = Proportion of S made up of the i_{th} species and ln = natural logarithm.

5.3.6. Shannon's Maximum Diversity Index

Shannon's maximum diversity index is the value that occurs when each species has same frequency. This normalizes the Shannon diversity index to a value between 0 and 1. Note that lower values indicate more diversity while higher values indicate less diversity (O'Keeffe, 2004). Shannon's maximum diversity index was calculated using

$$H_{max} = \ln(S)$$

Hmax = Shannon's maximum diversity index, S = total number of species in the parklands in each AEZ.

5.3.7 Species Evenness

Species evenness refers tree species closesness equitabilty (mathematically) in an environmental niche. It is represented in the follwing equation

$$J' = \frac{H'}{H'_{\max}}$$

Where H'max = Shannon's maximum diversity index. H' = Shannon-Wiener diversity index J' = Species eveness

5.3.8 Descriptive statistics of the tree variables

Summary of the data using descriptive statistical analysis to evaluate the relationships among the biodiversity and growth variables of the three sampled agroecological zones. The analysis of all variables of parkland trees in the studied three agroecological zones were undertaken in R programming (3.4.4) software package, except otherwise stated.

5.4. RESULTS

5.4.1 Variable indices of tree biodiversity

The population status of trees for each of the agroecological zones sampled is presented in table 5.1. A total of 278 individuals belonging to 19 species and 11 families were encountered across studied agroecological zones. Although the number of individual trees and species composition among the zones' parklands slightly differ, the number of species (14 each) and the species family (9 each) encountered is same between the Northern Guinea savannah and Southern Guinea savannah and the Sudan savannah (SS) and Southern Guinea savannah zones, respectively. Sudan savannah had two more species varieties and family of trees than the two sampled Guinea savannah zones. The tree species diversity index of all zones ranged from 1.27 to 1.39, with NGS having more diverse species composition than the SS and NGS. Shannon's index of species diversity of Northern Guinea savannah was slightly higher (H' [2.70] and Hmax [4.50]) than Sudan and Southern Guinea savannah zones but less than 20%

difference in quartile range. Similarly, the species evenness is also pronounced in the NGS (0.60) than the more arid SS zone, like the SGS zone. The trees biodiversity at the transitional zone exhibited abundance and diversity that are not different along the agroecosystem landscape changes between the arid land and the dry tropics of sub-Saharan Africa vegetation.

Table 5.1: Biodiversity indices of the trees sampled across three agroecological zones

Biodiversity indices	Sudan savannah	Northern Guinea savannah	Southern Guinea savannah
Tree Species diversity	1.27	1.39	1.35
Shannon Diversity index (H')	2.43	2.70	2.48
Shannon Maximum Diversity index (Hmax)	4.53	4.50	4.55
Equitability (Species evenness)	0.54	0.60	0.55
No. of individual trees	93	90	95
No of tree species	16	14	14
No of families	9	9	6

5.4.2 Tree species relative status

The species relative density (RD) for trees in the sampled parklands plots of Sudan savannah (SS), Northern Guinea savannah (NGS) and Southern Guinea savannah (SGS) ranged from 0.1 to 42.74%, 4.5 to 14.6% and 4.21 to 16.8% respectively. *Parkia biglobosa* had the highest RD among the tree species across the studied AEZs, accounting to 15.22%, 16.41%, and 16.84% in SS, NGS and SGS, respectively. Other tree species like *Vitellaria paradoxa* (11.24% for NGS, 15.79% for SGS) and *Mangifera indica* (10.5% for NGS, 10.11% for SGS) also had higher relative density in two of the three studied AEZ parklands. Though *Gliricidia sepium* had one of the lowest densities in SS and NGS, the *Prosopsis africana* and *Phoenix dactylifera* tree species in SS are relatively very low in density just as NGS's *Balanites aegyptiaca* and *Eucalytpus camaldulensis.* It was also observed that species classified as low densities are rare.

There is a distinct variability in the species relative dominance among the studied agroecological zones. Sudan savannah had the highest variability, ranging from 0.1% (*Diospyrous mespilliformis*) to 42.73% (*Tamarindus indica*) thereby highlighting the unevenness in the species in the driest AEZ compared to other studied savannahs in the table. *Parkia biglobosa* still remain the most dominant parkland species across the three zones, having between 27.01% in SGS and 42.64% in SS. This is establishing the fact that tree species ranked as most preferred in table 4.2 of section 4.3.1 in chapter 4 are densely populated on the farm plots across the zones. However, there is low relative dominance of *Vitellaria paradoxa* (1.06%) species in SS parklands, despite the species potentials in the Guinea savannah parklands is more evident.

The Importance Value Index (IVI) shows how dominant species is valued in a specified parkland area. In Table 5.2, the species with the highest IVI in the table, *Parkia biglobosa* cut across the three measured AEZ ranging between 31.2% - 50.25%. Other species with higher IVI in all the AEZs include *Mangifera indica* (14.18%), *Azadirachta indica* (13.7%), and *Adansonia digitata* (8%). On the species with lowest IVI, *Eucalyptus camaldulensis* (1.78%), *Gliricidia sepium* (3.01%), and *Phoenix dactylifera* (1.35%) were lowest for SGS, NGS and SS, respectively. Furthermore, *Eucalyptus camadulensis* value almost doubled as the agrobiodiversity gradient shifts northward across the AEZs, SS fields had more IVI for the tree species than the other two zones. The IVI increases for all species at the transitional AEZ (NGS) than the other zones sampled.

Table 5.2: Tree species distribution frequency, relative status in all sampled plots

AGROECOLOGICAL ZONE	TREE SPECIES	FAMILY	SPP FREQ.	RD	RDO	IVI	STATUS	TOTAL NO. OF TREES
Sudan savannah	*Mangifera indica*	Anacardiaceae	6	6.52	0.69	3.96	Abundant	92
	Phoenix dactylifera	Arecaceae	2	2.17	0.25	1.35	Rare	
	Diospyrous mespilliformis	Ebenaceae	4	4.35	0.10	2.277	Abundant	
	Vachellia nilotica	Fabaceae	4	4.35	0.28	2.46	Frequent	
	Tamarindus indica	Fabaceae	12	13.04	42.72	7.58	Abundant	
	Parkia biglobosa	Fabaceae	14	15.22	42.64	50.25	Abundant	
	Gliricidia spp	Fabaceae	1	1.09	0.08	0.62	Rare	
	Prosopsis africana	Fabaceae	1	1.09	0.82	1.36	Rare	
	Vitex altissima	Lamiaceae	4	4.35	0.73	2.90	Frequent	
	Adansonia digitata	Malvaceae	8	8.70	3.65	7.99	Abundant	
	Azadirachta indica	Meliaceae	19	20.65	3.37	13.69	Abundant	
	Ficus spp	Moraceae	4	4.35	0.96	3.13	Frequent	
	Eucalyptus camaldulensis	Myrtaceae	5	5.44	1.76	4.47	Abundant	
	Vitellaria paradoxa	Sapotaceae	4	3.26	1.06	3.23	Occasional	
	Balanites aegyptiaca	Zygophyllaceae	5	5.44	0.87	3.04	Abundant	
Northern Guinea savannah	*Mangifera indica*	Anacardiaceae	9	10.11	9.10	14.17	Abundant	89
	Phoenix dactilyfera	Arecaceae	5	5.62	5.55	8.36	Frequent	
	Diospyrous mespilliformis	Ebenaceae	4	4.49	3.71	5.96	Frequent	
	Vachellia nilotica	Fabaceae	4	4.49	5.41	4.43	Frequent	
	Tamarindus indica	Fabaceae	5	5.62	3.07	5.88	Abundant	
	Parkia biglobosa	Fabaceae	13	14.61	31.15	38.45	Abundant	
	Gliricidia spp	Fabaceae	4	4.49	0.76	3.01	Frequent	
	Vitex altissima	Lamiaceae	5	5.62	5.41	8.22	Abundant	
	Adansonia digitata	Malvaceae	10	11.24	12.50	18.11	Abundant	
	Azadirachta indica	Meliaceae	5	5.62	3.68	6.49	Abundant	

		Eucalyptus camaldulensis	Myrtaceae	10	11.24	0.41	6.03	Abundant	
		Psidium guajava	Myrtaceae	4	4.49	0.64	2.89	Frequent	
		Vitellaria paradoxa	Sapotaceae	10	11.23	19.61	25.24	Abundant	
		Balanites aegyptiaca	Zygophyllaceae	2	2.25	2.20	3.32	Rare	
Southern savannah	Guinea	*Mangifera indica*	Anacardiaceae	10	10.54	7.66	12.92	Abundant	
		Anarcadium occidentale	Anacardiaceae	6	6.32	8.27	11.43	Abundant	95
		Vachellia nilotica	Fabaceae	5	5.26	3.45	6.08	Frequent	
		Tamarindus indica	Fabaceae	7	7.37	3.58	7.26	Abundant	
		Parkia biglobosa	Fabaceae	16	16.84	27.01	35.43	Abundant	
		Gliricidia spp	Fabaceae	5	5.26	3.67	6.29	Abundant	
		Prosopsis africana	Fabaceae	8	8.42	8.51	12.72	Abundant	
		Danilie oliveri	Fabaceae	4	4.21	4.65	6.75	Frequent	
		Adansonia digitata	Malvaceae	4	4.21	1.80	3.90	Frequent	
		Azadirachta indica	Meliaceae	5	5.26	1.66	4.28	Abundant	
		Khaya senegalensis	Meliaceae	4	4.21	1.61	3.72	Frequent	
		Psidium guajava	Myrtaceae	4	4.21	0.65	2.76	Frequent	
		Eucalyptus camaldulensis	Myrtaceae	2	2.11	0.73	1.78	Rare	
		Vitellaria paradoxa	Sapotaceae	15	15.78	26.76	34.66	Abundant	

The abundance status of tree species across AEZ encountered is same (8 each) as presented in Fig. 3. The Fabaceae family were found in abundance with Sudan savannah (SS) and Southern Guinea savannah (SGS) zones having 5 and 6 tree species, respectively. Northern Guinea savannah had 4 species belong to fabaceae. Though Sudan savannah (SS) Fabaceae family status had 2 species (*Prosopsis africana and Gliricidia spp)* as rare and only 1 species (*V. nilotica*) as frequent. Other families that dominated were distinct in a particular zone include Meliaceae and Myrtaceae with 2 species each and average frequency in the two Guinea savannahs. Generally, on the tree species status, only the SS had one species (*V. paradoxa*) classified as occasional (fig. 3). Two fewer tree species were classified in the frequent status of SS trees than the NGS and SS. Meanwhile, 3 tree species of the SS were rare, making it it the zone with highest rare species in the studied AEZ.

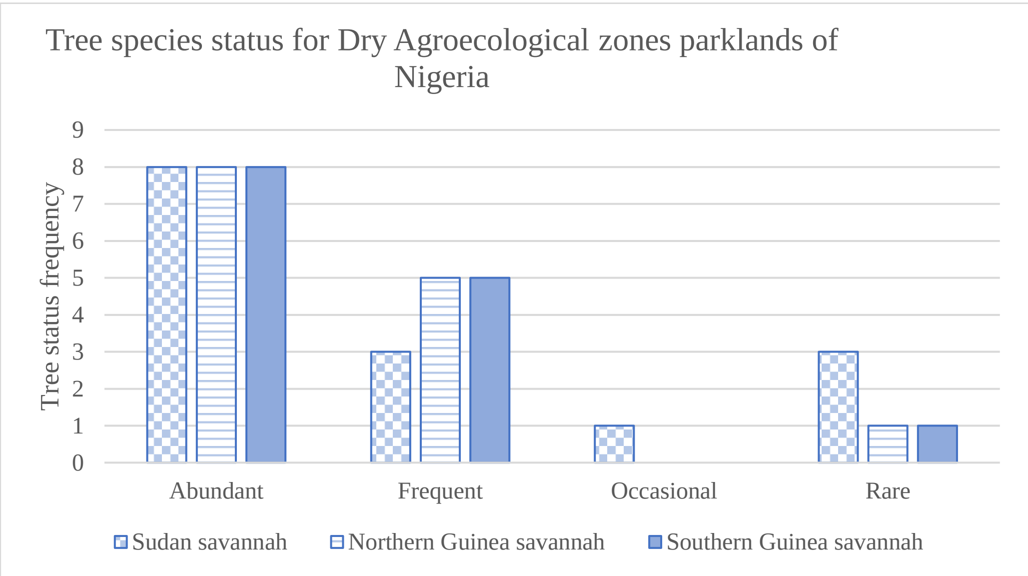


Figure 3: Tree species diversity status of studied parklands across the three agroecological zones of Nigeria

5.4.3 Diameter Distribution of parkland trees in all sampled plots

The tree species diameter distribution in the three agroecological zones sampled plots is as shown in Fig. 4. The graph revealed parkland species within the diameter class of 40-60 cm is the most frequent across the zones, with an average of at 18-30 trees/ha. The more frequent diameter class of parkland trees are the 20-40 cm and 60-80 cm with 10 and 15 trees/ha respectively. The least number of boles (<10 trees/ha) in the diameter distribution class had the highest frequency in the Sudan savannah zone. This is because the zone had younger, slender and diverse trees scattered on its landscapes, with thorny trees from *Acacia* and *Tamarindus* species having > 20 cm diameter at breast height (DBH). The Baobab trees dominated the monstrous (over 150cm) bole size and increases as we go further into the driest agroecological zone. This result revealed that there is low regeneration rate of parkland trees per hectare (N/ha) and young trees decreases in dbh as the AEZ moves from SS to SGS. This is clearly confirming that most valuable trees by farmers in chapter 4 are in the most frequent tree species dbh range (20-60 cm). These species include *Parkia biglobosa*, *Mangifera indica*, *Vitellaria paradoxa* and *Eucalyptus species.*

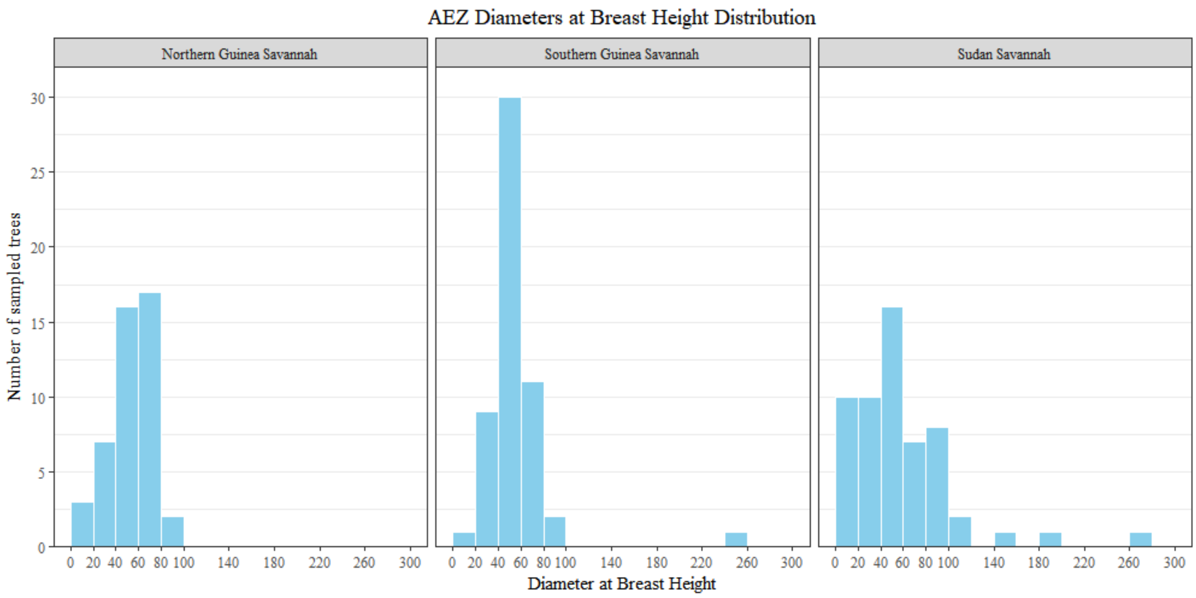


Figure 4: Tree species diameter distribution of studied parklands across the three agroecological zones of Nigeria

5.4.5 Soil chemical and physical properties

The descriptive statistics summary of some soil chemical and physical properties in the three agroecological zones is shown in Table 5.3. The soil pH for the zones ranged between 5.0 and 8.4 with Sudan savannah (SS) having the highest mean value of 6.67 ± 1.27. Northern Guinea savannah (NGS) pH tends to be more acidic than others. The Sudan savannah and Southern Guinea savannah (SGS) have averagely same minimum amount of phosphorus (P), but the element availability increased exponentially in the SGS with the highest mean value of 18.86±21.87. The soil available potassium (K) values for all the zones ranged between 18.2 and 184 mg/l with a high mean of 87±67.1 and showing the highest deviation from mean at the SGS. The Mg mean range for all zones studied is between 57.47 and 95.3 mg/l. The highest and lowest mean of K sampled were found in NGS and SS, respectively.

During the analysis, Nitrogen element was excluded for all the soil samples submitted at the NRM laboratory, UK. This was because of a biosafety policy that soil samples from outside Europe requiring liquification process during analysis, such as Nitrogen (N) element extraction are not be accepted by the laboratory. The soil samples had been collected from different locations (over 100km apart) in Nigeria and brought to the UK before the awareness of the policy by the researcher on N content extraction. Financial constraints made it difficult to send the samples back to Nigeria laboratories for N content measurement.

Furthermore, table 5.3 showed the Organic matter content ranged between 0.50 and 2.20 with the highest mean value of 1.8±0.28 at the NGS. The general low organic matter content is as a result of extensive agricultural practices under low precipitation and high temperature with very low input for soil improvement. This is one of the main factors behind low agricultural productivity among small scale farmers scattered across Sub-Saharan Africa. The highest mean percentages for Sand, Silt and Clay in the AEZ were 54.33±9.67, 36.33±8.73, and 9.33±0.94 at NGS zone, respectively.

Table 5.3: Some chemical and physical properties of the sampled sites

AGROECOLOGICAL ZONES	SUDAN SAVANNAH			NORTHERN GUINEA SAVANNAH			SOUTHERN GUINEA SAVANNAH		
Soil Properties	Min	Max	Mean±SD	Min	Max	Mean±SD	Min	Max	Mean±SD
pH water [1:2:5]	5.4	8.4	6.67±1.27	5	6	5.63±0.45	5.1	7.8	6.33±1.11
Available P (mg/l)	3	4.4	3.8±0.59	4	9.4	6±2.42	3	49.8	18.8±21.8
Available K (mg/l)	18.2	54.4	40.8±16.1	58	90.6	71±14.1	28.2	184	87±67.1
Available Mg mg/l	47.4	68	57.4±8.42	67.2	124	83.1±28.9	50.9	123	95.3±31.72
Sand (2.00 -0.063mm)	85	87	86±0.82	47	68	54.3±9.7	78	81	79.3±1.25
Silt (0.063-0.002 mm)	9	13	11±1.63	24	43	36.3±8.73	13	15	14±0.82
Clay (<0.002mm)	2	5	3±1.41	8	10	9.33±0.94	4	8	6.67±1.89
Available Ca (mg/l)	249	430	328±75.4	200	727	451±215	572	909	773.3±145.2
Organic Matter (w/w)	0.5	0.7	0.70+0.16	1.6	2.2	1.8±0.28	1	1.9	1.53±0.39

5.5 DISCUSSION

5.5.1 Variables Indices of Tree Biodiversity

This study confirmed that the parklands of northern Nigeria's agroecological zones are a repository of drought resistant indigenous and exotic but economic tree species scattered across major dry agroecosystems of West Africa (Adefisan, 2015; Bayala *et al.,* 2018; Weston *et al.,* 2015). The tree species diversity of the three transitional AEZs is slightly lower than the reports on tree population study in urban and sub-tropical forests of Nigeria (Adekunle, 2006; Adeyemi & Okedimma, 2015; Agbelade *et al.,* 2017). For instance, (Agbelade et al., 2017) reported an average of 3.56 and 2.24 Shannon-Wiener diversity index of trees species in North-Central Nigeria, respectively. The similarity in tree species diversity indices among the AEZ studied also affirmed with the diversity study findings in the southern agroecological zones farmlands, exhibiting less than 5% tree species diversity in comparison to farms in forest zones *(Lyam et al.,* 2012; Gonzalez, 2001). Thus, a large portion of economic tree species found in parklands is a fraction of tree species in tropical forest and farm landscapes across other agroecological zones in southern region Nigeria (Adeyemi & Okedimma, 2015; Agbelade *et al.,* 2017). This tree species abundance (frequency and count) were also similar among the three studied AEZ just as reported in the findings of Agbelade *et al.,* (2017) that there is no significant difference between urban and peri-urban areas of Guinea savannahs of Nigeria in terms of tree species diversity. Hence, parkland trees diversity serves as reservoir to biodiversity conservation, just as other forest landscapes despite the low rate in species richness.

Faye *et al.,* (2011) reported that, traditionally, west African parklands have been classified as landscapes of significant biodiversity dominated by native species; evidence from this research as well as those from published data showed that dry tropical forest landscapes does contain relatively high biodiversity rate, including non-native species like *Mangifera indica* and *Eucalyptus camaldulensis* (Adeyemi & Okedimma, 2015; Brown, 2009). In contrary to the conclusion of Faye *et al.,* (2011), there are indications that parklands contributed not only positively but also converting the negative functions to advantages through native and non-native trees outside forest to reduce drought and improve livelihoods. The results also showed that *Mangifera indica*, *Eucalyptus species, Azadirachta indica* are the three common exotic species found in the three studied AEZ. The high frequency of exotic species in the studied farmlands across the AEZ was reported as an invasive but useful trees contributing to livelihoods and managing environmental challenges facing savannahs of Africa (Amiebenomo, 2002; Ndegwa *et al.*, 2017). For instance, *Anarcadium occidentale* is an agroforestry fruit tree gaining momentum across farms in Southern Guinea savannah zone mainly for its resilience thereby increasing the richness of parklands (Aliyu & Awopetu, 2006; Aliyu, 2007).

5.5.2 Relative Dominance of Trees across Parklands

The effect of climate change-induced anthropogenic activities on regeneration and distribution of tree species on parklands may have affected the dominant status of individual species in the agroecosystem, thereby favouring few species over other equally significant species(Bainbridge, 2017; Miller *et al.*, 2016). The Fabaceae family was within the most prevalent family across the zones in the study. This might be because of their speedy regeneration potential, coupled with symbiotic characteristics enabling the species to establish a niche within dryland habitats. This finding is similar to studies by Adeyemi & Okedimma, (2015), Faye *et al.*,(2010) and Oyebamiji *et al.*, (2016) on parklands and forests in West Africa, the most prominent species were leguminous. This is because of the similarity in agricultural landscape cover and the protection of tree species that are within same family hierarchy, such as fabaceae spreading across dryland geographical boundaries of sub-Saharan Africa. The dominance of Fabaceae and families in the results is also an adaptation strategy that relatively favours environmental factors such as dispersal of seeds, pollination of flowers for fruits and establishment of wildlings that eventually become protected and managed species (Jalloh *et* *al.*, 2012; Leakey, 2014). The gradual disappearance of *Vitellaria paradoxa* in SS parklands is backed by some local community policy of managing conflict on land use resources through removal of the tree (especially along border lines of communal lands and farm plots). It is assumed that cutting down Shea trees will settle violent disputes among farmers in these arid communities where the species highly valuable nuts is used in soap making and as a produce for merchants coming from Southern Nigeria (Lagos). Generally, the results in the table also indicated that species with lowest relative dominance are similar to species observed with low relative density.

On the Importance Value Index (IVI), economic value was not considered while calculating the average between relative dominance and diversity of species in each AEZ but similar findings was reported in the species importance value in (Razavi et al., 2012) assessment of *Fagus orientali* species in Iran. Naidu & Kumar, (2016) in their research confirmed wild mango and Cashew as some of the species among 2227 trees sampled with high IVI in the dry tropical landscapes of India. This important index is useful in forest management and biodiversity preservation. As it can be used to improve tree regeneration potential and the adoption of agroforestry on farmlands in dry landscapes using the available resources.

The relative diversity status of species across the AEZs is overwhelmingly abundant for parkland trees and more frequent for other hierarchical families among the zones. The frequency and diversity of trees is also reported in the West African study of tree functions by Adeyemi & Okedimma (2015) & Aleza *et al.*,(2015) where the driest landscapes had the highest number of species diversity that are leguminous and most preferred by farmers for improving fertility as well as income.

5.5.3 Tree size abundance in parklands

In a participatory field work survey in Ghana, Lovett & Haq (2000) revealed how tree populations are selected by local farmers by eliminating unwanted woody species on parkland, favouring *V. paradoxa* based on size, spacing, growth and yield. The tree size matters as medium to large-diameter trees dominate the structure, function and dynamics of agroecosystems in sub-Saharan Africa landscapes (Brandt *et al.*, 2016; Ilstedt *et al*., 2016; Wezel *et al.*, 2006). The most frequent average tree diameter is at 40-60cm across the AEZs but the driest zone (Sudan savannah) exhibited higher regeneration potentials (10-40cm dbh) than other two zones, despite the drought threats. However, the species with the lowest dbh range are not necessarily the most dominant species just as confirmed in the tree dominance study by (Singh *et al.*, 2016) in India where *Quercus* species are dominating as the most frequent (up to 80%) the tropical landscapes but with poor regeneration potential. This is in line with secondary succession of dry forests resilience strategy, where dominant species success to regenerate differs and is dependent on different environmental factors, including climate and anthropogenic effects of the location (Ademiluyi *et al.*, 2008; Rishmawi & Prince, 2016)

5.5.4 Soil capacity across AEZ

Carsan *et al.*, (2014) and Cerdán *et al.*, (2012) explained that soil nutrients are an important edaphic factor that plays role in species richness and establishment of agroforestry species. They further highlighted that biodiversity variables responsible for the abundance and diversity of tree species across dryland landscapes are similar in soil nutrients. However, the Sudan savannah zone had more species diversity, despite the low fertility of the soil in that low rainfall zone. The scenario in the driest AEZ in this study contradicts the idea that higher the nutrient value in soils, the greater the species richness (Gonzalez, 2001). Resilient species (particularly the trees in Fabaceae family) can thrive even in extreme weather to provide manure for soil replenishment and thrive under harsh weather conditions as reported in studies done in West Africa landscapes (Bayala *et al.*, 2003; Ilstedt *et al.*, 2016; Ouedraogo *et al.* 2017).

5.6 CONCLUSION

McElhinny *et al.*, (2005) concluded that there is no specific structural attributes for tree stands as different outcomes from multiple researches emphasised but mathematical system of indexing facilitates attributes usage and interpretation. This is in terms of actual stand conditions that links attributes to the provision of measurable agrobiodiversity such as this study. Here, the Important Value Index and Species evenness are the attributes that facilitated the real stand richness and diversity of the study sites. Briefly, the highest and lowest Important Value Index (IVI) values were found in *Parkia biglobosa* (50.25%) and *Gliricidia sepium* (0.62%) in the Susan savannah zone, *Parkia biglobosa* (38.45%) and *Psidium guajava* (2.89%) in the Northern Guinea savannah zone and *Parkia biglobosa* (35.43%) and *Eucalyptus camaldulensis* (1.83) in the Southern Guinea savannah zone. The highest value for a parkland species in any zone suggests that the species is dominant in the agricultural landscape. Other parkland species with high IVI values in the results include *Vitellaria paradoxa, Anarcardium occidentale Mangifera indica, Adansonia digitata, and Prosopsis Africana.* These species are classified as abundant based on their relative density on the farms. In line with the farmers' interest of species ranking, the *Parkia biglobosa, Vitellaria paradoxa* and *Magifera indica* are prominent across the agroecological zones under study. On the species evenness, the Northern Guinea savannah slightly had provided more closeness in number of species because of the transitional vegetation attributes. This can be seen in the dominance of *Parkia biglobosa, Mangifera indica* and *Vitellaria paradoxa* in the zone. As mentioned previously in chapter 4, the highest IVI value suggested that species preference is strongly related to abundance/dominance in the farms. Faye *et al.*, (2010) reported the same results from northern Mali that *Parkia biglobosa* and *Vitellaria paradoxa* as two of the most important parkland trees contributing to farmers' livelihoods and improving agrobiodiversity management and preservation.

CHAPTER SIX: HOW CHANGING CLIMATE IS AFFECTING AGROFORESTRY TREE DISTRIBUTION IN DRYLANDS OF NIGERIA: MAXENT MODELLING PERSPECTIVE

6.1 INTRODUCTION

Quantifying expected changes in the spatial pattern of tree distribution for parkland landscapes species can assist farmers in appropriate species selection, enhancing trees outside forest contribution to sustainable livelihoods. The first stage in modelling parkland tree plant distribution is the evaluation of the relationship between current tree species occurrence and current environmental conditions. Next, future climate factors can be used to predict future growing conditions, and these used to determine the predictive distribution model. Output from such models is useful for landscape restoration (Chahouki & Sahragard, 2016). Predictive species distribution modelling (SDM) of trees has been applied in the study of invasive plant species trends and patterns (Thuiller *et al.*, 2005), modelling species habitat niche and suitability (Deblauwe *et al.*, 2016), deriving spatial information on species diversity and richness (Dubuis *et al.*, 2011) as well as trying to predict the impact of changing climate effects on agrobiodiversity survival (Kotschi, 2006; Verheyen *et al.*, 2016). There are species distribution models available for predicting the distribution of plant species and hydrology, each method having peculiar characteristics influencing the output factors (Moore *et al.*, 2007; Onojeghuo *et al.*, 2015; Oyerinde *et al.*, 2016; Phillips *et al.*, 1997; Prudhomme *et al.*, 2014). Austin (2002) described (a) the ecological model, (b) the data model, and (c) the statistical model as significant components contributing to fitting species distribution models. Species distribution predictive models are classified into two categories based on the required type of input data; the presence-absence models and the presence-only models (Guisan & Zimmermann, 2000). In this chapter, presence-only models were used because of its potential to maximise climate resource-use with limited amount of data generated for different SDM methods (Chahouki & Sahragard, 2016).

6.1.1 Why Maximum Entropy

The Maximum Entropy (MaxEnt) which is a species distribution modelling method is one presence-only model technique with better accuracy (and wider acceptance) in prediction than other methods (Buckley *et al.,* 2010; Phillips *et al.,* 2017). It is based on machine learning response designed to produce predictions from estimated or incomplete data. The model predicts plant species occurrence localities using the estimation of a set of environmental variables that explains factors influencing the suitability of a species niche in a given time (Phillips *et al.,* 1997). It is used for this research because Maximum entropy (Maxent) modelling has potential for identifying tree species distributions and selection of niche given its reliance on only presence locations. The species fundamental niche (e.g forests) is a combination of climate and ecological conditions that determine survivability in the long term. The real niche, a subset of the fundamental niche (e.g. parklands) that species occupies and can be predicted using the factors contributing to the overall agroecosystem (Case & Lawler, 2017; Li *et al.,* 2014). The MaxEnt model is considered the best fitter in predicting trees distribution because it is less sensitive to overfitting especially when samples size such as the real niche (parklands) is small, as it regularizes the input variables to help avoid the performance problems induced by over fitting. The model is run using linear and quadratic terms in combination with the MaxEnt software settings that are kept as default until modified. The training sample is focused on the input of environmental variables and species occurrences geographical information under the Maxent default settings to predict the model species distribution.

Lyam *et al.,* (2012) performed species distribution modelling for native *Chrysopyllium albidum* in South-western Nigeria using MaxEnt and reported 55% of the niche distribution was associated with temperature (in the coldest quarter) and only about 18% for precipitation for all potential sites for regeneration. Other research findings in sub-Saharan Africa also showed that MaxEnt predicts geographical distributions of plant and animal species more accurately compared to other spatial methods (Bocksberger *et al.,* 2016; Li *et al.,* 2014; Onojeghuo *et al.,* 2015). Furthermore, bioclimatic variables (see chapter 3) from worldclim.org are considered as one of the most significant climate records for global species modelling (Fick & Hijmans, 2017). This is because of climate influence on environmental factors in the plant species distribution at a regional and global scale as seen in scientific reports (Aleman *et al.,* 2018; Case & Lawler, 2017; Zomer *et al.,* 2016).

Despite the numerous findings of climate drivers affecting vegetation distribution in sub-Saharan Africa (Bakhoum *et al.,* 2012; Bone *et al.,* 2017; Gonzalez, 2001), existing literature on research to show the specific extent of future distribution, focusing on trees in the drylands of Nigeria is rare. Therefore, this research has hypothesised that understanding the spatial habitat suitability (niche) of regenerating *Parkia biglobosa* and *Vitellaria paradoxa* is contingent on bioclimatic factor response curves across different agroecological zones of Nigeria. In this research chapter, spatial species occurrence data (extracted from Chapter 3 [table 2] and illustrated in figure 1 below), and a detailed dataset of 19 bioclimatic variables at 10 seconds resolution (1km^2), were input into MaxEnt model for simulation of the spatial distribution of two selected tree species across parklands of three agroecological zones (See chapter 3). The main objective was to predict the ecological niche of *Parkia biglobosa* and *Vitellaria paradoxa*, to examine the geographical distribution of this niche, and to explore climatic factors that determine the distribution of the two parkland trees. This is then used to predict future occurrence of these species under a climate change scenario. The answers derived could support climate policymakers, farmers and forest managers in adopting suitable cultivation and regeneration management in locations suited for future distribution and survival of parkland trees.

6.2 MATERIALS AND METHODS

6.2.1 Species Data

During the sampling of tree attributes in chapter 5 (see sections 5.2.1-3), spatial information (field points) of *Parkia biglobosa*, and *Vitellaria paradoxa* were collected from all the farmlands across the agroecological zones of Nigeria (Figure 6.1). Tree abundance and frequency were assessed and simulated with the climate data at the presence locations.

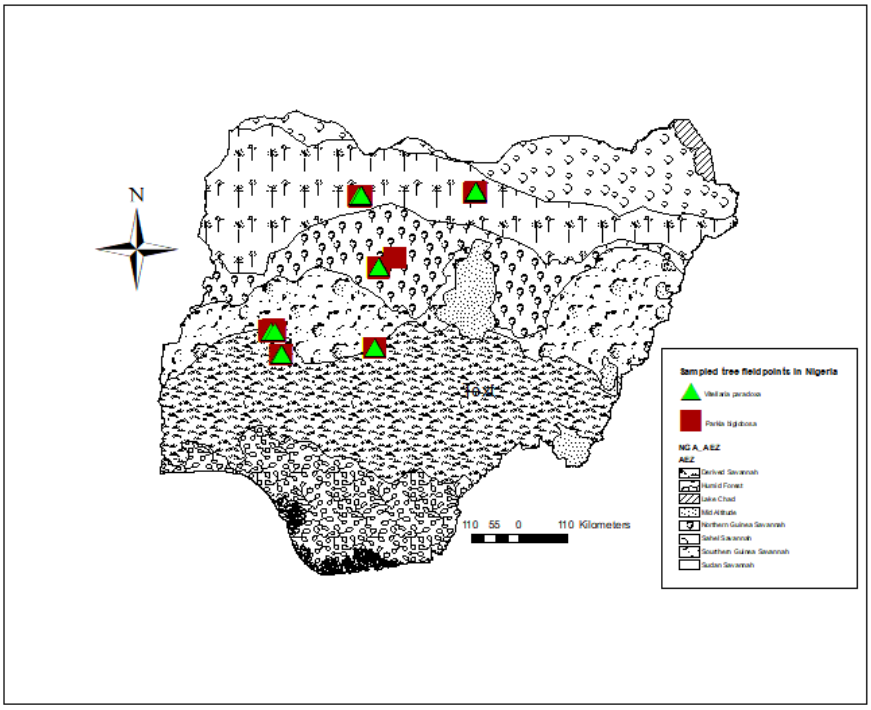


Figure 6.1: Map of Nigeria showing sampled parkland field points across selected Agroecological zones.

6.2.2 Environmental Data

Spatial bioclimatic datasets from the WorldClim database were used at 30′ resolution or 1 square kilometre grid (Hijmans *et al.*, 2005). These were the same 19 bioclimatic variables derived from global temperature and rainfall data of current (1975-2000) and future (2050 and 2070) climates seen in chapter 3, section 3.4.2-3 and in table 1 of chapter 2. Here, an estimation of the extracted 19 bioclimatic variables datapoints of 774 locations GPS coordinates using ArcGIS 10.6 software was done; each datapoint is a location within the lowest geopolitical administrative unit and evenly covers all spatial landscapes of Nigeria (Ekong *et al.,* 2012). Due to time constraint, the scenario is limited to the most extreme HadGEM3-ES model only with Representative Concentration Pathways (RCPs) 8.5 trajectory. The RCP is a trajectory adopted by the IPCC in 2014 of greenhouse gas concentration. Please refer to chapter 3 for more details on RCP scenarios. HadGEM3-ES model was chosen because it is the worst case scenario for future prediction of climate events used in species distribution predictability.

6.2.3 Species Distribution Modelling

Spatial interpolation is one of the commonest geographic techniques for spatial data visualization in Geographic Information Systems (GIS). Ordinary kriging, a geostatistical analysis was applied to the 19 bioclimatic variable datapoints for spatial interpolation and created 19 maps layers that covers the Nigeria territorial map in ArcGIS 10.6. Kriging involves spatial interpolation that applies complex mathematical equations to estimate values at unknown points in a pixel based on the values at known points. Ordinary kriging is one of the different types of kriging that estimator is used to visualise spatial data for better accuracy and interpretation. (Hengl, 2005; Meng *et al.,* 2013). It was used because of minimisation of error variance in spatial estimation interpolation by the kriging type over others (Lehfon *et al.* 2005). The interpolated maps were then subjected to modelling using the MaxEnt programming as done in Phillips and Dudik (2008). The maximum entropy distribution free software 3.4.1 version of MaxEnt (https://biodiversityinformatics.amnh.org/open_source/maxent/) was used to model the current and future distribution of parkland trees using bioclimatic variable map layers as well as species occurrence data.

In the MaxEnt programming software, all layers of 19 bioclimatic variables were inputed after the conversion to ASCII raster grids for accurate interpolation with tree location coordinates in decimal degrees. MaxEnt then predicted the potential spatial distribution of *Parkia bilobosa* and *Vitellaria paradoxa* across agroecological zones within Nigeria by probability distribution estimation on ASCII files. The ASCII files reproduced by the output in MaxEnt were taken into ArcMap for formating. The model classifications of years 2050 and 2070 climate data were altered and colours in stretched colour ramp of models of current climate data was modified for uniformity. This enabled the result predictions of all distribution maps to be visualised and edited in ArcMap.

6.2.4 Model Validation and species presence mapping

Model performance measurement is essential for model validation. Hence, we did model validation by dividing the dataset into the training data used to build the model, comprising 70% of all data and the test data (independent dataset) used to test run the model taking the remaining 30% of all data as seen in De'ath & Fabricius, (2000). The area under the curve (AUC) represents a model performance measure focusing on sensitivity against specificity. In other words, AUC is a measure of separability as it explains the capability of model to distinguish between classes (Hand *et al.*, 2001). The sensitivity for any threshold is a fraction of classified present positive instances while specificity is a fraction of classified negative instances that are not present. The AUC value typically is between 0.5 (random) and 1.0. The AUC value that shifts closer to 1.0 indicated a better model performance. So, the higher the AUC, the better the model is at prediction. Furthermore, the success of the model was also evaluated on how the mapped probability values correspond to the presence records visually. This is because in the continuous MaxEnt output (predicted maps), it is essential to regulate an optimal threshold for evaluating the presence/absence of target tree species in maps as seen in Phillips *et al.*, (2006) and Sahragard and Chahouki (2015). The geostatistical and modelling outputs between observed and predictive maps were determined in ArcGIS 10.6.1 release software. Monserud and Leemans (1992) defined the modelling accuracy in the following ranges of agreement:

No agreement - 0.05;

Very poor - 0.05−0.20;

Poor - 0.20−0.40;

Fair - 0.40−0.55;

Good - 0.55−0.70;

Very good - 0.70−0.85;

Excellent - 0.85−0.99;

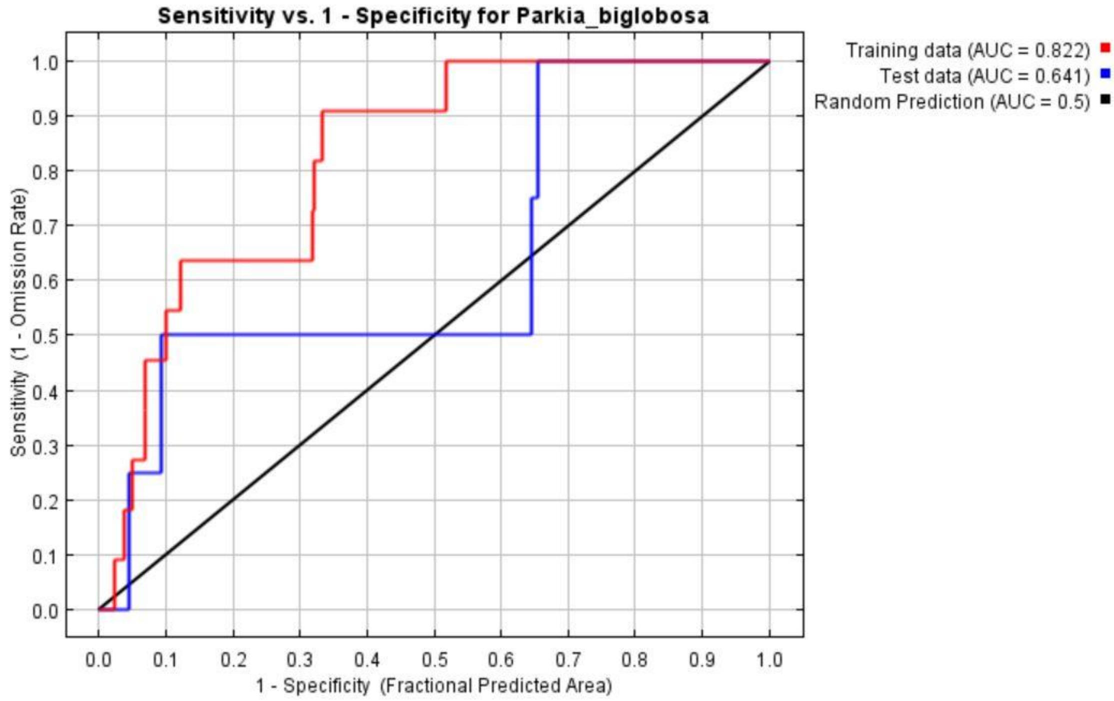
Perfect - 0.99−1.00.

Higher values indicate extremely good agreement with matched records. A good model produces landscapes of high probability covering the closest zones of presence records while landscapes of low probability generates only few or no presence points around the presence records.

6.3 RESULTS

6.3.1 Variable contribution and Model performance

In figure 6.2, the three lines in the graph are black, blue and red for random, test and training data predictions, respectively. The model fitness using testing data (blue line) is the real test of the model predictive power and at Area under the curve (AUC) value of 0.5. The AUC curve graph indicates how significant the maxent model is at predicting the current scenario sampled tree data because it measures the degree of separability. In this instance, the AUC had >0.8 for current scenarios training data in both species sampled for this study (figure 2). This implies that the chances of correct predictability are highly positive. The figure also indicated predicted areas AUC test data for *V. paradaoxa* is 0.2 lesser than *P. biglobosa* specificity for prediction of defined areas within the maps.



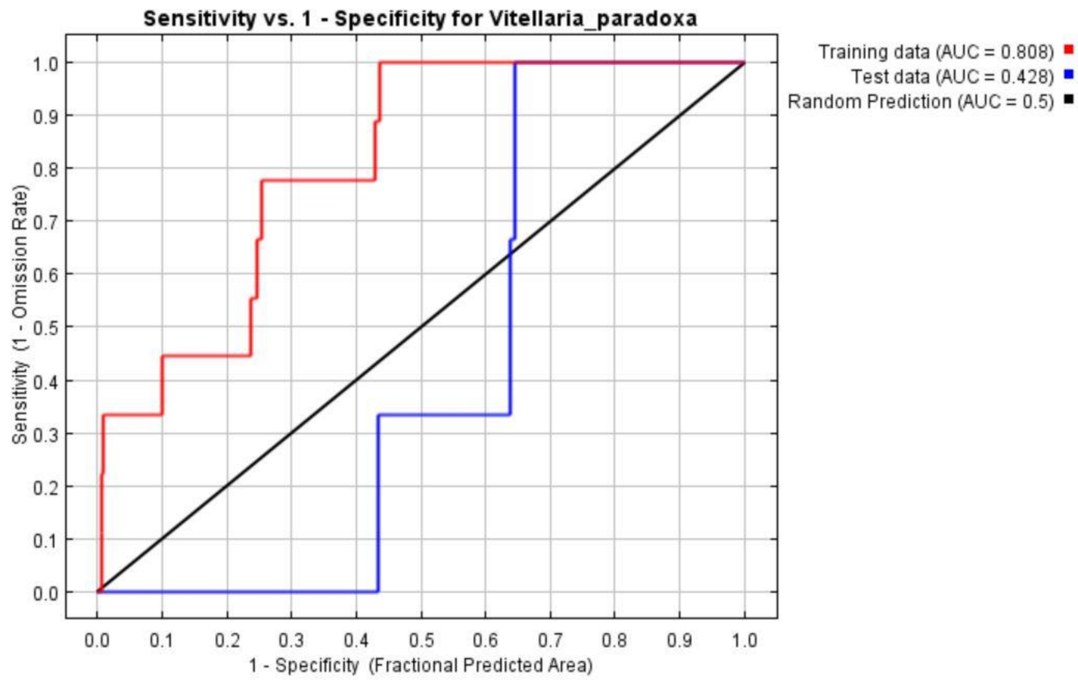


Figure 6.2: Specificity versus sensitivity of predicted maps of sample tree distribution across the AEZ

The jackknife test of variable importance in MaxEnt modelling showed that tree distribution across the agroecological zones landscapes was affected most by precipitation seasonality in the 19 bioclimatic variables, particularly drought regimes. Jackknife test is similar to bootstrapping. It is used in estimating the bias and standard error in a statistical inference, when a random sample of observations is used to calculate the datapoints (Walsh, 2000). For instance, when used individually the bio14w2 (precipitation of driest month) and bio17w2 (precicipitation of driest quarter) were the leading important predictors across all the scenarios of the two sampled tree distribution in this study, except for *Vitellaria paradoxa* at year 2050 (Fig 6.2). Though bio06w2 made the temperature seasonality of coldest months most important variable predicting the changes in 2050 for *V.paradoxa*, the drought indices on the biovariables tend to predict *P.biglobosa* distribution across the agroecological landscapes of Nigeria. Results also indicated that ecological distribution of *V. paradoxa* was not only meaningfully influenced by precipitation level in dry seasons but also by cold temperature regimes (Figure 6.3). In addition, parkland distribution of *P.biglobosa* and *V. paradoxa*, all the most important variables that were significant predictors with optimum variable range across the three scenarios are presented in Table 6.1. In the table, the percent contribution of each variable is calculated using the modification of coefficient for a single feature and assigns the addition to the environmental variable that the feature depends on before converting the value to a percentage. However, permutation importance is more relevant because it involves the contribution for each environmental variable, determined by permuting values randomly among the training datapoints and measuring the resulting decrease in training AUC (Phillips, 2006).

6.3.2 Current and future distribution of *Parkia biglobosa* and *Vitellaria paradoxa* across dryland savannahs of Nigeria

The logistic map predicting *Parkia biglobosa* and *Vitellaria paradoxa* distribution using current 19 bioclimatic climate data is shown in Figure 6.3 below. The zones with the highest parkland potential for each species (red) are seen as thus: *P. biglobosa* in Sudan savannah, Northern Guinea savannah and Southern Guinea savannah and *V. paradoxa* in Sahel savannah, Sudan savannah, Northern Guinea savannah and Southern Guinea savannah. Other agroecological zones with potential (light yellow) are seen extending from the drylands of Sahel savannah in the northern region down to the forested edges of the Derived savannah AEZ.

Table 6.1: The biovariables percent contribution and permutation importance of *Parkia biglobosa* and *Vitellaria paradoxa* MaxEnt model predictions

Scenario	*Parkia biglobosa*	Percent contribution	Permutation importance	*Vitellaria paradoxa*	Percent contribution	Permutation importance
Current	bio14w2	66.7	45.8	bio11w2	43	19.2
	bio17w2	22.7	0	bio17w2	29	0
	bio12w2	5.1	12.3	bio14w2	28	75.9
	bio18w2	3.4	30	bio12w2	0	4.9
	bio13w2	2.1	11.9			

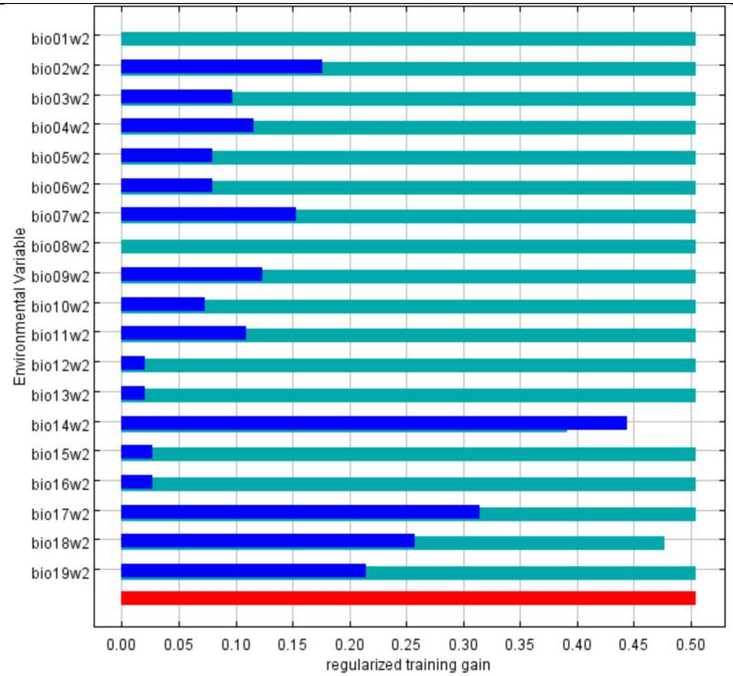
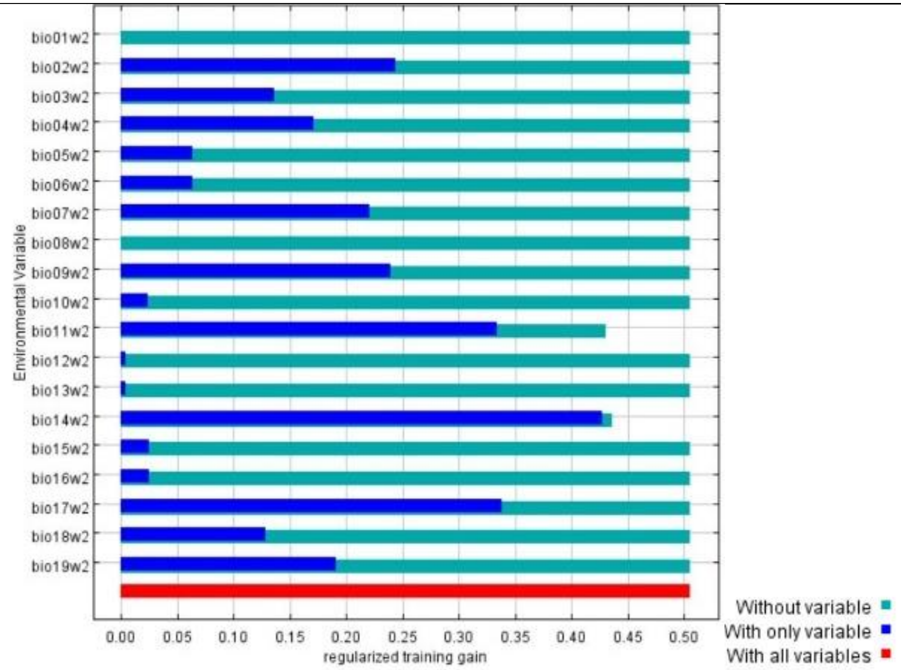
<table>
<tr><td>Scenario</td><td>Parkia biglobosa</td><td>Vitellaria paradoxa</td></tr>
<tr><td>Current</td><td>
</td><td>
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Figure 6.3: The jackknife of regularize training gain for the two parkland tree species

Figure 6.4 also shows the 2050 and 2070 future parkland distribution maps for *Parkia biglobosa* and *Vitellaria paradoxa* across the AEZ of Nigeria. The zones with highest suitability index (0.6-1.0) in future climates correspond to the current climate highest potential distribution areas but decreased in size in 2050 scenario, showing the extension of yellow colours in both species and increasing lower suitability index (0.4-0.6). The highly suitable areas in 2050 scenario tends to stretch towards north-eastern Sudan and Sahel savannah zones, with few patches found between NGS and SS zones in central region. The 2050 scenario in both species predicted areas had an increasing mid-range potential (yellow), over 44% lower suitability (0.4-0.6) in sampled AEZ parkland distributions predictions. The 2070 future potential distribution maps for both *P.biglobosa* and *V.paradoxa* display large variations in parkland area suitability compared to 2050, showing a significant increase in areas climatically suitable for both species to regenerate and thrive. Areas that indicated the highest suitability index (0.6-1.0) significantly increased (53%) compared to similar areas in current conditions that exhibited high potential parkland tree distribution. Generally, all geopoints marked in Figure 1 have reduced in suitability under future climate predictions, as half of the geopoints are located in areas below high suitability index. There is difference in suitability as seen in the maps with shifts occurring from west to east or north-eastern ward species movement but not significant reduction (45%) in area size. In other words, future distribution of the species with high regeneration and distribution potentials can be located at the Sudan and Northern Guinea savannahs of north eastern region. The model also showed areas with similar environmental conditions for prediction outside the sampled area, in neighbouring countries of Niger and Cameroon.

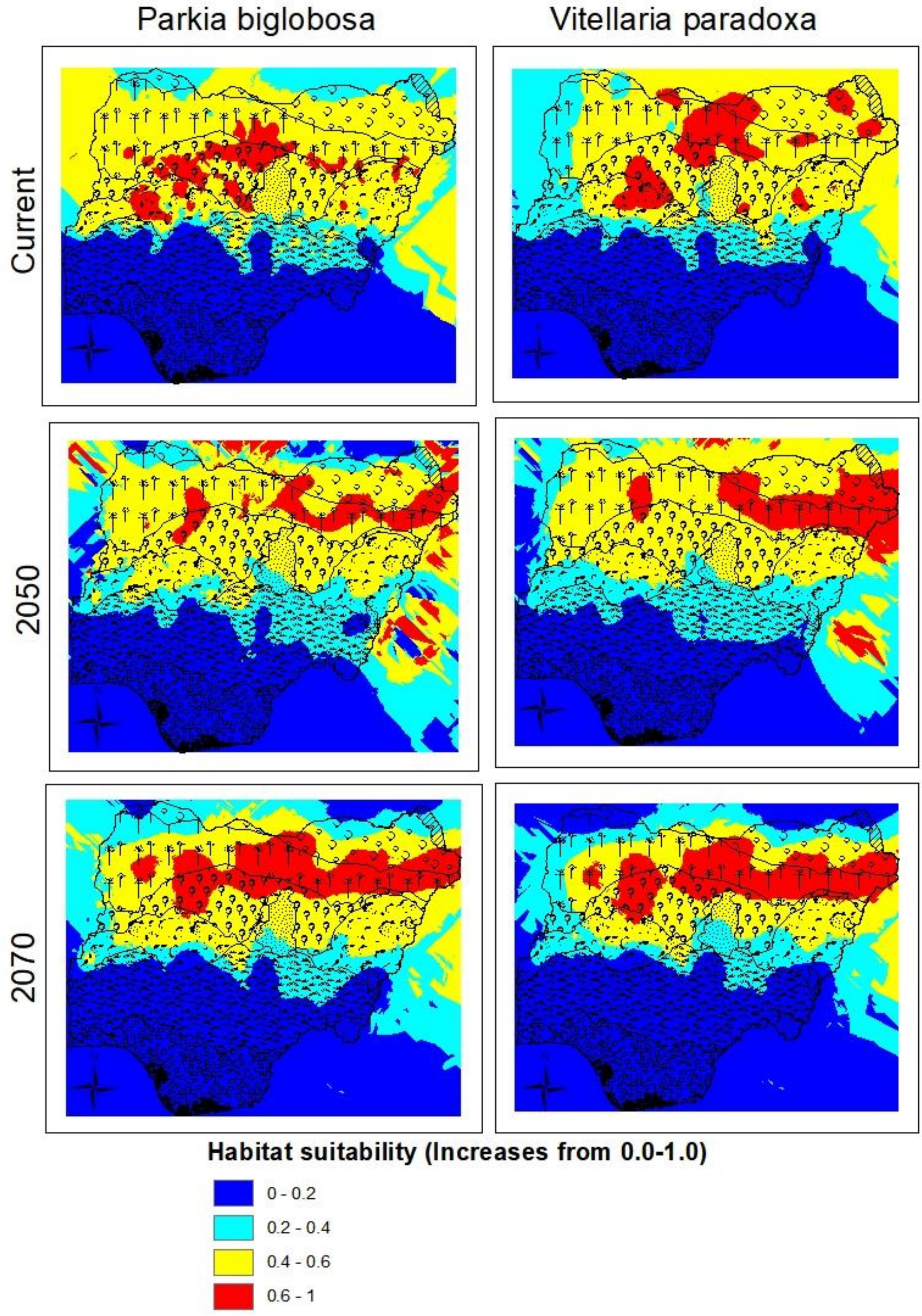


Figure 6.4: Maxent model map of the distribution of *Parkia biglobosa* and *Viteallria paradoxa*

6.4 DISCUSSION

6.4.1 Agroecological distribution effect on species suitability in Nigeria parklands

Based on the AUC graphs, MaxEnt did successfully predict the sampled parkland species distribution within sparse range to enhance trees outside forests distribution in severe climatic conditions. It can be deduced that predictive performance of MaxEnt can be affected by species geographical range and the climate of the habitats among other factors (Chahouki & Sahragard, 2016). This is shown in the high AUC ratings in sensitivity over specificity curve. Suitable future conditions were predicted for both species with highly probable occurrence in the dryland areas of the north-eastern region as shown in figure 2. This means the tree species are may thrive well in modelled future areas, despite variable weather conditions, similar to the MaxEnt model prediction of *Chrysophyllum albidum* distribution in Nigeria (Lyam *et al.,* 2012). Similar strategy is employed in climate analogues tool to enhance crop varieties adaptation to climate change (Ramirez-Villegas *et al.*, 2011). Moreover, each bioclimatic variable percent contribution is determined by the iterations performance and change in coefficients for a single characteristic as during jackknife test. This model feature permits identification of variables with more influence on the occurrence of different tree species by users. In other words, farmers and policy makers should focus on the important variables only, increasing the accuracy of predictive models and saving time and energy. In this instance, the regenerative species that thrive during the months of January to March are the most suitable, based on the result of permutation importance that rated precipitation at the driest periods as main predictor variables for two parkland species distribution for this research.

The MaxEnt jackknife test also indicated that precipitation at the driest month and quarter, and mean temperature at the coldest month and quarter were the most important bioclimatic variables on distribution of *P.biglobosa* and *V.paradoxa* respectively in the study area. These variables provided higher gain in comparison to other 19 bioclimatic variables in the model.(Deblauwe *et al.,* 2016; Onojeghuo *et al.,* 2015; Booth *et al.* 2013) reported that precipitation seasonality is the most significant in environmental factors affecting vegetation distribution in drylands, particularly the drought regime and cold temperature. Hence, there is a strong relationship between species occurrence and precipitation regime. It was also confirmed that precipitation seasonality is the most common predictor for parkland vegetation predictive models (Naughton, Lovett, & Mihelcic, 2015). Therefore, parkland tree distribution habitat is highly dependent on precipitation regime particularly during the driest seasons (January to March) and temperature at the coldest months.

Based on the jackknife test of variable importance and AUC, *P. biglobosa* current occurrence was related to precipitation at the driest month and quarter. Similarly, the future scenarios (2050 and 2070) for the species occurrence had precipitation at the driest, with an additional variable of precipitation at the wettest month influencing the model outcomes. The variation of climate conditions across the AEZs affects precipitation, temperature and evapotranspiration directly, based on reports (Chahouki & Sahragard, 2016; Sahragard *et al.,* 2011). In addition, bioclimatic conditions can determine parkland tree distribution through affecting edaphic characteristics such as soil moisture content, organic matter among others(Bayala *et al.*, 2006; Zomer *et al.,* 2016). Consequently, tree plant species are established within a specific ecological range in the drylands based on the climate and topographical needs. This is supported by many studies on the effect of drought on plant habitat distribution (Amissah *et al.,* 2014; Brandt *et al.,* 2016; Otieno *et al.,* 2005; Thiel *et al.,* 2014). Distribution of *P.biglobosa* was significantly affected by precipitation regime at the driest season (monthly and quarterly) and wettest month in current and 2050 scenarios, reducing the regeneration potentials in future climate. The 2070 scenario of *P. biglobosa* is also influenced by precipitation in the driest and wettest months as well as temperature in the coldest month. In other words, precipitation remains the most important predictor of the tree distribution in the parklands. The 2070 scenario for *V.paradoxa* just as *P.biglobosa*, shows an inverse in suitability with precipitation regimes at the driest and wettest months exhibiting long drought periods followed by high volume but erratic rainfall in the periods. Table 1 indicated *Vitellaria paradoxa* is significantly influenced by the bioclimatic variables and distribution similar to *P.biglobosa* at 2070. It seems that an increase in precipitation volume increased the future habitat suitability for both sampled species. Because the test of jackknife variable importance revealed that the 2070 distribution contained high but variable precipitation regimes and low temperature rates. Remya *et al.,* (2015) report on *Myristica dactyloides* future occurrence in India differs as the species distribution had no correlation with increase in precipitation volume when predicted on maxent using 2050 and 2070 scenarios, despite strong AUC results. (Khanum *et al.,* 2013) also reported in the study of *V. arnottianum* and *T. hirsuta* in Pakistan showed that range expansions are likely facilitated through adaptations to microclimate based on the predictions of bioclimatic variables done by MaxEnt.

The AUC values results revealed the environmental variables that affected the ecological niche of parkland tree species. Climate factors, including precipitation duration, tend to be useful for species with vast distribution range, such as the two species in this study. This study confirms the results of Bocksberger et al., (2016); Gaal *et al.*, (2012) and Guisan & Zimmermann, (2000) that modelling habitat suitability for more appropriate species ecological niche with MaxEnt requires high AUC value for suitability. Sahragard and Chahouki (2015) also reported model performance variability is affected by the niche of the specific species and the response curve shapes of the variables as seen in AUC curve graph (Fig. 2)

6.5 CONCLUSION

Maximum Entropy model is very good at predicting spatial distributions of tree species with lean ecological niches, such as parklands, as it can perform well with few species samples, provided there is a strong regularization (kriging) support. The habitat suitability of *Parkia* *biglobosa* and *Vitellaria paradoxa* for the current climate scenario were successfully modelled. The most important environmental variables are drought regime and temperature of the dry season, ranging between December and April across the three studied agroecological zones. Tree species distribution as influenced by climatic variability depended mainly on rainfall pattern to adaptive regeneration potentials. This study confirms reduction in habitat suitability of the two species at the current location under the extreme climate change scenario for the year 2050 but increase in suitability range that spread to the north eastern region in the year 2070 period. This implies that future climate suitability for parkland species distribution is existing in north-eastern Nigeria. Therefore, farmers in the Guinea savannah agroecological zones should learn from restoration and farming strategies of communities in the drylands of north-eastern region. Strategies such as collecting dispersed seeds from economic trees, silvopastoral farm management, and crops grown to improve soil fertility. On the side of policy and decision makers, to restore degraded agroecosystems, the focus needs to shift to timely planning (using weather calendar) for improved adaptation and mitigation strategies among affected communities. The strategies will not only help in the protection and regeneration of tree species on farms of existing parklands but also in reducing future extinction and improve agroecological productivity and sustainable livelihoods.

CHAPTER SEVEN: ASSESSING PARKLAND SPECIES REGENERATION AND SURVIVAL POTENTIALS USING COST-EFFECTIVE PROPAGATION METHOD ON FARMLANDS IN NORTHERN NIGERIA AND IN GLASSHOUSE IN NORTH WALES.

7.1 INTRODUCTION

Drought is considered one of the most challenging environmental factors across west African parkland landscapes, limiting agricultural yield and significantly impairing land restoration (Adeaga, 2013; Badejo, 1998). It is the main climate driver responsible for over 60% mortality rates in the first year of protected wildlings on parklands in the dry tropic and semi-arid part of Northern Nigeria (Ayanlade *et al.,* 2018; Brandt *et al.,* 2016; Miller *et al.,* 2016). Scattered trees on agricultural fields are peculiar characteristics of the Nigerian savannah parklands. The trees are deliberately protected and managed within the agroecosystem because of their distinct but multiple uses. Tree seedling mortality in parklands is related to the pattern of agrobiodiversity with more mortality rates in less fertile and precipitated areas (Jalloh *et al.*, 2012). Thus, moisture availability contributes directly or indirectly to tree survival (Bourgeois *et al.,* 2016; Padilla *et al.,* 2009). Consequently, tree species survival was hypothesized to vary predictably among species along provenance gradients in the drylands such that locally popular species are considered more resistant to drought (Bayala *et al.*, 2017; Poorter & Markesteijn, 2008)

Vegetative propagation techniques (stem cuttings and marcotting) provide alternatives for farmers and gardeners in developing countries avoiding the germination problem of recalcitrant seeds predominantly found in tropical regions (Gbadamosi & Oni, 2005). It also makes the transfer of genetic potential and multiplication of plant stocks from the parent to the new plants cheaper and easier, particularly for poor-resource farmers practicing agroforestry systems (Simons & Leakey, 2004).

In the two previous chapters (4 and 5) of this thesis, it was established that species dominance is positively related to farmers' species preference. This is because current agricultural systems in the drylands across the AEZ support species' ability to survive via protection, as water stress resistance is an essential attribute of parkland tree propagules; however, the few comparative studies on the agroecological provenance variation of the resistance to water stress of cuttings and seedlings are not locally focused on Nigerian parkland species. Hence, gap still exists on the impact of drought on Nigeria's savannah tree seedlings across the AEZ, with focus on its survival due to the extreme projected climate conditions.

In this chapter, a glasshouse experiment was carried out on the morphological drought resistance for first year tree seedlings of 3 parkland species on survivorship response across the three agroecological zones of Nigeria. The drought resistance of these tree seedling is basically the ability to withstand moisture stress in a period while struggling for growth and survival (Brunner *et al.,* 2015; Otieno *et al.*, 2005). The experimental method involves simulation of future climate (precipitation regimes of three AEZ) of Nigeria to evaluate the drought effect from other agroecological factors influencing survival of tree species juveniles on farm landscapes. It also involved the asexual propagation of one of the species through cuttings (from seedlings raised ex-situ after a week moisture stress and marcotting on the trees in the field. The choice of young seedlings of *Parkia biglobosa*, *Vitellaria paradoxa* and *Anarcadium occidentale* species is due to their abundance and preference (as discussed in chapters 4-6), not morphological traits or competition for soil resources. By subjecting the parkland species to prolonged stress, we can determine the degree to which species occurrence differs in response to drought based on the agroecological climate characteristics. This may change our perspective on the variation of species' drought resistance to distribution pattern and abundance across local ecological landscapes in tree-crop interactions. To do this, the research addressed the following specific questions for growing tree seedlings under extreme climate-simulated conditions.

- How does watering affect species from different agroecological zones during early germination of seedlings? (Experiment 1)
- Do tree species from drier agroecological zones resist drought more in extreme climate conditions at juvenile stage? (Experiment 1)
- Can root morphology influence tree seedlings survival using adaptive measures during climate extreme events i.e fine root vs tap root system? (Experiment 2)
- Can asexual propagation induce enough rooting and provide sustainable propagules for survival mechanism in extreme dry medium conditions i.e multiplication of tree seedlings as plant materials for agroforestry (Experiment 3)

The main aim is to study the seedling growth characteristics and the propagation of selected parkland species at the juvenile development phase across the three studied agroecological zones under water stress.

7.2 MATERIALS AND METHODS

7.2.1 EXPERIMENT 1 (GLASSHOUSE EXPERIMENT): RAISING TREE SEEDLINGS

7.2.1.1 Plant material and planting medium

The plant materials were sourced as seeds from trees on farms based on phenotypic features identified by farm owners' in 9 different locations across three sampled AEZ (see location and respondents' details in chapters 4 and 5). The seeds were then planted for seedling emergence in a tropical glasshouse chamber at Henfaes Research Centre, Bangor University, Abergwyngregyn, Wales between June 2016 and February 2018. The seedlings grown were *Parkia biglobosa* (SGS, NGS and SS), *Vitellaria paradoxa* (SGS and NGS), and *Anacardium occidentale* (SS). The glasshouse temperature was set at Max. 35^{o}C for 16 h (day) and 28 ^{o}C for 8 h (night). During the day, lights provided in the glasshouse has photon flux density ranging between 10 - 16 μmol m^{-2} s^{-1}. The tree seedlings were in a black plastic pots (diameter 10 cm base, 15cm top; height 20 cm), allowing more space for root spread at juvenile stage and reduction in pot limitation. A total of 420 black plastic pots were filled with mixture of john innes compost 2, fine grade vermiculite and river sand in a ratio 2:1:2 for the first planting experiment. The average depth of the mixture in the pots was 12.5 cm deep as plant medium for all the pots. Watering was done to saturation as recommended in Ward and Robinson (2000) once in 3 days for the duration of the seedling treatment. Excess water exit through punctured holes at the base of each pot.

Plate 6.1: Seedling establishment of the selected species in glasshouse. Photo: Ibrahim Abdullahi

7.2.2 EXPERIMENT 1 (GLASSHOUSE EXPERIMENT): DROUGHT REGIME

7.2.2.1 Seedling establishment

Forty-five seedlings were raised with one seed per species per pot for each of the three agroecological zones in this study. They are Sudan savannah (SS), Northern Guinea savannah (NGS) and Southern Guinea savannah (SGS). Beating up was done 2 weeks after planting to replace the species that did not germinate or loss vigour. After the first five months of establishment and continuous watering, 15 seedling pots each per species per agroecological zones were selected for drought treatment. The second and third treatments also had 15 seedlings pots isolated from watering at 7 and 9 months for seedling resistance to drought trial. Data collected for seedling establishment of all treatments include the number of shoots (100% across all treatments), number of leaves, shoot height (petiole elongation), shoot girth (petiole enlargement).

7.2.2.2 Drought preconditioning

The first drought regime treatments started on 7 February 2017, 150 days after the seedling establishment. Five plant pots per AEZ were selected at random as treatment replications from the 15 seedlings isolated from further watering after 5, 7 and 9 months for SS, NGS and SGS respectively. The pots with multiple stem were reduced to one stem only, i.e. stem with form and vigour. This was done for each AEZ treatment seedlings for consistency and uniformity as reported in (Otieno *et al.*, 2005; Schreeg *et al.*, 2005). The drought regime is the treatment considered independent factor with three levels, namely 5,7 and 9 months, and the AEZ is the dependent factor with different levels (SS, NGS and SGS). Figure 7.1 illustrates the period of watering, drought regime and harvest time. The drought regime corresponds to the predicted extreme future climate model (refer to chapter 3 - random forest classification) of Nigeria's dryland agroecology, focusing on moisture as induced by bioclimatic variable. The water-stressed period lasted for six months per treatment. During the stress treatment period, data on number of (compound) leaves, stem height (cm), stem girth (at the base in mm), wilting stage (normal - 1, slightly wilted - 2, wilted - 3, severely wilted - 4, dead - 5) and chlorophyll content (using Spad-502 Plus Chlorophyll Meter). The soil water content of the seedling medium was based on gravimetric soil dry weight at 105◦C for the upper 10 cm and uniform water was applied in each plot.

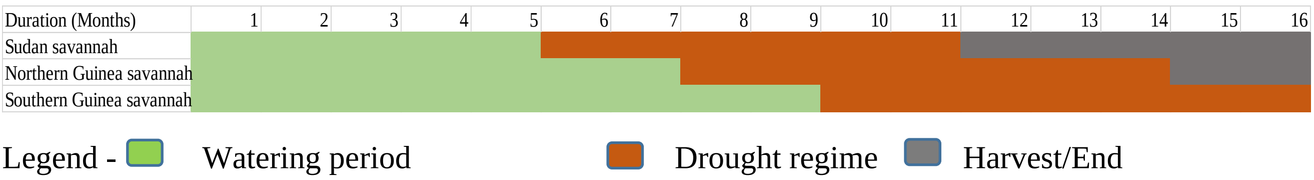


Figure 7.1: Drought preconditioning time interval for the tree species across the AEZ sampled.

7.2.3 EXPERIMENT 1 (ROOT SCANNING IN THE LABORATORY): The Root morphology metric analysis

7.2.3.1 Whole seedling plant harvests

The entire seedling pots were carefully excavated after six months per treatment, to check root growth at the end of the droughting sessions. The planting medium (See 7.2.1.1) enabled recovery of quantifiable root extents (lateral and fine roots), although some tiny fine roots were severed from the wilted and dead seedlings during the harvesting process. After harvest, plant materials were placed in plastic zip-lock bags and taken to Environment Centre Wales (ECW) Laboratory, Bangor University, UK where the storage was done in a cool dry cupboard before processing. Samples were stored for a maximum of 2 days.

7.2.3.2 WINRHIZO and Biomass

Deionized water was used to remove soil from the seedlings and divided into root, stem, and dry leaf. The root length and diameter (surface area) were scanned using “WinRhizo” software. The WinRhizo software (version 3.10, Régent Instruments Inc., Blaine, Quebec, Canada) analysed plants into images obtained at 300 dots per inch using a scanner. This was done by submerging roots for floatation, in a thin film of water on a flatbed scanner to encourage separation but overlapping of surrounding roots is unavoidable. As roots were crossing against each other, variability in produced length and volume distributions was expected. Hence, a percentage error of 10% is used globally from the root length-weighted determination to improve root length diameter categories variability (Beckett *et al.*, 2017). This will reduce uncertainty as stained roots and other physical micro factors (refraction) can alter image analysis. The individual rooting depth was estimated by measuring the length of all roots scanned and dividing into five classes (See table 7.1).

Table 7.1: Root size classes and the root type for both species measured

Root size classes (mm)	Root type
0.01-0.50	Fibrous
0.51-1.00	Fibrous
1.01-1.50	Fibrous
1.51-2.00	Tap
2.01 & above	Tap

7.2.4 EXPERIMENT 2: PROPAGATION OF *Anacardium occidentale* USING CUTTINGS

7.2.4.1 Planting materials for cuttings

Ten cuttings collected from pre-treated *Anarcadium occidentale* seedlings of 5, 7 and 9 months old each were used as parent materials. They were collected using sterilised pair of shears to cut out the desired specification. All the cuttings length and diameter were between 5-10 cm and 0.5-1.0 cm respectively. To ensure consistency, initial conditions for the cuttings at 4 cm from the top of shoot, cuttings were clipped, and leaves stripped off except from the two nodes at the bottom (plate 6.3). Measurements of the stem cuttings were done with ruler and RS pro 150mm digital vernier calliper.

Plate 6.3: *Anacardium occidentale* cuttings in pots at the glass house. Photo: Ibrahim Abdullahi

7.2.3.2 Rooting medium

The compost mixture used for the cutting experiment in fraction of two-third river sand (2/3) and one-third peat (1/3).

7.2.3.3 Rooting Hormone and Fungicide

Powdery form of indol-butyric acid (IBA) weighing 1g, 3g and 5g were dissolved in one litre of distilled water to form 10,000 ppm, 30,000ppm and 50000ppm solution, respectively. To reduce fungicide effect on all treatments, 10 gram of fungicide powder was dissolved in one litre of distilled water to form a fungicidal solution of 100,000 pp and applied, prior to hormonal treatment. Collected cuttings were dipped in a fungicide solution from the top end for about 3 minutes.

7.2.3.4 Greenhouse and watering

Treated cuttings in the tropical glasshouse had a thick hanging blanket covering the cuttings bench. The cover created a microclimate around the bench, increasing relative humidity by up to 30% and reducing direct sunlight intensity. The watering was done using mist burst four times daily equal interval between 7am and 7pm and set at 4 minutes duration same (though treated blanket retained moisture after watering as pictured in plate 6.4). Light and temperature regime was the same as above. Weeding was done manually by hand pulling and brush cleaning.

Plate 6.4: Pots containing treated cuttings of *Anarcadium occidentale* being watered by mist with a treated blanket hanged to retain moisture and increase humidity (Photo: Ibrahim Abdullahi)

7.2.4 EXPERIMENT 3: PROPAGATION USING MARCOTTING

7.2.3.1 Planting materials for marcotting

The marcotting experiment was conducted between October 2017 to May 2018, during the beginning of the dry season coinciding with flowering season of the selected species, *Anacardium occidentale* trees on agricultural fields in Gwako village (SGS) in Abuja, Nigeria. Average climatic conditions of the location are shown in Chapter 4, Table 1. With the support of farm owners', selected trees' secondary branch extended shoot at three different girth sizes had the cambium (ring bark) of about 3 cm width removed for rooting purpose. The peeled shoots were then covered with a rooting medium containing treated sandy-loam soil and clay (1:1) and strapped with a transparent polythene sheet (plate 6.4). The mixed sandy loam and clay medium treatment was sterilised via cooking for 8 hours in a local metal bucket to reduce fungal and viral infection. The rooting medium had regular spraying of water once in three days through punctured holes and were continuously monitored for rooting response. The first root initiation was observed after 5-6 weeks after random observations of all the treated tree branches, and the experiment lasted for 15 weeks.

Plate 6.4: Young farmer dressing the rooting medium after learning from the author on his farm plot. Photo: Ibrahim Abdullahi

7.2.3.2 Rooting of marcotting

Three different girth sizes *Anacardium occidentale* tree shoots were tested as treatments for field experiment: 0.0-1.0cm, 1.1-2.0 cm, and 2.1– 3.0cm. These sizes had shown significant root growth rates in vegetative propagation experiments of cashew in India (Eganathan et al., 2000). Four secondary branch shoots per treatment were selected based on morphological characteristics of the mother tree plant. There was no artificial hormonal treatment. The mother plant will keep the photosynthate supply for vigour and growth. Number of roots, Root length, using 30 cm ruler and root collar diameter, using a Vernier calliper (to the nearest 1/10 millimeter), were measured after root emergence from the secondary branches during the propagation period (plate 6.5).

Plate 6.5: Picture showing protruding roots from punctured hole of marcotted stems of *Anarcadium occidentale* after 8 weeks. Photo: Ibrahim Abdullahi

7.2.3.3 Acclimatization

Acclimatization is a process of conditioning young plants to survive in new natural medium or habitat (Trimanto, 2017). Fourteen weeks after the observation of rooting across all treatments, the plant materials were cut out from the secondary branches and acclimatization process was as follows:

i. Unwrapping the polythene that holds the soil medium to expose the roots while maintaining moisture content after detachment from mother plant.

ii. Exposing the plant material root for measurement

iii. Putting of the plant materials in a container containing rich loamy soil to keep the plant fresh

iv. Growing the plant materials under shade to recover from shock and reduce heat stress while watering every 2 days

v. Transplanting the plant materials on the farmer's field using a mixture of loamy soil, animal compost, and rice husk of 1:1:1/2 ratio. The picture below illustrates the stages i-v.

i	ii	iii	iv	v

Figure 6.2: The marcotting acclimatization stages from cutting out the rooted stock to planting on the field.

7.3 DATA ANALYSIS FOR ALL THE EXPERIMENTS

Data collection started after three weeks of planting, when a significant number of seeds had germinated (Section 7.2.2.1). Data collected for seedling establishment of all treatments include number of shoots (100% across all treatments), number of leaves, shoot height (petiole elongation), shoot girth (petiole enlargement) and chlorophyll content (using Spad-502 Plus Chlorophyll Meter). Analysis of variance (ANOVA) using completely randomised design determined the mean differences of all treatments with focus on interactions between agroecological zones per species. The rationale behind the design is the one-way treatment of AEZ response to water during germination. Genstat Package Release 19.1 was used for the analysis of the initial seedling establishment.

For seedling establishment and drought regime, data was computed using repeated measure analysis of variance (ANOVA) in a completely randomised design to determine the mean differences between AEZ per species for all parameters, except the survival rate. Although the parameters were same as the initial seedling establishment, they were measured multiple times to see changes in the treatments. Therefore repeated measures were applied as more than one condition (the AEZ and time) and the response to each of these conditions needs to be compared.

On the stressed-treated plant roots, the morphological effects were evaluated by analysing the root diameter class using from Winrhizo for all treatments in experiment 2. In this experiment stage, factorial analysis of variance was employed for analysis because it compares more than one independent factor i.e AEZ and the root classes. Hence, the need for factorial arrangement in completely randomised design to see the relationship of the means among the AEZ for all the classes (See table 7.1). Shoot-root biomass ratio was also determined by weighing after over drying 105℃

On the two-field propagation experimental trials (cuttings and marcotting) conducted on farm trees in Northern Nigeria, observations started after two weeks to ascertain rooting occurrence under controlled conditions. Mean differences within same species between the treatments were analyzed with ANOVA, while differences between the two propagation methods were analysed using t-test. The t-test was employed because the analysis involved two independent variables with similar outcomes. The parameters included the root length, Number of total roots observed, root girth, number of roots alive, number of dead roots.

Where necessary, significant mean values were further tested using Least Significant Difference (LSD) at 5%. Three missing values (one per treatment in experiments 2 and 3) recorded. The missing values were replaced by using the average of the remaining values within the treatment.

7.4 RESULTS

7.4.1 Seedling growth across the three agroecological zones

The result indicate germination rate of tree species seedlings is dependent on water availability among other factors. Here, all species grown from seeds to obtain seedlings had no significant differences across the zones and within the zones except in *Vitellaria paradoxa* Girth size across the AEZ tested and shedding of leaves during drought (Table 7.1). The results also showed in the box and whisker plots below did not differ for *Parkia biglobosa* except during the chlorophyll content measurement. Though not a seedling parameter, chlorophyll content was measured to monitor the photosynthetic change as the germination continues before the water cessation trial. The outliers on the graph were prominent in *Vitellaria paradoxa*, found in all parameters (Figure 1A). Thus, all the three species (including *Anarcadium occidentale)* responded to well to adequate moisture from the low fertile soil medium used in the experiment; conversely, species association with provenance at the juvenile stage under blanket treatment cannot exhibit a noticeable difference in the growth of stem and roots resources. Species morphological traits at four months had similar size in the growth of stem and roots across soil medium in all treatment pots. However, the NGS species of *Parkia biglobosa* generally tend to grow taller and more vigorous (Fig 1A b-d), just as *Vitellaria paradoxa* of SGS (Fig. 1B b-d) possess higher shoot characteristics except for chlorophyll content. The *Anarcadium occidentale* plant materials were used in cuttings that would be discussed in 7.5.4. This implies that the selected tree juvenile germination rate from seeds across the AEZ under regular water supply and suitable climatic condition is very high.

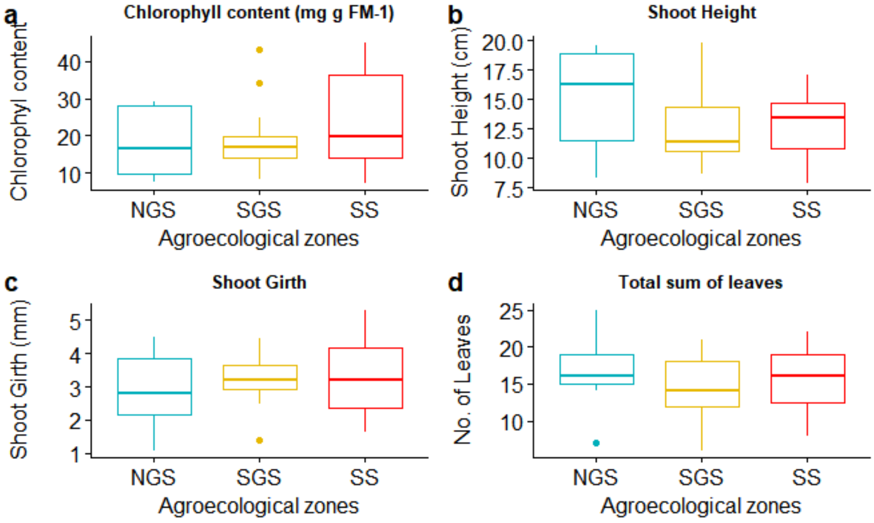


Figure 1A: *Parkia biglobosa* initial seedling growth establishment parameters including (a) Chlorophyll content (b) shoot height (c) Shoot Girth and (d) Total number of leaves for the three AEZ plant materials in the glasshouse.

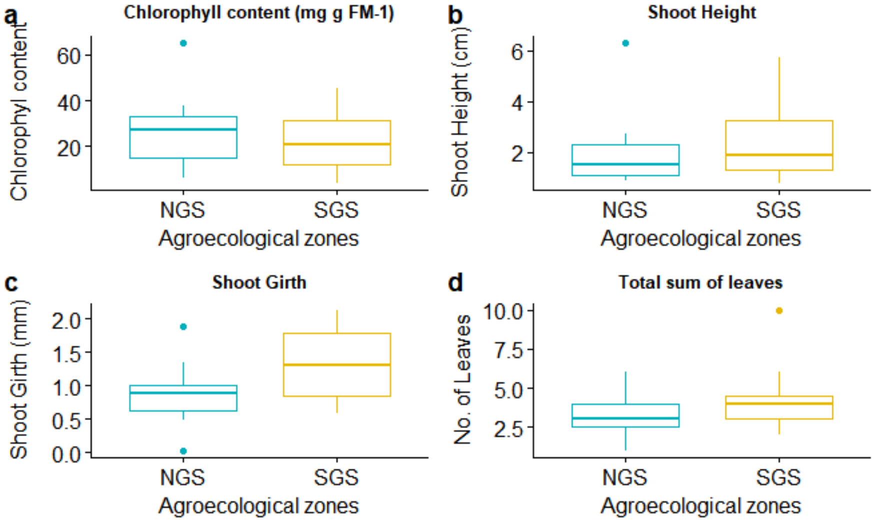


Figure 1B: *Vitellaria paradoxa* initial seedling growth establishment parameters including (a) Chlorophyll content (b) shoot height (c) Shoot Girth and (d) Total number of leaves for the three AEZ plant materials in the glasshouse.

Table 7.1: Statistical analysis results for the effects of the agroecological zone and the drought regime of *Parkia biglobosa, Vitellaria paradoxa* and *Anacardium occidentale* seedling

Species	VARIABLE	EFFECTS	D.F	M.S	V.r	F>P.r
Parkia biglobosa	Shoot Height(cm)	AEZ	2	0.350	0.05	0.955
		Drought	2	1.689	0.22	0.801
		AEZ.drought	4	4.041	0.53	0.712
	Girth(mm)	AEZ	2	0.8287	0.94	0.398
		drought	2	1.3672	1.56	0.224
		AEZ.drought	4	1.7313	1.97	0.120
	Number of Leaves	AEZ	2	6.29	0.25	0.781
		drought	2	12.42	0.49	0.615
		AEZ.drought	4	12.09	0.12	0.975
	Chloro. content(mg g FM^{-1})	AEZ	2	225.0	1.23	0.305
		Drought	2	173.7	0.95	0.397
		AEZ.drought	4	522.1	2.85	0.038*
Vitellaria paradoxa	Shoot Height(cm)	AEZ	1	2.640	1.23	0.279
		Drought	2	14.233	3.31	0.054
		AEZ.drought	2	0.654	0.30	0.740
	Girth(mm)	AEZ	1	1.5550	5.69	0.025*
		Drought	2	0.0929	0.34	0.715
		AEZ.drought	2	0.0222	0.08	0.922
	Number of Leaves	AEZ	1	4.033	1.68	0.207
		Drought	2	9.233	3.85	0.036*

		AEZ.drought	2	0.633	0.26	0.770
	Chloro. content(mg g FM^{-1})	AEZ	1	1.555	5.69	0.025*
		Drought	2	0.0929	0.34	0.715
		AEZ.drought	2	0.0222	0.08	0.922
Anacardium occidentale	Shoot Height (cm)	Drought	2	12.235	2.12	0.162
	Number of Leaves	Drought	2	0.867	0.27	0.771
	Girth (mm)	Drought	2	0.768	0.60	0.565
	Chloro. Content (mg g FM^{-1})	Drought	2	77.2	0.33	0.724

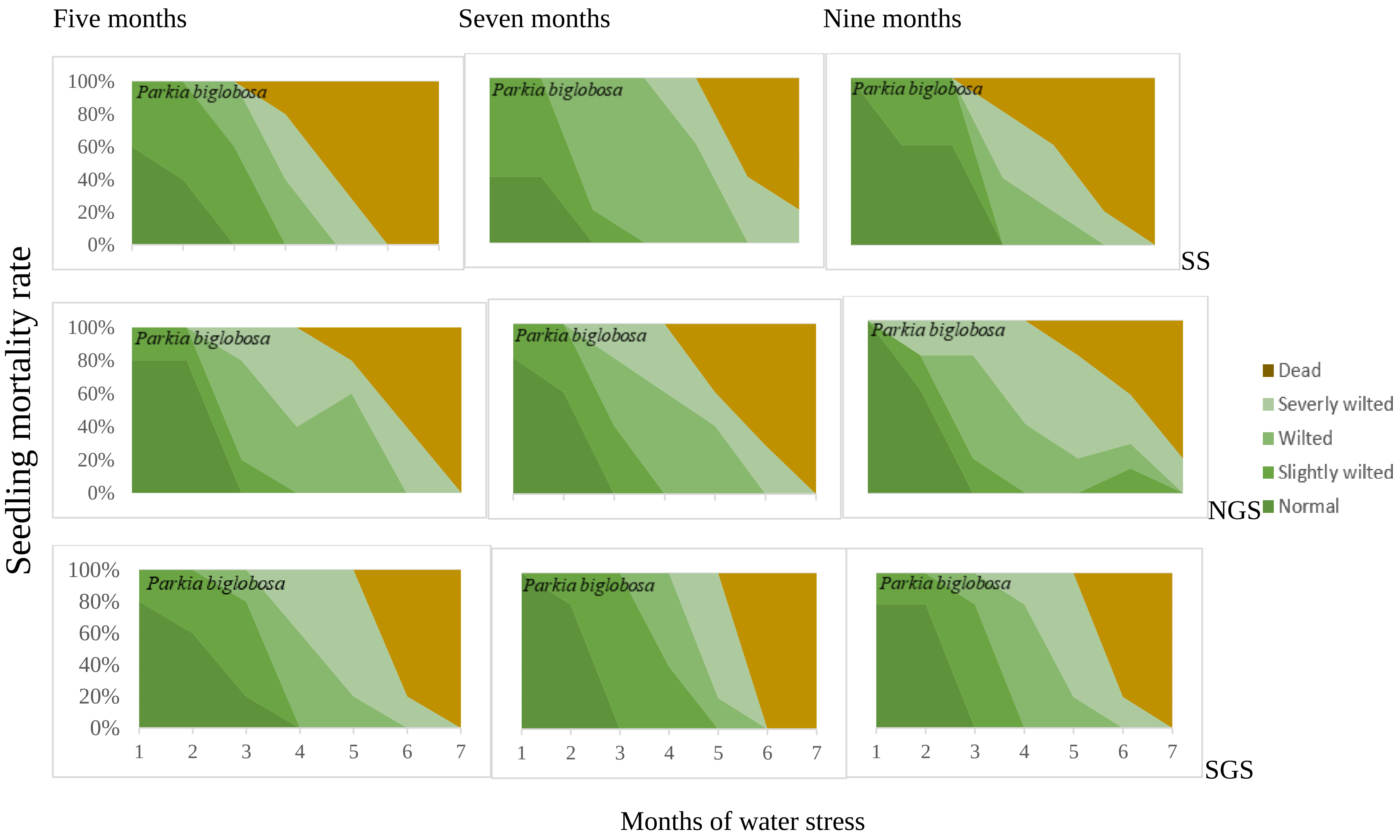
7.4.2 Survival of the species under drought

7.4.2.1 Wilting of parkland species at the glasshouse

The Seedling survival rate was calculated as the proportion of individuals alive after the targeted time aimed in this research. This was done using Bognounou *et al.,* (2010) where Survival rate was computed in percentage using the number of seedlings alive divided by number seedlings transplanted and multiply by 100. At the seedling establishment stage of the experiment, just before drought regimes stress application, the seedling survival rate was 100 % for all treatments. In the drought experiment above, the hypothesis was that there would be differences in how drought regime would influence tree regeneration across AEZ, with focus on the mortality rate. The mortality rate is the opposite of the survival rate and was so pronounced by the end of the third month into stress, implying drought-induced mortality affects over 70% of the seedlings. Based on the AEZ, *P. biglobosa* seedling of SS responded to the first stage of wilting after 2, 2 and 4 months for 5-, 7- and 9-months drought stress treatment, respectively (Figure 2). The NGS and SGS had similar results with all treatment replicate responding wilting stages change after two months, except at the 5-month of SGS where the species endured and for a further 4 weeks. There was severe mortality in the experiment, and all the species died before the 6th month. Though the last wilting stage (dead) of the trial occurred between 3 and 6 months, there was a significant change in wilting stages across the drought regime and AEZ for the two species (Figure 2a and b). The 9-month treatment of *P.biglobosa* resisting drought increases, as the AEZ transects from the SS to the SGS.

The *V.paradoxa* seedlings resistance increased with seedling age, and across the north-south transect of the studied AEZ (Fig. 2B). The 9-month treatment of NGS resisted drought longer, with 80% of the treatments severely wilted but not dead up to 4.5 months of trial. All other Shea tree species treatments in the glasshouse did not differ in their mortality rate range. The *Anacardium occidentale* seedlings had highest mortality rate (100%) with all seedlings reaching wilting stage 5 (Dead stage) at the 3rd month. As the popular species among farmers in SGS hardly spent a week in all other stages of wilting, further research on its adaptation to drought scenarios using propagation techniques will be discussed in section 7.5.5.

(A)


Five months
Seven months
Nine months
Parkia biglobosa
100%
80%
60%
40%
20%
0%
1
2
3
4
5
6
7
SS
NGS
SGS
Dead
Severly wilted
Wilted
Slightly wilted
Normal
Seedling mortality rate
Months of water stress

(B)

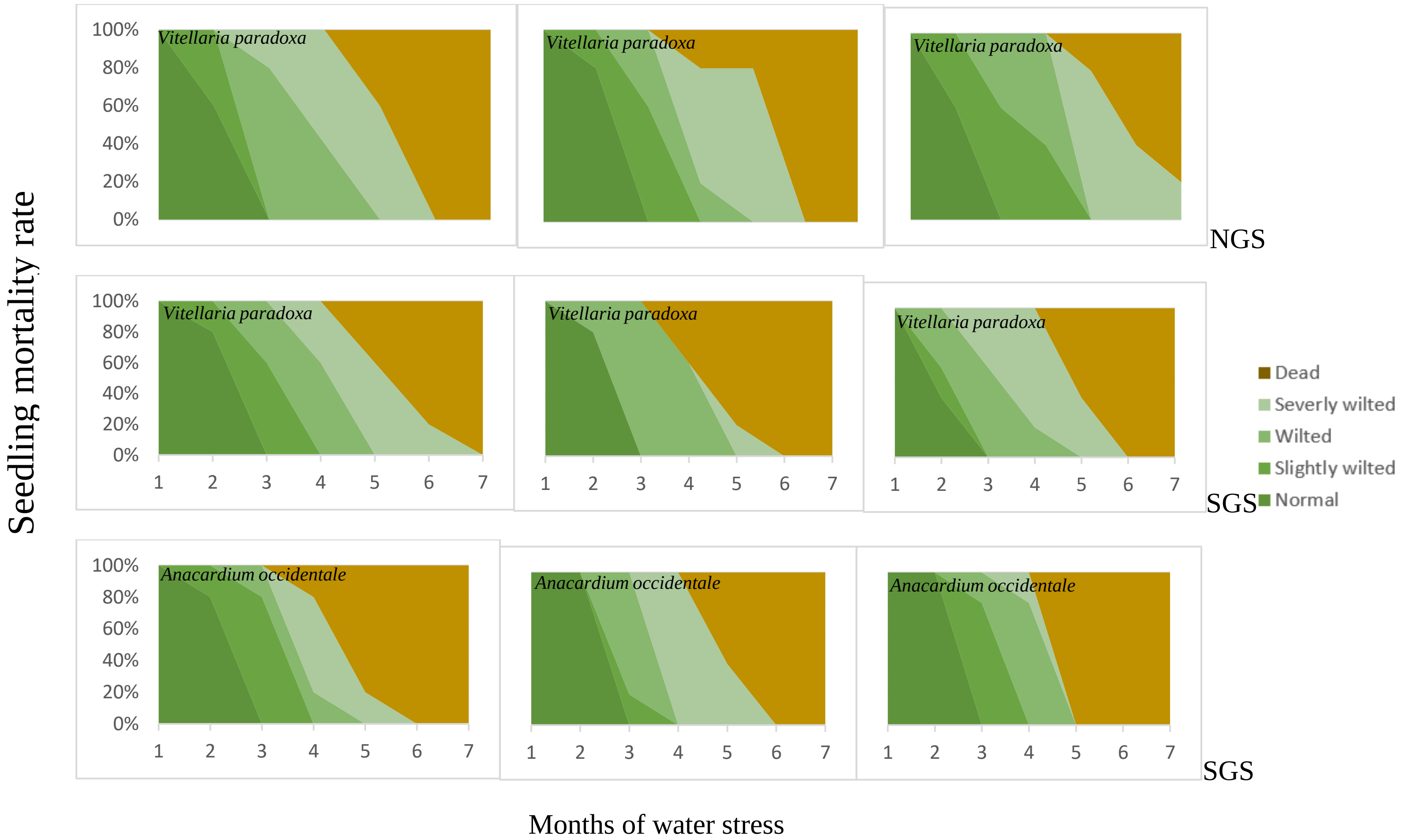


Figure 7.3: The stages of Wilting and mortality in the drought treatment. Three parkland species across three AEZ.

7.4.2.2 Morphological parameters of shoot variables after drought stress

The shoot of *Parkia biglobosa* and *Vitellaria paradoxa* 6 months after applying drought stress by seizing regular water at different times for different species. This is seen in table 2 statistical analysis of variance using monthly repeated measures affected only shoot height, shoot girth and number of leaves for *P.biglobosa*. difference was found between provenances for the number of stems. The result in the table further showed no significant differences in the interaction of AEZ and drought period (months) of *P. biglobosa*. However, the interaction plots (figure 3) of the parameters indicated an exclusive trend in the response of the species to drought. For stem girth, the highest mean values were observed in SGS at the beginning of the drought, the trend continues for all AEZ until the 4th month of drought. There was decrease in general mean of the stem girth, sign of loss of turgidity after reaching wilt stage 3. The seedlings exhibited a trait of extreme resilience to drought at the 2nd week of the 4th month, which initiated the stem recovery for a short period making NGS the most resistance AEZ as seen in Fig. 3A. Similarly, the height of *P. biglobosa* responded to drought with SGS having the highest mean (Fig. 3A) but NGS species resistance to drought was more pronounced over the duration of the experiment, with stiff competition from other AEZ treatments. On the total number of leaves, the leaves were counted using petioles that connects *P. biglobosa* double compound leaf to its stem. All the treatments shed over 80% of their leaves before reaching the dead stage. The NGS species had the highest number of leaves but shed the least number of leaves in the experiment.

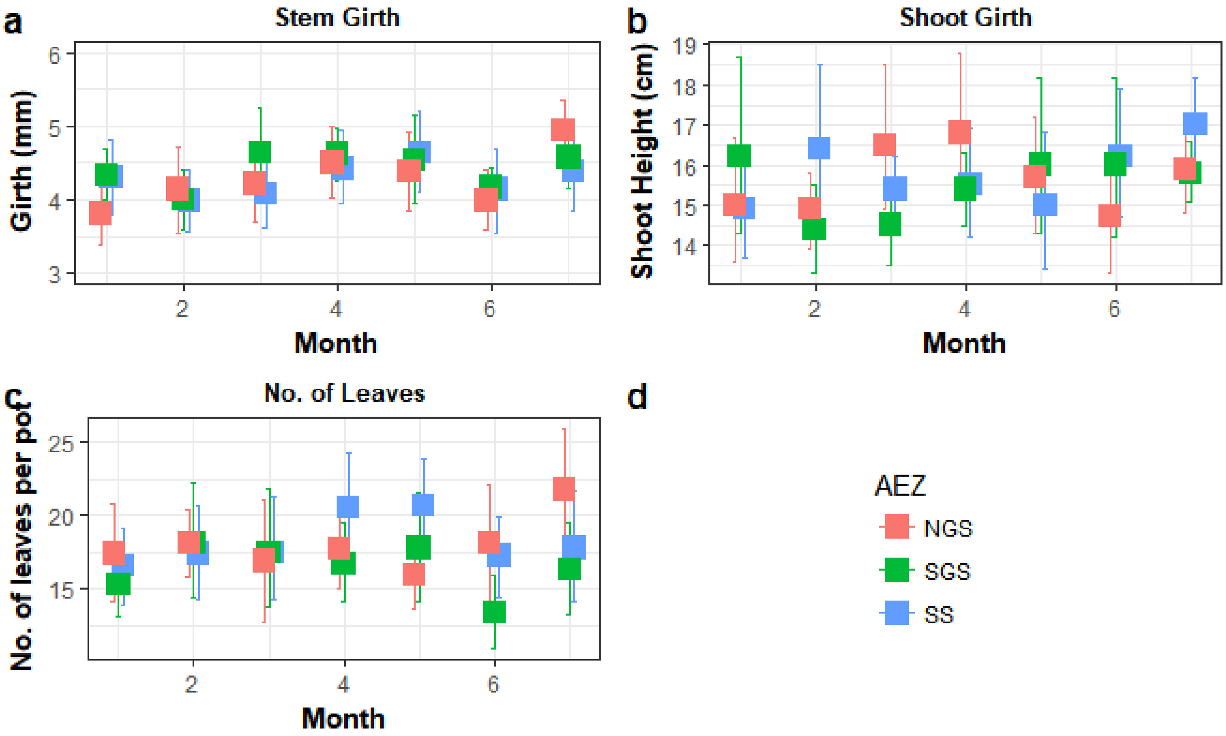
Table 7.2: Statistical analysis result for the effects of the AEZ and the drought regime overtime of *P. biglobosa and Vitellaria paradoxa* seedlings after 6 months of water stress treatment

Species	Variables	Effects	DF	F-value	p-value
Parkia biglobosa					
	Shoot Height (cm)				
		AEZ	2	0.194	0.823
		Month	5	1.923	0.166
		AEZ:Month	4	0.266	0.766
	Girth(mm)				
		AEZ	2	0.37	0.688
		Month	5	2.75	0.098
		AEZ:Month	4	0.93	0.395
	No. of Leaves				
		AEZ	2	2.08	0.125
		Month	5	0.68	0.407
		AEZ:Month	4	0.54	0.579
Vitellaria paradoxa					
	Shoot Height (cm)				
		AEZ	1	0.097	0.755
		Month	4	11.87	0.007*
		AEZ:Month	3	0.703	0.402
	Girth (mm)				
		AEZ	1	42.72	<.001*
		Month	4	4.27	0.039*
		AEZ:Month	3	0.03	0.859
	No. of Leaves				
		AEZ	1	5.51	0.019*
		Month	4	31.45	<.001*
		AEZ:Month	3	0.28	0.595

There were no significant differences in the interaction between AEZ and months of *V. paradoxa* seedlings subjected to different drought regimes. However, the watering seizure exerted a significant impact on all morphological variables measured ($P < 0.05$), except for shoot height AEZ (Table 7.2). In the table, all months differed significantly for stem girth, shoot height and number of leaves. There was also a significant effect of AEZ for shoot height and number of leaves ($P < 0.05$). Though *V. paradoxa* was selected based on its high score in preference and uses in Chapter 4 results, the plant material was obtainable for only NGS and

SGS. Figure 3B shows how the highest mean values were obtained in SGS for the stem girth and total number of leaves (simple leaf), but not in shoot height. The plots further show that *V.paradoxa* resistance to drought declined gradually form the start of third month, unlike *P.biglobosa.* The NGS shoot height tend to exhibit resilience traits by sustaining the 3rd stage of wilting compared to SGS, thereby having a significant height increment during the months of the trial.

(A) *Parkia biglobosa*



(B) *Vitellaria paradoxa*

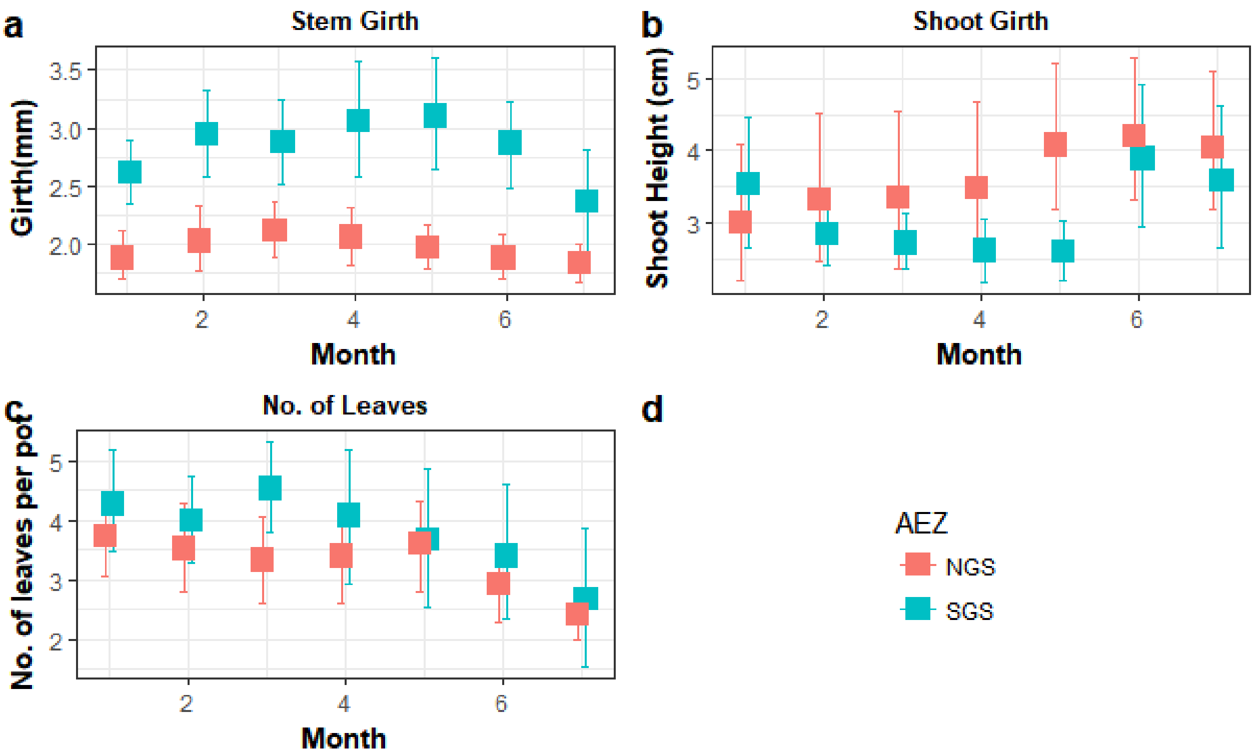


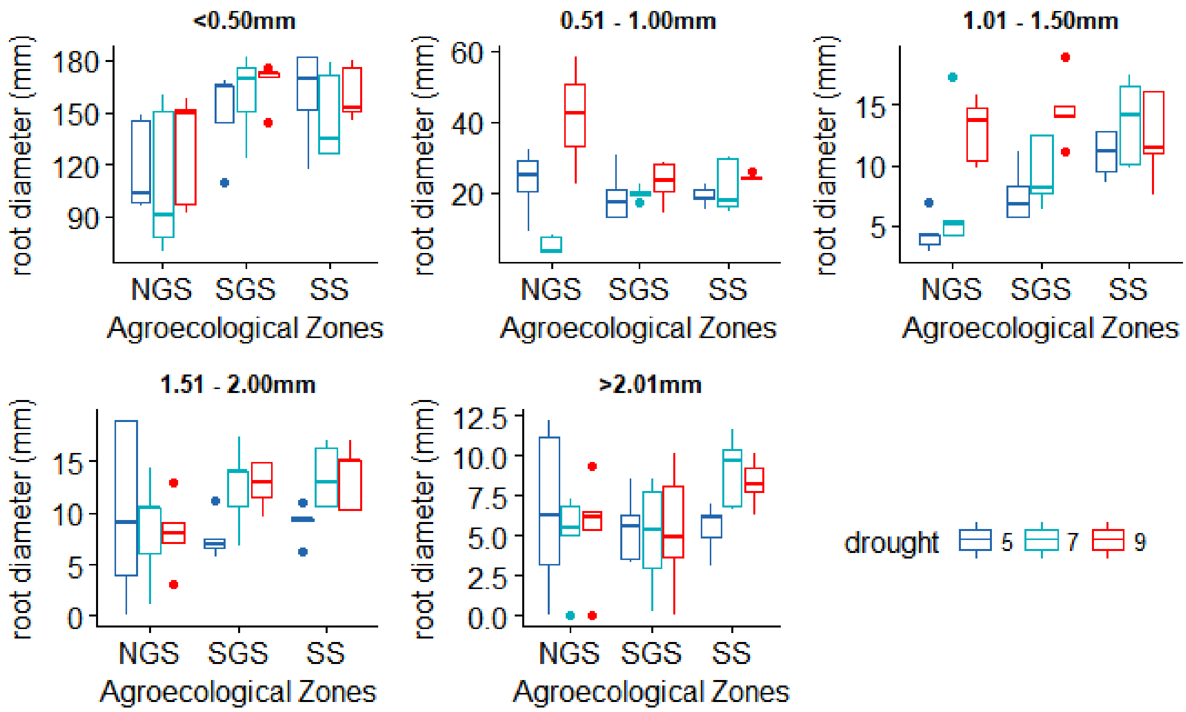
Figure 7.4: The mean effects of Agroecological zones and drought regime interactions of *P. biglobosa* and *V. pa radoxa* after six months of drought.

7.4.2.3 Morphological parameters of root variable after drought stress

For root data after 6 months drought, the root diameter was divided into 5 classes (Table 7.1), and the root type categorised into fine roots (<1mm) and tap roots (>1mm). Significant differences was observed between the AEZs at different root diameter class of both species in the drought experiment. This can be found on tiny roots with less than 0.5mm diameter for both *P. biglobosa* and *V. paradoxa* (Table 7.3). The diameter class above 1mm had significant differences (p-value > 0.05) at the 1.0-1.5mm and above 2.0mm roots of *P. biglobosa* only. All other classifications in the table were not statistically different in their means. The mean plots in figure 7.3 showed that *P. biglobosa* highest mean is found at the <0.50mm, with 9-month old SGS at the top. The trend continues of the 9-month old drought treated seedlings across all the diameter classes and among the AEZ treatments. The 7-month had more variability in its root structure than the 5- and 9-month old seedling roots observed in Winrhizo, except at 0.5-1.0mm.

The plots in figure 3B showed that analysis of variance proved *Vitellaria paradoxa* roots are drought-resistant species, just as *Parkia biglobosa* seedlings grown in sampled AEZs. Seedling root structure mean from 7-months old *V. paradoxa* species are lowest across the diameter class of the two AEZ, except at the above 2.0mm SGS treatment. The highest mean was observed more among the 9-month old treatment for all diameter class in the two studied AEZs. The Vitellaria paradoxa roots had more variability (prominent outliers) in comparison to *P. biglobosa* due to the morphological differences in germination i.e. The germination is crypto-hypogeal.

(a) *Parkia biglobosa*



(b) *Vitelleria paradoxa*

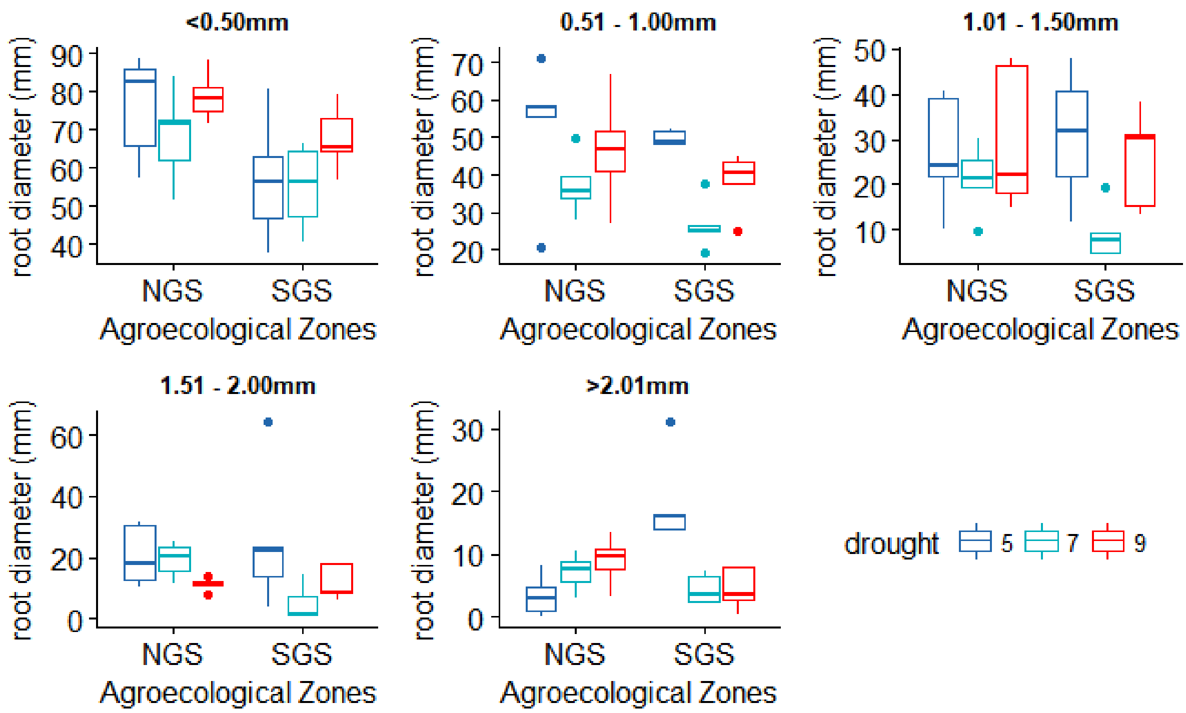


Figure 7.5: Mean comparison of all the root diameter classes for *Parkia biglobosa* and *Vitelleria paradoxa.*

Table 7.3: The means comparison of the root diameter class *of Parkia biglobosa* and *Vitellaria paradoxa* measured using Winrhizo scan.

AEZ	0.0-0.5mm		0.5-1.0mm		1.0-1.5mm		1.5-2.0mm		ABOVE 2.0mm	
	P.biglo	*V.para.*	*P.biglo.*	*V.para.*	*P.biglo.*	*V.para.*	*P.biglo.*	*V.para.*	*P.biglo*	*V.para.*
Sudan savannah	156.40a	NA	21.67a	NA	12.32a	NA	11.99a	NA	7.63a	NA
Northern Guinea savannah	119.31b	74.94a	23.18a	45.59a	8.16b	26.06a	8.92a	17.01a	5.68ab	9.11a
Southern Guinea savannah	159.30a	59.84b	20.48a	38.27a	10.51ab	21.88a	10.94a	14.09a	5.28b	6.41a

Same letters mean not significantly different at 5%. P.biglo= *Parkia biglobosa*, V.para=*Vitellaria paradoxa*. The roots below 1.00mm are classified as fine (tiny) roots and labelled green colour.

7.4.3 Biomass allocation of the parkland species

The relation between dry matter variables were statistically similar (p-value > 0.05), showing a gradient of morphological traits exhibited among trees under different agroecology and water availability as seen in Table 4 below. In the table, *Parkia biglobosa* 9-month old seedling had the highest biomass across with SGS weighing 2g more than the SS and NGS zones. However, the SGS treatment had more variability in dry matter accumulation while NGS had the lowest biomass mean and standard error. The *Vitellaria paradoxa* susceptibility to water limitation did not show significant different in biomass accumulation. The species had a relative average mass across the drought regime and two AEZ studied, and a very similar variability under water-stressed condition.

The difference between shoot and root biomass allocation seen in table 4 further indicate that extended water availability would improve tree species turgidity and weight. As SGS species of both *P.biglobosa* and *V.paradoxa.* at 9 months had more shoot to root allocation than other treatments, despite the similarity in morphological structure of the plants.

Table 7.4: Dry weight accumulation and partitioning in zones of *P. biglobosa* and *Vitellaria paradoxa* under three drought regimes after stress for 6 months

		Dry Matter(g)			Shoot to root ratio		
Species	AEZ	5month	7month	9month	5month	7month	9month
P.biglobosa	SS	23.93±1.80	19.31±0.87	23.20±0.93	0.40±0.02	0.47±0.06	0.49±0.08
	NGS	22.70±1.08	19.00±0.66	23.19±0.43	0.89±0.18	0.74±0.07	0.71±0.28
	SGS	19.23±2.88	21.67±1.57	25.46±1.36	0.50±0.21	0.66±0.07	1.18±0.29
V.paradoxa	NGS	25.57±1.67	25.41±1.72	25.64±1.72	0.51±0.06	0.50±0.06	0.52±0.06
	SGS	25.62±1.73	25.84±1.66	25.55±1.67	0.50±0.05	0.51±0.06	0.56±0.05

Values are Variable Mean±Standard error.

7.4.4 Adaptation to improve parkland trees surviving changing climate induced drought at juvenile stage

In this section, due to time factor and economic benefits for farmers, the propagation was focused on only *Anacardium occidentale* using stem cuttings method and marcotting method (Refer to Chapter 2)

7.4.4.1 Using cuttings to multiply *Anacardium occidentale* seedlings under extreme climate

The cuttings propagation success rate was 39.2% in total. This is the number of cuttings that rooted and sustain vigour throughout at the end of the 6 months glasshouse trial in Henfaes. The cuttings experiment results showed that analysis of variance high significant difference (p-value > 0.01) in age of the cuttings as well as the interaction between age and hormone concentration in number of roots counted (Table 5). Significant differences

Table 7.5. Summary of analysis of variance for root length, Total number of roots, Root diameter and number of alive and roots per treatment of *Anacardium occidentale* cuttings.

SV	Root length			No. of Roots			Root Diameter			Alive			Dead		
	MS	DF	Fvalue	MS	DF	Fvalue	MS	DF	Fvalue	MS	DF	Fvalue	MS	DF	Fvalue
Age	0.621	2	0.621^{ns}	51.36	2	6.564**	1.748	2	5.39*	35.19	2	5.79*	1.194	2	1.04^{ns}
Treatment	0.509	2	0.364^{ns}	13.36	2	1.708^{ns}	0.783	2	2.08^{ns}	4.86	2	0.80^{ns}	1.86	2	1.63^{ns}
Interaction	4.141	4	0.038*	34.40	4	4.397**	0.582	4	3.09*	24.44	4	0.01*	1.194	4	1.05^{ns}

* = Significant at 0.05; **= Significant at 0.01; ns = not significant at 0.05 level of probability.

Table 7.6: Summary of analysis of variance for root length, Total number of roots, Root diameter and number of alive and roots per treatment of Marcotted *Anacardium occidentale*.

SV	Root length			No. of Roots			Root Diameter			Alive			Dead		
	DF	MS	Fvalue	DF	MS	Fvalue	DF	MS	Fvalue	DF	MS	Fvalue	DF	MS	Fvalue
Treatments	17.61	2	6.71*	105.17	2	12.06**	4.14	2	5.39*	98.16	2	8.70*	0.50	2	0.43^{ns}
Replication	6.58	3	1.67	15.33	3	1.17	1.89	3	1.64	14.92	3	0.88	2.25	3	1.29

* = Significant at 0.05; **= Significant at 0.01; ns = not significant at 0.05 level of probability.

were observed in the root length, root diameter and number of roots alive at 5% probability. There was no significant difference in the number of dead roots, just as the hormone concentration across other parameters in the table.

The mean plots (Figure 7.5) outline the trend of all the cuttings response to hormonal concentration factor based on cuttings age. The 5-month old cuttings had higher mean and variability for functional roots (a-d), except for the dead roots. The sustainable cuttings in response to IBA hormone is the 9-month old cuttings. There is a trend in the mean for all variables, increasing with age. This indicates a strong positive response of the species to rooting, if treated in a highly protected environment. The highly sanitised and secured glasshouse contributed to the plant materials reduction in plant diseases that are vector-induced (e.g flies found in open nurseries). The experiment could not be transplanted to the field due to location distance and cost.

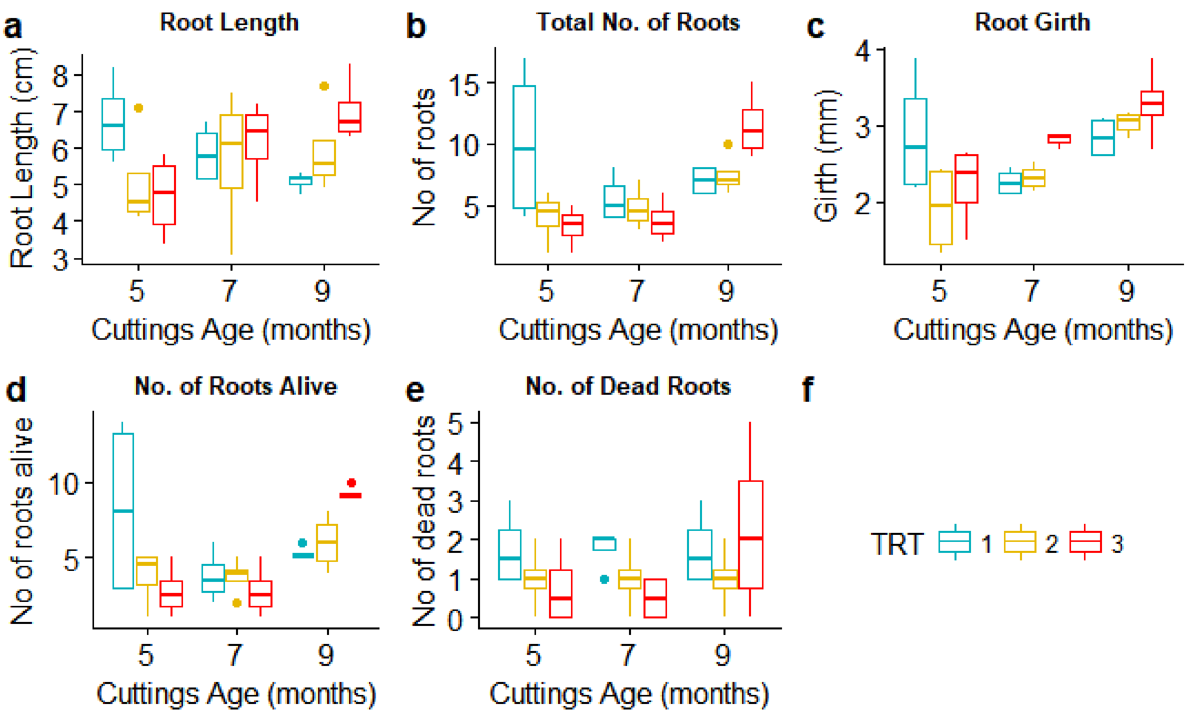


Figure 7.5: Mean comparison of the root cuttings for *Anacardium occidentale* spp.

7.4.4.2 Using marcotting to multiply *Anarcardium occidentale* seedlings on farmers' field

Marcotting methods on the fields of SGS zones had 28.7% success rate. Table 6 above showed that their significant difference in the root length, root diameter and number of roots alive. The analysis of variance also showed that there is a high significant difference (p>0.01) in the total number of roots but the dead roots are not statistically different. Figure 7.6 indicated highest mean across all the variables are in stem sizes under 1cm in girth diameter, just as the slimmest species generated more roots than the other two treatment sizes. This can be attributed to the auxin and sugar concentration that are readily available for auxillary stems in trees.

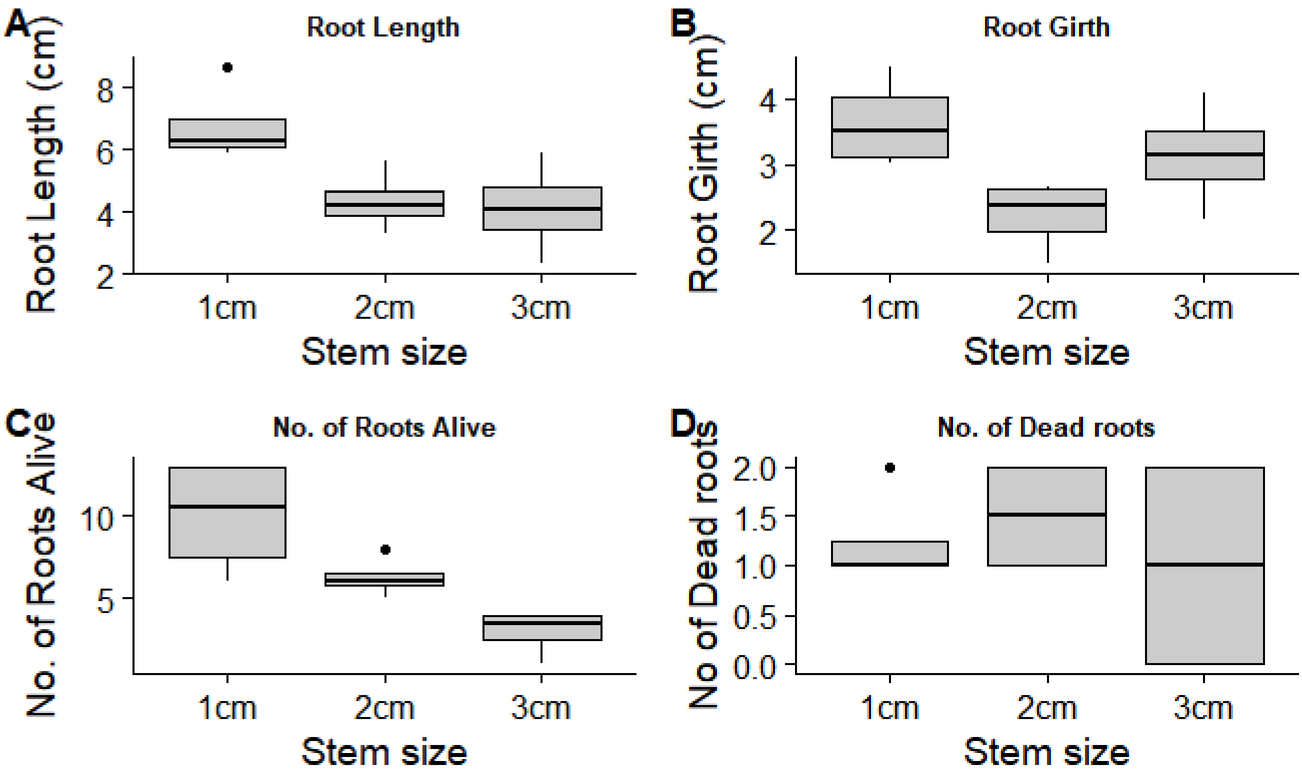


Figure 7.6: The *Anacardium occidentale* marcotting mean differences using a one-way anova experiment.

7.5 DISCUSSION

7.5.1 Seedling germination of trees from farms

Simulated extreme climate condition (temperature – 35/45ºC and intense light duration – 16 hours) at the tropical glasshouse did not affect the performance of all parkland species seedlings for germination and growth, therefore agreeing with the hypothesis that provenances of tree species may not differ at early stage in response to heat and light conditions only, if moisture is sustainably available. Similar results are available on parkland species drought and vegetative propagation experiment in Mali, Burkina Faso and Ghana (Bouda *et al.,* 2013; Yeboah *et al.,* 2011). In essence, water availability influences the seedling growth and emergence more than temperature of the surrounding.

7.5.2 Survival of parkland seedlings under different (simulated) drought regimes

The *Parkia biglobosa* and *Vitellaria paradoxa* in all AEZ exhibited more resilience at the 3rd month of the experiment before an overwhelming wilting process pushed over 75% of the studied species to the dead stage. This is in agreement with other researches that soil moisture contents and soil water depletion variability at different ecological scale can affect species survivorship, up to 90% mortality rate despite the resistant to drought by species from drier zones (Bayala *et al.,* 2018; Poorter & Markesteijn, 2007; Schreeg *et al.,* 2005). The physiological mechanisms through which parkland species adapts to drought stress involved some of the wilting stages traits that includes leaf shedding and leaf formation suppression to reduce photosynthetic process. This process was mentioned in (Tobella *et al.,* 2017; Ky-Dembele *et al.,* 2016; Valero-Galván *et al.*, 2013) where studies of seasonal characteristics on tropical trees seedlings were extensively studied. Seedling survival was not exclusively dependant on AEZ as the 7-month old SS of *P. biglobosa* survival rate was similar to the SGS zone. The SGS zone had more resistant *P.biglobosa* seedlings but not statistically different as seen in section 7.4.2.1. Similarly, the 9-month old *V. paradoxa* had more survived better than the wetter SGS zone. The SGS zone had more precipitation as discussed in chapters 4 and 5. Thus, species low resistant to drought is not only dependent to the AEZ but also seedling age and species type and leaf structure. This agrees with other studies that recorded no significant effects on species survival based on site characteristics despite the resistance of drier land species (Allen et al., 2010a; Bouda et al., 2013; Engelbrecht et al., 2005). In general, drought-induced stress impedes tree seedling morphological variables at a significant rate, except the number of primary stems. This is agreement with results of drought-induced tree regeneration such as *V.paradoxa* (Bayala *et al.,* 2017) and *Parkia biglobosa* (Bouda *et al.,* 2013). Hence drought resistance as a factor should be considered for selecting tree species regeneration on farms in the dry landscapes of Nigeria with focus on seedling age and provenance of species.

7.5.3 Root morphology and biomass allocation

The AEZs had differences in the root response to drought for both species, particularly the fine roots less than 0.5mm in diameter. Fine roots generally tend to absorb and adsorb water and nutrients for seedling growth and support. The third and last root diameter classification (see detailed table above) were different for *P. biglobosa* because the species fibrous roots are essential for leguminous activity. This was confirmed in Bouda *et al.,* (2013) that *Parkia bigl*obosa adaptation strategy included development of more fibrous roots as a coping mechanism to stress. The *V. paradoxa* indifference is basically due to its physiological structure of sapotaceae family producing extensive tap root system to escape drought at the topsoil surface. More studies on *V.paradoxa* roots discussed similar findings (Amissah *et al.,* 2013; Sanou *et al.,* 2004; Yeboah *et al.,* 2009).

The result findings of dry matter accumulation indicate variability from one AEZ to another AEZ, despite the non-statistical difference in provenance that is relatively unaffected by drought stress. The SGS show an increase in the in the dry matter content for both *P. biglobosa* and *V. paradoxa* species. This can be attributed to unclear species attributes. Okao *et al.,*(2016) and Ouedraogo *et al.,* (2017) reported also under propagation of parkland species that response of water use efficiency to determine dry matter from different provenance depending on the intensity of stress is difficult to explain without further investigations.

The ratio between shoot and root also increased with the age of the seedlings, meaning that treated plants stored adequate water content before treatment. This corroborates with findings of (Bayala *et al.,* 2003; Tchoundjeu *et al.,* 2004; Teklehaimanot *et al.,* 1996) on measuring the impact of shoot and root biomass after germination. However, the AEZ were very similar weight and differences from the drier north to wetter south of the landscape. As the shoot to root ratio in the shoot to root dry mass for this present study show a trend in response to water stress, favouring the SGS seedlings at 9 months more.

7.5.4 Propagation as an adaptive mechanism to tree regeneration on farms

The success rate of the cuttings in this experiment was 20% lower in comparison to other similar propagation studies done on Cashew tree in Nigeria (Adeigbe *et al.,* 2015; Aliyu, 2007). However, the conditions were not same as the species was propagated under a high temperature and different hormonal application. The propagation method is the most common asexual propagation method used in the tropics for Cashew seedling multiplication (Chipojola *et al.,* 2009; Thimmappaiah *et al.,* 2008). The experiment proved that drought-stressed plants can also be used as plant materials for multiplication. This can be used as an adaptive mechanism in extreme situations and save cost and resources for tree regeneration on farms either as alley or as monoculture plantation.

On the use of marcotting to produce more seedlings by inducing roots for cashew regeneration on farms, the success rate was less than the cuttings by 11%. It is the easiest and cheapest method of vegetative propagation. Marcotting is reported to significantly increased rooting, up to 45% when treated with hormones (Libunao *et al.*, 2013). The experiment carried out in the field in Nigeria is a pilot test that involves young farmers that lacked basic skill of propagation. Hence, the low success rate recorded due to poor management and challenges facing trees on farms discussed in chapter 3.

7.6 CONCLUSION

Despite the non-differences in the studied parkland species seed germination, seedlings survival rate, the performance of the drought-induced seedlings did not conform with the seeds AEZs. the morphological attributes displayed some differences between the SS and SGS, particularly at the response to drought over time. Indeed, irrespective of the seedlings original AEZ, water-stressed plants showed reduction in growth variables. In addition, within the species, the 9-month seedlings performed better in growth and resistance than the others, confirming the importance of age for improving growth at initial stage of *Parkia biglobosa* and *V. paradoxa* seedlings. . In contrast, the highest values were observed more in the SGS than the other two AEZs for the studied variables, implying that species in SGS could be used on farms in SS and NGS environment. Hence, it is advised that farmers in the drier zones northwards collect seeds of *Parkia biglobosa* from the neighbouring zones. The collected seeds are raised for minimum of six months and planted at the beginning of wet season and minimum evapotranspiration in their respective locality. However, with only two species used in the study, no indisputable recommendation from this conclusion can be drawn yet. This is because limited number of seedlings and external climate factors were not all present in the experiment due to the location differences. So, it is recommended that seedlings are raised in the nursery plots under natural environmental conditions and regular watering before establishment on farms. This is a sustainable climate smart adaptation that will eventually reduce seed mortality and increase survival rate among high valued native parkland species.

CHAPTER EIGHT: GENERAL CONCLUSION

Chazdon & Guariguata (2016) concluded that natural tree regeneration and restoration is highly cost-effective to achieve ambitious landscape restoration goals. The management of savannah parklands has a multiplier effect on sustainability, particularly in the regeneration of agroforestry species in the savannahs to enhance climate change adaptation on agricultural landscapes. Keeping in mind the objectives set forth in Chapter 1, research questions were answered by synthesizing a multidimensional approach to tackle parkland sustainability in Northern Nigeria. This approach is ranging from investigating farmer knowledge of parkland trees and evaluating present distribution on the field to predict future spatial distribution to modelling spatial future climate at the beginning, and finally using the results to proffering climate-smart solution for enhancing tree regeneration through propagation on farms. The outcomes of the research from Chapters 3 and 7 are interconnected and summarized as follows:

Chapter three evaluates AEZ classification using random forest model in R to predict the impacts of current changing climate on future Nigeria's agrobiodiversity. The training (70%) and test data (30%) predicted Sudan savannah zone spread and dominating the over 60% of Northern Nigeria based on the four representative concentration pathways (RCP) (Chapter 3, table 2) used in this study. The result highlighted the influence of biodiversity shift induced by climate change drivers led by temperature and precipitation variables and spatially identified our locations within the sampled AEZ for further research. Important decisions about parkland trees suitability on farms, such as adaptation strategies involving shifts of agrobiodiversity revolve around gradual climate alteration in the nearest future as observed in Chapter 3, Fig. 4 and 5. For instance, to check the impact of future climate on agricultural productivity, farmers currently in Southern Guinea savannah zone can introduce alternative parkland farming system by planting some of the dominant tree species on Sudan savannah zone landscapes.

The need to identify the contribution of trees and its distribution on the three studied AEZ as the climate changes to complement predicted agroecology is discussed in chapters 4 and 5. Whilst the Random Forest model (chapter 3) identified the disappearance of trees through the expansion of Sudan savannah southwards in its reclassification of AEZ, the local agroforestry knowledge from farmers' interviews showed rankings of drought-tolerant tree species with respect to preference on farms per zone. The preference is collectively biased towards services associated with specific tree species, not potential to regenerate (Chapter 4 results). For example, as documented in the sampled AEZ, farmers' knowledge about parkland tree species originates from personal experiences of trees on their respective farms and often limited to trees with either fruits to harvest or quality wood for fuel: Top native trees include *Parkia biglobosa, Vitellaria paradoxa, Tamarindus indica* while exotic species are *Mangifera indica* and *Eucalyptus camaldulensis* topped the ranks of species preferred by farmers across the three studied zones, except *V. paradoxa* is declining at the SS due to competition and conflict over the tree resource. So, *Parkia biglobosa* is the best tree species chosen based on preference for ecosystem services and regeneration survival rate by farmers across the AEZ.

On chapter 5, the distribution of tree species on farms further confirmed the preference across the AEZ based on the current tree stand. The results indicated that SGS had more trees than the other two AEZs but tree diversity in NGS slightly higher than other zones but not significant. Species richness and regeneration potentials also increase as the agroecological zones move northwards or as precipitation decreases. Though *Pakia biglobosa* and *Vitellaria paradoxa* wildings were allowed to thrive, only 34.6% of total *P. biglobosa* had few root sprouts or coppiced. Generally, Fabaceae family with potential to fix nitrogen on the soil are the dominant species on parklands, with *Parkia biglobosa* leading in dominating of agricultural landscape niche across the studied zones. The other species with strong presence included *Vitellaria paradoxa, Tamarindus indica, Mangifera indica* and *Anacardium occidentale.* What all the species had in common is the economic incentive provided by the species to farmers, especially at the end of dry season and the beginning of raining season in Northern Nigeria. This serves as buffer for farmers' wives to earn income (between ₦30,000 and ₦60,000 ~ £60 - £120), depending on species from husband farms after annual crop harvest.

The prediction of future parkland tree distribution via Maximum entropy model using the combination of tree stands spatial location in chapter 5 and the climate data in chapter 4 confirmed that *Parkia biglobosa* and *Vitellaria paradoxa* can survive the heat and low rainfall predicted for future climate in the studied landscapes and across Northern Nigeria AEZ parklands. The prediction in chapter 6 shows suitability index ranges between 45-55/100 for the years 2050 and 2070, with Sudan and Northern Guinea savannah zones land cover possessing sustainable index for tree survival under biophysical factors. In other words, the chances of the species growing productively on farms under future climate is predicted as up to 50% if properly managed.

Chapter 7 experiment close the biophysical data gap with tree plant adaptation experiment. In order to improve the adaptability of parkland species to drought, water stress experiment was conducted to evaluate the droughting effect on tree species suitability for modelled future climates. The observation in this study did not confirm our hypothesis that the AEZ in the north are more tolerant to drought stress than southern AEZ for all the species tested. Just as Bouda *et al.,* (2013) confirmed that best provenances vary and are not necessarily concentrated in a provenance or drought regimes in Mali and Burkina Faso. However, it was confirmed that age of the seedlings tended to have different effects on the different species. *Anacardium occidentale*, *Parkia biglonbosa* and *Vitellaria paradoxa* at 9 months old after planting performed best in comparison to the 5- and 7-months old seedlings subjected to same treatment. This is not unconnected to the anatomical and morphological structure of young tree plants to withstand aridity using the traits that involve slowing down the physiological process before wilting. Despite the significance of monthly period on wilting, the species could not survive 6 months drought treatment but over 50% of the 9-months old seedlings for all species (except *A. occidentale*) scaled past 90 days as survivors. The biomass and root structure results did not show a clear trend but that there is a difference between fine roots and taproot system (Chapter 7, table 4). As tree species had more fine roots than for both species tested, the ratio did show slow and not steady increase with age. The fine roots are essential for moisture and mineral absorption and adsorption to aid the tap root support mechanism. As shoot to root biomass ratio is drifted towards shoots for all AEZ, the SGS and 9-month old seedling treatments had more biomass than the other AEZ for both species. Therefore, parkland seedlings survival is not only impacted by provenance and drought regimes but also dependent on tree root morphology and age.

Though time and financial constraint did not allow vegetative propagation for all species in the study as an adaptation strategy, *Anacardium occidentale* (Cashew) was chosen based on popular demand by farmers due to its economic value. Therefore, the importance of root morphology in the regeneration of parkland seedlings was further tested in the nursery and the field via propagation – Cuttings and Marcotting of Cashew tree seedlings in chapter 7 to produce propagules under extreme conditions. The two methods resulted in root rapid germination in length and in numbers, slow seedling growth rates but low survival rates and were close. For instance, the roots cuttings had a promising root multiplication at 3000ppm treated 9-months old cuttings in the beginning than other age cuttings as treatment was significant for cuttings. Marcotting, on the other hand, performed on farmer's started slowly but also looks promising for multiplication of propagules as the success rate was just 10% lower than cutting success rate at 39.2%. From ecological restoration perspective, nursery propagation of parkland species for sustainability is essential and achievable if comprehensive evaluation of local conditions including socio-economic value (farmers' preference), climate information (projected local weather) and species morphological trait response are tailored in restoration management programs and agroforestry practices.

8.1 GENERAL RECOMMENDATION

To reverse the gradual degrading agroecosystem resilience in the face of future shocks and disturbances as modelled in this research, i. dominant parkland species from Southern Guinea savannah is planted northwards, while farming practices from Sudan savannah is adopted southwards. ii. *Parkia biglobosa* plant materials at 9 months old and above from Southern Guinea savannah agroecological zone are more resistant to droughting. Hence, collection of the seeds and planting the tree species across Northern Guinea and Sudan savannah zones landscapes to check extreme future climates (years 2050 and 2070) as adaptation and mitigation strategy. It is also strongly advised that different actor groups approach the agroforestry parkland sustainability in multidimensional ways. Based on the recommendation, the following suggestions will enhance adopting climate adaptation strategy for agroforestry and landscape restoration to improve rural livelihoods in Northern Nigeria:

1. Farmers and community leaders: Based on the findings in tree preference study on parklands, to combat desertification and land degradation, parkland community farmers need to embark on planting native economic trees such as one-year-old *Parkia biglobosa* and *Vitellaria paradoxa* among other notable agroforestry species in chapter 4 using farmer-managed natural regeneration method, with little modification on propagation based on precipitation regimes (April – June) to adopt a climate-smart agriculture. This is because the trees are important in mitigating the changes in climate as predicted in chapter 3, where Sudan savannah is gradually replacing the two other studied zones in the study and cover the entire zones by the year 2050. This would also

provide livelihood opportunities and increase local resources to address developmental issues related to agricultural productivity, environment and malnutrition.

2. Nursery owners: This research study also discovered in chapter 4 that the local ethnobotanical knowledge of the local community on trees is resourceful. It is therefore recommended that communities in Northern Nigeria need to incorporate market-based drivers into reforestation and landscape restoration plans. Assigning an economic value to forest resources through incentive to restore and protect the environment. In this instance, for a sustainable climate-smart solution recommended above, there is a gap in local seedling production across the AEZ. Training local youths and women on skills of propagating native species (such as marcotting) to become small community nursery owners would boost local entrepreneurship. The nursery owners will raise and boost the supply of tree seedlings as a way of making extra cash at the beginning of rainy season. The farmers and landowners will, in turn, protect their investment (trees) on community parklands. This is a win-win for the agroecosystems and the people living in the drylands of Nigeria.
3. Federal, States and Local Governments: Based on the modelled parameters in chapters 3 and 5, there would be shifts in agrobiodiversity under a hotter and drier scenario by the years 2050 and 2070, the government climate mitigation framework should consider the need to adopt not only the local social and economic criteria in agroecological research but also the local spatiotemporal information and weather characteristics, particularly the evapotranspiration data to manage drought effect, for improving afforestation and reforestation projects. This would include connecting climate records to policymaking in order to overcome the historic disintegration of forestry and farming. Also, ensuring small-scale farmers, especially women are at the heart of policy instruments and investments that drive sustainable agroforestry and other climate-smart

agriculture programmes. This will include promoting not less than 10% tree cover for all existing parkland landscape to address ecological, social and economic challenges of parklands.

4. Research scientists: It is also recommended that research scientists focused more on developing more local climate-smart adaptation methods. These methods would include improving mass regeneration of drought-tolerant parkland trees on farms for future at community and landscape levels, using analogous spatial information to improve tree species survival on farms.
5. Extension agents: The local extension workers can derive from the findings of the research that there is the need to do more in the simulation of weather information with landscape restoration projects. As the most important stakeholder linking communities and policymakers, this research recommendation include evaluating climate policy to increase resources in local adaptation and mitigation, provided through agroforestry parkland landscape regeneration through climate solution championed by communities.
6. Development partners: There is an opportunity for partners like African Development Bank to invest in climate-smart solutions for parkland regeneration that involve women empowerment, youth participation and environmental sustainability. With farmers and community landowners at the centre of managing land use, this research is recommending the acceleration of alley cropping and agroforestry systems through loans and grants to create a synergy of developing dryland productivity under drought. The synergy should include small scale farmers using strong cooperative societies to empower the people and improve productivity as well as the academic community to collect data and improve on agroforestry research.

8.2 FUTURE RESEARCH ON PARKLAND SUSTAINABILITY

The need for more research in the following aspects of parkland management is necessary:

1. Most models of agroecological zones have underestimated advantages. In this research, focused was on parkland trees agroecosystems and limited to climate data only. Improving classification of Nigeria agroecosystems beyond climate data for crop farming, by adding the global land cover data variables combined with more economic variables to determine the actual (formal) cost and benefits.
2. Further study is also required to evaluate different asexual propagation methods, particularly on native parkland trees of all AEZ for agroforestry purposes. This study should include the genetic traits responsible for drought-tolerant trees based on provenance and survivability traits. The study may also include the use of micropropagation of plantlets using seeds (somatic embryogenesis) in the local tissue culture laboratories in the region.
3. The research on savannah agroecological zone tree genetic resources variation is fundamental to determine genes responsible for adaptation for each AEZ and tree species. For example, we need to know what trait is responsible for ecological adaptation for farmers planting 9-months old and above *Parkia biglobosa* seedlings of Southern Guinea savannah, to increase the survival rate of the species on farms across the Northern Guinea savannah and Sudan savannah

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APPENDIX 1.1

QUESTIONAIRE ON THE ADAPTABILITY STRATEGIES OF SAVANNAH FARM TREES IN NIGERIA

I am Ibrahim Abdullahi, a research student at Bangor University, UK.

The research is aim at improving the strategies for adaptation of farm trees in drought threatened regions of Nigeria's savannah.

All responses are confidential

BIODATA

Name:				
Gender	Male		Female	
Ownership	Home owner		Landowner	
How many hectares?		Ha		
Family	Parent		Grandparent	
How many dependants				
Do you have a job (besides farming)?	Yes		No	

SAVANNAH FARM TREE SPECIES: FARMERS' PREFERENCE

Tree Species Diversity and Range

Please name all the tree species found on your farm plots, and score each tree based on its natural regeneration by seed:

#	Species (local name or scientific name)	Prolific regeneration	Sporadic/ Sparse	Very little natural/ none
1				
2				
3				
4				
5				
6	Other1			
7	Other2			
8	Other3			

Tree Growth and Germination

Score each tree species based on its growth rate compared to the selected examples as shown in the picture below.

When does each tree species above shed its leaves? Dry season, wet season, evergreen.

1

2

3

	Growth rate			Leaf shed		
Species #	1	2	3	Dry	Wet	Evergreen
1						
2						
3						
4						
5						
6						
7						
8						

Soil Quality

Do you have any problems with soils in your farm? Things like erosion, low soil fertility, seasonal flooding, sand dunes.

	Erosion	Low fertility	Flooding	Sand	Other (specify)
Problem?					

Which of the tree species grow well in each of these erosion prone areas?

Species #	Erosion	Low fertility	Flooding	Sand	How this species helps in improving soil

Farmers' Usage

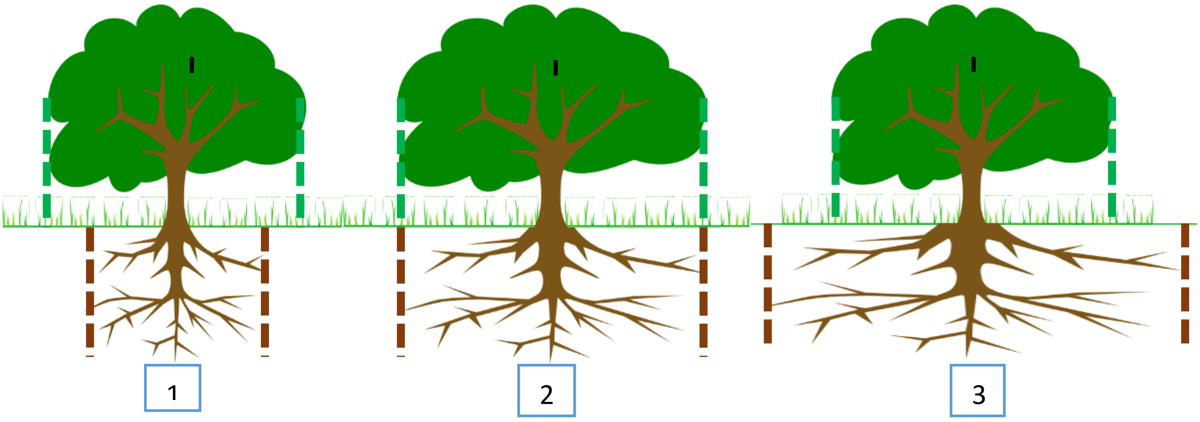
Why do you grow this tree? Tick all that apply.

	Products and Services										
Species #	Soft fruits	Nuts/ Seeds	Construction	fuelwood	Leaves - Fodder	Leaves - Medicine	Soil fertility	Shade	Erosion control	Other (specify)
1										
2										
3										
4										
5										
6										
7										
8										

STATUS OF PROPAGATION OF SAVANNAH FARM TREES

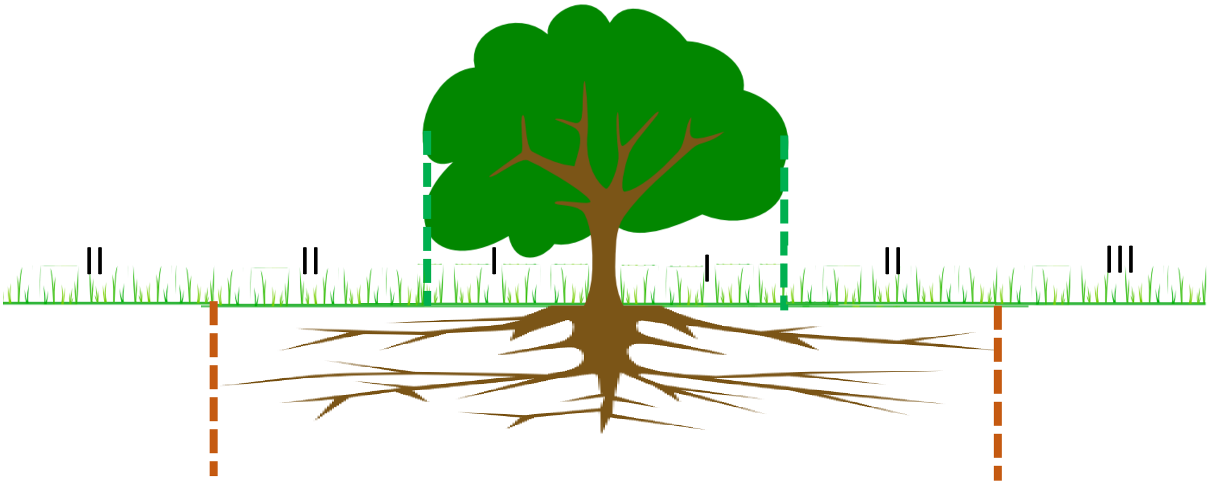
Root Abundance/Morphology

Score each tree species for how its roots spread



	Root spread		
Species #	1	2	3
1			
2			
3			
4			
5			
6			
7			
8			

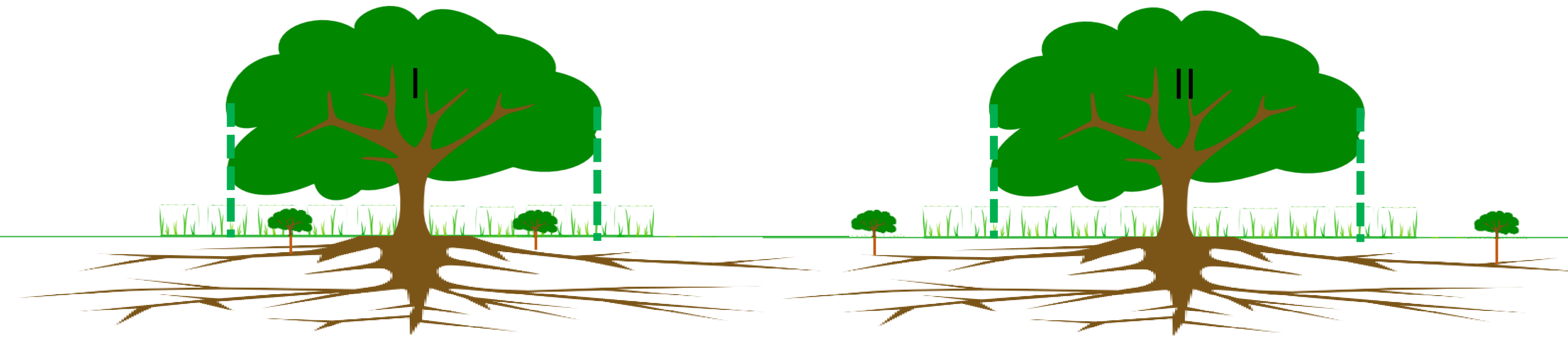
Where do you plant your annual crops?



I & II=IV
II & III=V
I & II & III=VI

Species #	I	II	III	IV	V	VI
1						
2						
3						
4						
5						
6						
7						
8						

Does the tree regenerate through the suckers within or outside the crown shade?



III = BOTH INSIDE AND OUTSIDE 0 = NOSUCKERS

Species #	0	I	II	III
1				
2				
3				
4				
5				
6				
7				
8				

Root Morphology Response to Stress

Questions 1. What happens to tree roots during drought?

2. Do different species respond differently?

Regeneration Techniques

Questions 1. For each specie in (1) that scored 2 or 3, how is it regenerated?

Seeds ( ) Coppicing ( ) Vegetative propagation [(cutting) (layering) (budding) (grafting) ( )]

2. If no mention of grafting, have you ever heard about grafting?

Description and Constraints in Regeneration of Savannah Trees on Farms

Questions: For each species mentioned above

1. Describe in details how you propagate the species in the field?
2. What are the challenges faced propagating this tree?
3. Do you have any suggestions for better tree regeneration in parklands?

If you would like to receive a copy of the report when it's done, please provide your contact details, (email)……………………………………………………………………

APPENDIX 1.2

SOIL ANALYSIS REPORT

nrm laboratories

ANALYTICAL REPORT

Report Number	25385-16	K908	LLINOS HUGHES	Client NIGERIA
Date Received	21-JUL-2016		HENFAES RESEARCH CENTRE	
Date Reported	29-JUL-2016		PRIFYSGOL	
Project	FOREIGN SOIL		BANGOR UNIVERSITY	
Reference	NIGERIA		ABERGWYNGREGYN	
Order Number			LLANFAIRFECHAN GWYNEDD LL33 0LB	

Laboratory Reference		SOIL312346	SOIL312347	SOIL312348	SOIL312349	SOIL312350	SOIL312351	SOIL312352	SOIL312353	SOIL312354
Sample Reference		1	2	3	4	5	6	7	8	9
Determinand	**Unit**	**SOIL**	**SOIL**	**SOIL**	**SOIL**	**SOIL**	**SOIL**	**SOIL**	**SOIL**	**SOIL**
pH water [1:2.5]		7.8	6.1	5.1	5.0	5.9	6.0	5.4	8.4	6.2
Available Phosphorus (Index)	mg/l	49.8 (4)	3.8 (0)	3.0 (0)	4.6 (0)	9.4 (0)	4.0 (0)	4.0 (0)	3.0 (0)	4.4 (0)
Available Potassium (Index)	mg/l	184 (2+)	48.8 (0)	28.2 (0)	64.5 (1)	58.0 (0)	90.6 (1)	54.4 (0)	18.2 (0)	50.0 (0)
Available Magnesium (Index)	mg/l	123 (3)	50.9 (2)	112 (3)	61.7 (2)	63.5 (2)	124 (3)	68.0 (2)	47.4 (1)	57.0 (2)
Sand 2.00-0.063mm	% w/w	78	79	81	47	68	48	86	87	85
Silt 0.063-0.002mm	% w/w	14	13	15	43	24	42	9	11	13
Clay <0.002mm	% w/w	8	8	4	10	8	10	5	2	2
Available Calcium	mg/l	909	839	572	428	<200	727	430	249	307
Organic Matter LOI	% w/w	1.9	1.7	1.0	1.6	1.6	2.2	0.9	0.5	0.7
Textural Class **		LS/SL	LS	LS	SZL	SL	SZL	LS	S	LS

Notes

Analysis Notes: The sample submitted was of adequate size to complete all analysis requested.
The results as reported relate only to the item(s) submitted for testing.
The results are presented on a dry matter basis unless otherwise stipulated.

Document Control: **This test report shall not be reproduced, except in full, without the written approval of the laboratory.**

** Please see the attached document for the definition of textural classes.

Reported by: *Katie Dunn*
Natural Resource Management, a trading division of Cawood Scientific Ltd.
Coopers Bridge, Braziers Lane, Bracknell, Berkshire, RG42 6NS
Tel: 01344 886338
Fax: 01344 890972
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APPENDIX 1.3

RANDOM FOREST R CODES

```
####Load packages####
library(randomForest)
library(ggplot2)
library(dismo)
library(pROC)
library(caret)
library(gridExtra)
library(ROCR)
library(dplyr)
library (rgeos)
library(raster)
library(rgdal)
library(sp)
####Set working directory and Load in data files for analysis.####
setwd("C:/Users/ndagi/Documents/R/")
ftcur.w2 <- read.csv("C:/Users/ndagi/Documents/R/BiOCLIM_w2.csv", header = T)
ft2050 <- read.csv("C:/Users/ndagi/Documents/R/he85bio2050.csv", header = T)
ft2070 <- read.csv("C:/Users/ndagi/Documents/R/he85bi2070.csv", header = T)
loctn <- read.csv("C:/Users/ndagi/Documents/R/location.csv", header = T)
```

```
####Random Forest Model ####
#modelling current climate data
set.seed(7)
current$LocationName <- NULL
cur <- sample(2, nrow(current), replace = T, prob = c(0.7, 0.3))
train.cur <- current[cur==1,]
test.cur <- current[cur==2,]
model.cur <- randomForest(AEZ~. , data = train.cur)
model.cur
#modelling 2050 bioclimatic data
set.seed(7)
future$LocationName<- NULL
m50 <- sample(2, nrow(future), replace = T, prob = c(0.7, 0.3))
train.m50 <- future[m50==1,]
test.m50 <- future[cur==2,]
model.m50 <- randomForest(AEZ~. , data = train.m50)
model.m50
#modelling 2070 bioclimatic data
set.seed(7)
f70 <- sample(2, nrow(future70), replace = T, prob = c(0.7, 0.3))
train.f70 <- future70[f70==1,]
test.f70 <- future70[f70==2,]
model.f70 <- randomForest(AEZ~., data = train.f70)
model.f70
## Predict the model using test data
# current data
predict.cur<- predict(model.cur, test.cur, type="prob", norm.votes=TRUE,
predict.all=FALSE, nodes=FALSE)
predict.cur
# modelled 2050 data
predict.m50<- predict(model.m50, test.m50, type="prob", norm.votes=TRUE,
predict.all=FALSE, nodes=FALSE)
test.result50 <- cbind(test.m50$AEZ, data.frame(predict.m50))
View(test.result50)
#modelled 2070 data
predict.f70<- predict(model.f70, test.f70, type="prob", norm.votes=TRUE,
predict.all=FALSE, nodes=FALSE)
test.result70 <- cbind(test.f70$AEZ, data.frame(predict.f70))
View(test.result70)
####Out of Bag sample error####
#current OOB error
oob.error.data <- data.frame(Trees=rep(1:nrow(model.cur$err.rate), times=4),
Type=rep(c("OOB", "Derived Savannah", "Humid Forest", "Mid Altitude", "Northern
Guinea Savannah", "Sahel Savannah", "Sourthern Guinea Savannah", "Sudan Savannah"),
each=nrow(model.cur$err.rate)), Error=c(model.cur$err.rate[,"OOB"],
model.cur$err.rate[,"Derived Savannah"],
```

```
model.cur$err.rate[,"Humid Forest"],
model.cur$err.rate[,"Mid Altitude"],
model.cur$err.rate[,"Northern Guinea Savannah"],
model.cur$err.rate[,"Sahel Savannah"],
model.cur$err.rate[,"Sourthern Guinea Savannah"],
model.cur$err.rate[,"Sudan Savannah"]))
OOB.Cur.Error <- ggplot(data=oob.error.data, aes(x=Trees, y=Error))+
geom_line(aes(color=Type))+ theme_bw()+ggtitle("Current Climate Data")+labs(colour =
"Agroecological zones and Out of Bag(OOB)")
OOB.Cur.Error
#Year 2050 OOB error
m50.error.data <- data.frame(Trees=rep(1:nrow(model.m50$err.rate), times=4),
Type=rep(c("OOB", "Derived Savannah", "Humid Forest", "Mid Altitude", "Northern
Guinea Savannah", "Sahel Savannah", "Sourthern Guinea Savannah", "Sudan Savannah"),
each=nrow(model.m50$err.rate)), Error=c(model.m50$err.rate[,"OOB"],
model.m50$err.rate[,"Derived Savannah"],
model.m50$err.rate[,"Humid Forest"],
model.m50$err.rate[,"Mid Altitude"],
model.m50$err.rate[,"Northern Guinea Savannah"],
model.m50$err.rate[,"Sahel Savannah"],
model.m50$err.rate[,"Sourthern Guinea Savannah"],
model.m50$err.rate[,"Sudan Savannah"]))
m50err.graph<- ggplot(data=m50.error.data, aes(x=Trees, y=Error))+
geom_line(aes(color=Type))+ theme_bw()+ggtitle("2050 Scenario Climate
Data")+labs(colour = "Agroecological zones and Out of Bag(OOB)")
m50err.graph
#Year 2070 OOB error
mf70.error.data <- data.frame(Trees=rep(1:nrow(model.f70$err.rate), times=4),
Type=rep(c("OOB", "Derived Savannah", "Humid Forest", "Mid Altitude", "Northern
Guinea Savannah", "Sahel Savannah", "Sourthern Guinea Savannah", "Sudan Savannah"),
each=nrow(model.f70$err.rate)), Error=c(model.f70$err.rate[,"OOB"],
model.f70$err.rate[,"Derived Savannah"],
model.f70$err.rate[,"Humid Forest"],
model.f70$err.rate[,"Mid Altitude"],
model.f70$err.rate[,"Northern Guinea Savannah"],
model.f70$err.rate[,"Sahel Savannah"],
model.f70$err.rate[,"Sourthern Guinea Savannah"],
model.f70$err.rate[,"Sudan Savannah"]))
mf70err.graph<- ggplot(data=mf70.error.data, aes(x=Trees, y=Error))+
geom_line(aes(color=Type))+ theme_bw()+ggtitle("2070 Scenario Climate
Data")+labs(colour = "Agroecological zones and Out of Bag(OOB)")
mf70err.graph
#Arranging the graph in rows for publication
# Arrange the graph vertically for publication
grid.arrange(OOB.Cur.Error, m50err.graph, mf70err.graph, ncol = 1)
```

```
#Remove x axis label on current and 2050 OOB plots
OOB.Cur.Error <- OOB.Cur.Error + theme(axis.title.x = element_blank(), axis.text.x =
element_blank())
m50err.graph <- m50err.graph + theme(axis.title.x = element_blank(), axis.text.x =
element_blank())
m50err.graph
# remove legend from current and 2070 plots
OOB.Cur.Error <- OOB.Cur.Error +guides(colour=FALSE, fill=FALSE)
mf70err.graph <- mf70err.graph +guides(colour=FALSE, fill=FALSE)
grid.arrange(OOB.Cur.Error, m50err.graph, mf70err.graph, ncol = 1)
#Set it on same width
m50err.graph <- ggplotGrob(m50err.graph)
OOB.Cur.Error<- ggplotGrob(OOB.Cur.Error)
mf70err.graph <- ggplotGrob(mf70err.graph)
OOB.Cur.Error$widths=m50err.graph$widths
m50err.graph$widths=mf70err.graph$widths
OOB.Cur.Error$widths=mf70err.graph$widths
grid.arrange(OOB.Cur.Error, m50err.graph, mf70err.graph)

####Variable importance Graphs####
#plot varimportance in random forest for current, 2050 and 2070
varImpPlot(model.cur)
VarCurrent <-varImpPlot(model.cur)
VarCurrent
Var.2050<- varImpPlot(model.m50)
Var.2050
Var.2070<- varImpPlot(model.f70)
####Rasters####
biclim.rasters <- list.files('C:/Users/ndagi/Documents/R/nigeria_rasters/', pattern='.tif$',
full.names = TRUE)
biclim.rasters50 <- list.files('C:/Users/ndagi/Documents/R/rasters_2050/', pattern='.tif$',
full.names = TRUE)
biclim.rasters70 <- list.files('C:/Users/ndagi/Documents/R/rasters_70/', pattern='.tif$',
full.names = TRUE)
## Get Nigeria shape files
nigeria <- readOGR('C:/Users/ndagi/Documents/R/Nigeria.shp')
plot(nigeria)

##masking raster for three climate data
raster.curr <- lapply(biclim.rasters, raster)
raster.50 <- lapply(biclim.rasters50, raster)
raster.70 <- lapply(biclim.rasters70, raster)

masked.raster <- lapply(raster.curr, crop, nigeria)
masked.raster50 <- lapply(raster.50, crop, nigeria)
```

```
masked.raster70 <- lapply(raster.70, crop, nigeria)
pred.raster50 <- lapply(masked.raster50, mask, nigeria)
pred.raster70 <- lapply(masked.raster70, mask, nigeria)
writeRaster(pred.rasters50, 'C:/Users/ndagi/Documents/R/2050Ngaraster.tif')
writeRaster(pred.rasters50, names(pred.rasters50), bylayer=TRUE, format='GTiff')
pred.50r<- writeRaster(pred.rasters50, names(pred.rasters50), bylayer=TRUE,
format='GTiff', overwrite=TRUE)
#applying mapply to the lists
mapply(writeRaster, pred.raster50, names(pred.raster50), 'GTiff')

pred.rasters <- list()
for (i in seq(19)) {
pred.rasters[[i]] <-
raster(paste0('C:/Users/ndagi/Documents/R/nigeria_rasters/',rasternames[[i]],'.tif'))
}
stacked.nigeria <- stack(pred.rasters)
plot(stacked.nigeria)
nigeria.cur <- predict(stacked.nigeria, model.cur)
plot(nigeria.cur)



#2050
pred.rasters50 <- stack(pred.raster50)
pred.rasters50 <- list()
for (i in seq(19)) {
pred.50r[[i]]<-
raster(paste0('C:/Users/ndagi/Documents/R/raster50Nigeria/',rasternames[[i]],'.tif'))
}
plot(pred.rasters50)
#plot modelled AEZ map of nigeria
nigeria.2050<- predict(pred.50r, model.m50)
plot(nigeria.2050)


#2070
pred.rasters70 <- stack(pred.raster70)
plot(pred.rasters70)


#Write the rasters to a file in R folder
pred.raster50.r <- writeRaster(pred.rasters50, filename="nigeria2050.tif",
overwrite=TRUE)

plot(pred.raster50)
```

```
#Mapping current Nigeria map
pred.rasters <- list()
for (i in seq(19)) {
pred.rasters[[i]] <-
raster(paste0('C:/Users/ndagi/Documents/R/nigeria_rasters/',rasternames[[i]],'.tif'))
}
pred.rasters50.list <- list()
for (i in seq(19)) {
pred.raster50[[i]] <-
raster(paste0('C:/Users/ndagi/Documents/R/raster50Nigeria/',rasternames[[i]],'.tif'))
}

stacked.nigeria <- stack(pred.rasters)
plot(stacked.nigeria)
nigeria.cur <- predict(stacked.nigeria, model.cur)
plot(nigeria.cur)
#Add AEZ MAP TO THE MODEELD CURRENT MAP
lines(nigeria)
nigeria.cur
#Mapping 2050 Nigeria map
Nigeria.raster50 <- crop(biclim.rasters50[[1]], nigeria)
head(raster.50)
mask.stack.50 <- stack(masked.raster50)
plot(mask.stack.50)
plot(stacked.nigeria)
test.50rr <- crop(masked.rasters50[[1]], nigeria)
nigeria.2050 <- predict(mask.stack.50, model.m50)
pred.rasters <- list()
for (i in seq(19)) {
raster.50[[i]] <-
raster(paste0('C:/Users/ndagi/Documents/R/rasters_50/',rasternames[[i]],'.tif'))}
```

KRUSKAS WALLIS TEST RESULT SCRIPTS FOR CROPPING EDGE, SUCKERS AND ROOT SPREAD.

All the analysis were done on R programming package

- CROPPING EDGE

Kruskal-Wallis rank sum test

data: OutRootzone by AEZ
Kruskal-Wallis chi-squared = 3.806, df = 2, p-value =
0.1491

Kruskal-Wallis rank sum test

data: Undercanopy.Root by AEZ
Kruskal-Wallis chi-squared = 0.94785, df = 2, p-value = 0.6226

- ROOT SPREAD

Kruskal-Wallis rank sum test

data: Under by AEZ
Kruskal-Wallis chi-squared = 1.7658, df = 2, p-value = 0.4136

kruskal.test(Equal ~ AEZ, data = spread)

Kruskal-Wallis rank sum test

data: Equal by AEZ
Kruskal-Wallis chi-squared = 2.5553, df = 2, p-value = 0.2787

kruskal.test(Above ~ AEZ, data = spread)

Kruskal-Wallis rank sum test

data: Above by AEZ
Kruskal-Wallis chi-squared = 2.343, df = 2, p-value = 0.3099

- SUCKERS

kruskal.test(None ~ AEZ, data = suck)

Kruskal-Wallis rank sum test

data: None by AEZ
Kruskal-Wallis chi-squared = 0.14536, df = 2, p-value = 0.9299

kruskal.test(UnderCanopy ~ AEZ, data = suck)

Kruskal-Wallis rank sum test

data: UnderCanopy by AEZ
Kruskal-Wallis chi-squared = 3.5195, df = 2, p-value =0.1721

Kruskal-Wallis rank sum test

data: OutCanopy by AEZ
Kruskal-Wallis chi-squared = 0.46859, df = 2, p-value =0.7911

Kruskal-Wallis rank sum test

data: Both by AEZ
Kruskal-Wallis chi-squared = 4.7582, df = 2, p-value =0.09263

APPENDIX 1.4

Some images showing the drought-treated tree seedlings, stem cuuttings and tree plant propagation materials (marcotting) at different stages in the glasshouse (Henfaes-Bangor) and in Farms (Northern Nigeria). These include propagation, acclimatization and planting on the filed by the farmer.