UNIVERSITY OF CAPE COAST

# EFFECTS OF HARVESTING TIMES AND FERTILIZER APPLICATION ON CASSAVA YIELD AND QUALITY IN TWO AGROECOLOGICAL ZONES OF NIGERIA

BY

JUMOKE OMOWUNMI SOBAMOWO

Thesis submitted to the Department of Soil Science of the School of Agriculture, College of Agriculture and Natural Sciences, University of Cape Coast, in partial fulfilment of the requirements for the award of Doctor of Philosophy degree in Soil Science

AUGUST 2016

# DECLARATION

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature:................................................ Date: 25/08/2016

Name: Jumoke Omowunmi Sobamowo

**Supervisors' Declaration**

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor's Signature:.................................... Date: 25/08/2016

Name: Dr. Kwame Agyei Frimpong

Co-Supervisor's Signature:............................................ Date: 25/08/2016

Name: Dr. Adebayo Abass

Mentor's Signature:.............................................. Date: 25/8/2016

Name: Dr. Thomas Gaiser

## ABSTRACT

Farmers desire to harvest cassava roots with high total dry matter and of good quality at shorter times. However, they have limited knowledge regarding combinations of improved varieties and right types and rates of fertilizer application that are most suitable for their agro-ecological zones. The study was carried out to quantify total dry matter and root quality response of six cassava varieties to fertilizer application and intra-annual rainfall variability in two agro-ecological zones of Nigeria. Two field experiments were conducted at Oke-oyi and Ikenne. Three inorganic NPK fertilizer types were applied at two rates to six cassava varieties in a split split plot arrangement with three replicates. In each experiment cassava was harvested destructively at 6, 8, 10 and 12 MAP. Data on yield and quality parameters were analyzed using SAS, means separation by LSD 5%. The results revealed that fertilizer application significantly increased all the parameters measured at Ikenne (at both experimental sites) except fresh storage root weight and dry matter content at Oke-oyi. TME 419 had higher starch content at Ikenne while TMS 96/1632 had significant higher starch content at Oke-oyi. Cyanide potential was highest in TMS 96/1632 and TMS 30572 at 12 MAP at Oke-oyi and Ikenne respectively. NPK 12-12-17 was observed to perform better than other fertilizer types. This study showed that application of NPK 12-12-17 fertilizer at 300 kg $ha^{-1}$ to cassava varieties TME 419 and TMS 98/0505 at study sites, increased total dry matter root yield, starch content and showed low cyanide potential. Farmers who plant these two cassava varieties either for food or for industrial purposes at the two sites will earn higher income.

## KEY WORDS

Fertilizer types

Inter-annual rainfall variability

Cassava varieties

Root yield

Total dry yield

Root quality

## ACKNOWLEDGEMENTS

This work would not have been possible without the immense and relentless inputs of my supervisors. I sincerely thank Dr. Adebayo Abass for accepting to supervise my work, for his comments, corrections and assistance throughout my study, for providing the opportunity to use IITA facilities. My profound gratitude goes to Dr. Thomas Gaiser, for the immeasurable assistance I received throughout my study and whose constructive criticisms and advice resulted in this piece of work. My heartfelt gratitude goes to Dr. Kwame Agyei Frimpong for his very prompt comments, corrections and assistance in this study.

I wish to thank German Federal Ministry of Education and Research (BMBF) through WASCAL for funding this research and providing the opportunity for my PhD studies. I appreciate Dr. Richardson Okechukwu for the support, encouragement and assistance especially during the field work.

I also thank all members of the Cassava Outreach team of IITA. I appreciate Sola Olaniyan, Sola Kareem, Jonathan Alumona, Pascal Chianu, Obi Chukwuma, Stephen Olusesan, Ayodele Wunmi for the field assistance. I appreciate my mother for the love and care and for taking care of my children when I was away writing this thesis. I thank Deji Sobamowo, for paying the school fees for my MSc degree. I appreciate the Omoniyis, Biodun and Bose Oyafajo, and the entire members of MIV, for the supports and encouragement. I thank my Father for the life of my husband and children (ErianuOluwa and Ayooluwa). My utmost appreciation goes to my Father for his unfailing mercies.

DEDICATION

To my husband, Ezekiel Babatunde Omoniyi

TABLE OF CONTENTS

# LIST OF TABLES

LIST OF FIGURES

## LIST OF ACRONYMS

| | |
|---|---|
| $^0C$ | Degree Centigrade |
| AAS | Atomic Absorption Spectrophotometer |
| ANOVA | Analysis of Variance |
| Ca | Calcium |
| BMBF | German Federal Ministry of Education and Research |
| CEC | Cation Exchange Capacity |
| CMD | Cassava Mosaic Disease |
| CNP | Cyanogenic Potential |
| DMC | Dry Matter Content |
| DNA | Deoxyribonucleic acid |
| DYLD | Dry Matter Yield |
| ECEC | Effective Cation Exchange Capacity |
| FAO | Food and Agriculture Organisation |
| GIS | Geographical Information System |
| ha | Hectare |
| HCN | Hydrogen Cyanide |
| IBPGR | International Board for Plant Genetic Resources |
| IITA | International Institute of Tropical Agriculture |
| K | Potassium |
| kg | Kilogram |
| $km^2$ | Square kilometer |
| LDS | Little Dry Season |
| LGA | Local Government Area |

| | |
|---|---|
| m | Meter |
| MAP | Months After Planting |
| mg | Milligram |
| mm | Millimeter |
| N | Nitrogen |
| NRCRI | National Root Crop Research Institute |
| P | Phosphorus |
| PPD | Postharvest Physiological Deterioration |
| ppm | Parts per million |
| RAPD | Random amplified polymorphic DNA |
| RCBD | Randomized Complete Block Design |
| RFLP | Restriction fragment polymorphic DNA |
| SSA | sub-Saharan Africa |
| t | Tonnes/meteric tons |
| TME | Tropical Manihot esculenta |
| TMS | Tropical Manihot species |
| UN | United Nations |
| USDA | United States Department of Agriculture |
| WAP | Weeks After Planting |
| WASCAL | West African Science Service Centre on Climate Change and Adapted Land use |

# CHAPTER ONE

# INTRODUCTION

## Background to the Study

In most areas in sub-Saharan Africa (SSA) soil fertility is low as a result of inherently low nutrient parent materials and/or continuous cropping without external inputs. Soil fertility depletion has been described as one of the most important constraints to food security in SSA (Sanchez et al. 1997; Fermont, 2009). Rapid population growth throughout Africa increases land pressure and aggravates the strain on natural resources. If the fragile environment must continue to provide food for the needs of an increasing population both now and in the future, farming systems which utilize the available resources for sustained crop production, while conserving the natural resource base will have to be evolved (Kang & Gutteridge, 2011).

In 2014, the United Nations (UN) revised their projections for population growth: the world's population is no longer expected to stabilize after 2050, but is now forecast to continue to grow and approach 11 billion people by 2100 (Gerland et al. 2014). The increase in global population is driven by growth in the developing countries characterized by low-income and food-deficit. Food and Agriculture Organization (FAO) estimated that the world may need to increase food production by 60% over the period 2005-2050, in order to feed a predicted population of more than 9 billion (Alexandratos & Bruinsma, 2012).

Farming systems in SSA can be categorized as smallholder systems which are highly diversified, heterogeneous and dynamic. Spatial soil variability across regions and within farms, are high as a result of inherent differences in soil properties related to parent materials, position on the toposequence, differential nutrient as well as crop and water management (Zingore, 2006; Tittonel, 2008). Consequently, management strategies that may work in one part of the farm may not work in another part (Vanlauwe, Titonell & Mukalama, 2006).

Traditionally, fields are usually left fallow for a number of years to regrow and regain fertility. However, with increasing population densities and associated demands for land, this practice is no longer preferred in many areas of SSA (Vanlauwe, Six, Sanginga, & Adesina, 2015). As a result, soil degradation processes have intensified. The challenges of achieving both food security and environmental sustainability have resulted in a confluence of demands on land (Schulte et al. 2015) as the land is expected to provide food, feed and fuel, to purify water, to sequester carbon and provide a home to biodiversity as well as external nutrients in the form of waste from humans and intensive livestock enterprises (Schulte et al.).

Most soils in Nigeria are low in nutrient content while fallow periods are becoming shorter (Salami & Sangoyomi, 2013). Therefore, additional nutrient in the form of organic or inorganic fertilizer must be applied to boost soil fertility. These systems already have the problem of low soil fertility resulting in low crop yields posing challenges for development such as insufficient domestic production, national food insecurity and poverty

(Gwalema, 2010). According to Vanlauwe et al. (2015), soil nutrient mining is the most common form of soil degradation, and results in low crop productivity, biomass and soil cover, thereby exacerbating other soil degradation processes, such as erosion, acidification and the formation of hard pans (dense soil layers that are largely impervious to water infiltration and root growth).

Most African smallholder farmers use little or no fertilizer at all (an average of 9 kg $ha^{-1}$ $yr^{-1}$, compared with 73 and 135 kg $ha^{-1}$ $yr^{-1}$ used in Latin-America and Asia, respectively (Kelly, 2006). Fertilizer is rarely used on cassava (Nweke, 1994a), as there appears to be a common belief that cassava does not need fertilizer. This assumption could be based on the ability of cassava to produce reasonable yield in marginal soils where other crops fail.

Cassava (*Manihot esculenta* Crantz) is an important crop in many African farming systems. It was introduced into Africa in the 16$^{th}$ to 18$^{th}$ century, but it took until the 20$^{th}$ century for production to seriously take off (Jones, 1959; Hillocks & Thresh, 2002; Fermont, 2009). Cassava plays an important role in food security, as a cash crop and raw material for the industries for the production of food, feed, starch, biofuel and other uses (Ayling, Ferguson, Rounsley, & Kulakow, 2012). It is currently ranked as the third most important source of calories in the tropics, after rice and maize (FAO, 2011b).

At present, approximately half of the world production of cassava is in Africa where it is cultivated in around 40 countries, stretching through a wide belt from Madagascar in the southeast to Senegal and Cape Verde in the northwest. Cassava is grown by millions of poor African farmers, many of them women, often on marginal land. For these people, the crop is vital for both food security and income generation. According to FAO, 2011 approximately 75% of Africa's cassava output is harvested in Nigeria, the Democratic Republic of Congo, Ghana, Tanzania and Mozambique. Cassava is one of the most important food crops in Africa, and a major source of edible carbohydrate for over 800 million people around the world. World production of the crop increased from 209 million tonnes in 2005 to 237 million tonnes in 2010 (FAO, 2011b). The crop has been rated as Africa's second most important staple food after maize, with respect to calories consumed, being a major source of calorie for two out of every five Africans (Nweke, 2004).

The economic value for cassava products for the farmer and industries is the dry matter content which is the chemical potential of the crop and reflects the true biological yield (Teye, Asare, Amoah, & Tetteh, 2011). According to Lain (1985), the dry matter is influenced by several factors such as the age of the plant, crop season, location and efficiency of the canopy to trap sunlight. Dry matter of cassava varies from one accession to another and ranged from 17 and 47% with the majority lying between 20% and 40% (Braima et al. 2000); values above 30% are considered high. The dry matter of the roots has become an important character for the acceptance of cassava by researchers and consumers who boil or process them (Teye et al.).

Cassava can be eaten boiled, processed into *garri*, flour and livestock feeds. Apart from the roots, cassava leaves are also eaten as vegetable in East, Central and some West African countries (Okpara, Agoha, & Iroegbu, 2010).

It is also an industrial raw material for the production of alcohol, dextrose for soft drinks, fuel, sweeteners, paper, textiles, plywood, sodium glutamate food seasoning and flour for confectioneries (Okechukwu et al. 2005; Bud, 2008). Though cassava is an important crop, its productivity is limited by a number of factors. The constraints in cassava production include soil moisture availability, weed infestation (Ezedinma et al. 2007), diseases especially the cassava mosaic disease (CMD) which can cause yield reduction of between 20-60% (Ogbe, 2001) and genetic factors which are inherent in the development process necessary for the attainment of characteristic form and function (IITA, 1990). Low soil fertility adversely affects cassava yield since cassava extracts large amounts of the macro nutrients from the soil to produce optimum yield (Obigbesan, 1977). In order to achieve sustainable production to feed the ever-increasing population amidst the prevailing land use pattern and shortened fallow periods, it is imperative to use fertilizers to obtain optimum yield of the crop.

**Statement of the Problem**

The Nigerian cassava farmers seek to produce cassava roots with high yield, high total dry matter and of good quality, harvested at an optimum time in a changing rainfall pattern and amount. The right variety, fertilizers (right type and rate) and moisture availability (in term of rainfall) are some important inputs of achieving this goal.

However, in spite of the numerous improved cassava varieties farmers currently do not have knowledge of varieties and fertilizers that are suitable for their agro-ecological zone. It is common for the farmers to plant local varieties with little or no fertilizer application. This has been the cause of lower yields, low total dry matter and low quality. This has led to little raw material for cassava based industries. This had not only led to under-production by these industries, it has also left these farmers in impoverished state. Varietal improvement for higher yield and root dry matter content should bring additional cash income to a great number of small farmers.

In response to this problem, this study seeks to identify options for making cassava crop production more rewarding for farmers by planting the niche suitable cassava variety (ies) for their agro ecology, applying the right type and rate of fertilizer and harvesting at an optimum time that will lead to the production of high root yield, high total dry matter and good quality cassava roots.

**Purpose of the Study**

The purpose of the research is to evaluate quantity and quality response of six cassava varieties to fertilizer application in the rainforest and guinea savannah agro-ecological zones of Nigeria.

**Specific Objectives**

To achieve this, the following specific objectives were followed to determine:

1. the effect of different harvest periods on biomass production, fresh root yield, root dry matter yield, hydrogen cyanide concentration and starch contents from the root of two cassava varieties

2. the interactive effect of fertilizer application with harvesting time yield on the above variables
3. fresh root yield and total dry matter response of different cassava varieties to the application of different fertilizer NPK types and rates
4. the quality (starch and HCN) response of different cassava varieties to the application of different fertilizer NPK types and rates
5. the locational effects of intra-seasonal rainfall variability on quality and total dry matter production of cassava varieties at two agro-ecological zones of Nigeria.

**Research Hypotheses**

1. Harvesting dates, fertilizer applications have an influence on fresh and dry matter yield of cassava
2. Root quality (Starch and HCN) of cassava varieties respond differently to fertilizer types and rates
3. Within season rainfall variability affect yield and quality of cassava roots

**Significance of the Study**

The findings of this study will contribute to the evolving cassava industry in Nigeria both as food and industrial crop, considering that cassava plays an important role in the calorie intake of Nigerians and that there is an increasing demand for cassava starch and chips in the industries. The great demand for cassava and its products justifies the need for more effective production techniques. Farmers that apply the recommended approaches of improved variety (ies), fertilizer type and rate derived from the results of this study will produce good dry matter yield and quality.

**Organization of the Study**

The thesis is structured into nine main chapters. The first of the chapters of the thesis gives an introduction and defined the context of which the study was done. It also outlines the objectives that guided the study. Chapter two presents a review of relevant literature. Chapter 3 provides a description of the study area and materials and methods used in the study. Chapter 4 is on the effect of harvesting time on growth, yield and quality of cassava. Chapter 5 is set to determine the effect of variety, fertilizer type and rate on biomass production and yield of cassava. Chapter 6 seeks to determine the effect of variety, fertilizer type and rate on the quality of cassava roots while chapter 7 deals with the effect of intra-seasonal rainfall variability on yield and quality of cassava. Chapter 8 discusses all the results of the study and chapter 9 gives a summary of the major findings of the study and recommendation for further study.

# CHAPTER TWO

# LITERATURE REVIEW

## Cassava: Characteristics and Production

Cassava (*Manihot esculenta* Crantz), is a globally important food and industrial crop produced for food, feed, starch, biofuel and other uses (Ayling et al. 2012). It is currently ranked as the third most important source of calories in the tropics, after rice and maize (FAO, 2011). It is produced in almost all tropical countries and grows in rich and degraded soils where almost nothing else can grow (Kuiper et al. 2007). Native to South America, cassava has historically been a human and animal feed source, and currently has many industrial applications (Daff, 2010). Based on its hydrocyanic acid content, it is categorized into sweet cassava (directly consumed) and bitter cassava for making starch and other industrial purposes (TTDI, 2013). The composition of cassava root is organically rich in carbohydrates, in the form of starch and but contains small amounts of protein, vitamins and minerals (Lancaster, Ingram, Lim, & Coursey, 1982). The protein contents of fresh and dry cassava were also reported as 1% and 1.41%, respectively. Soccol (1996), reported that fresh cassava roots had 65% of moisture, 0.9% ash and 0.03% phosphorus.

Cassava is a shrub of 1 to 4m height that produces large storage roots, which are harvested 6 to 30 months after planting (MAP). It produces yields in a wide variety of rainfall conditions ranging from less than 600 mm in unimodal rainfall areas to well over 2000 mm in bimodal rainfall areas

(Molongo et al. 2015). Due to its perennial nature, the crop experiences alternating periods of vegetative growth and storage of carbohydrates in the roots (Alves, 2002). Generally speaking, the plant develops most of its stems and leaves during the first 6 months after planting and maximum canopy size is reached at 6 MAP (Fermont, Tittonell, Baguma, Ntawuruhunga, & Giller, 2010). Storage root formation is initiated between 6 to 10 MAP. Final root yields are determined by both the source supply (the amount of carbohydrate available in the above ground biomass) and the sink demand (the amount of carbohydrate that can be stored in the storage roots). The first is related to the leaf area index and the net assimilatory rate, while the second is related to the number of storage roots and their mean weight (Alves, 2002; El-Sharkawy, 2004).

Though cassava is an important crop, its productivity is limited by a number of factors. The constraints include soil moisture availability, weed infestation (Ezedinma et al. 2007), diseases especially the cassava mosaic disease (CMD) which can cause yield reduction of between 20-60% (Ogbe, 2001) and genetic factors which are inherent in the development process necessary for the attainment of characteristic form and function (IITA, 1990). Low soil fertility adversely affects cassava yield since cassava extracts large amounts of the macro nutrients from the soil to produce optimum yield (Obigbesan, 1977). In order to achieve sustainable production to feed the ever-increasing population amidst the prevailing land use pattern and shortened fallow periods, it is imperative to use fertilizers to obtain optimum yield of the crop. Table 1 shows the area harvested, yield and total production of cassava in Nigeria from 2000 to 2012 (FAOSTAT, 2016).

Table 1: *Area Harvested, Yield and Total Production of Cassava in Nigeria from 2000 - 2012*

| Year | Area harvested (Ha) | Yield (t $ha^{-1}$) | Production ('000 MMT). |
|---|---|---|---|
| 2000 | 3300000 | 9.7 | 32.010 |
| 2001 | 3340000 | 9.60 | 32.068 |
| 2002 | 3446000 | 9.90 | 34.120 |
| 2003 | 3490000 | 10.40 | 36.304 |
| 2004 | 3531000 | 11.00 | 38.845 |
| 2005 | 3782000 | 10.99 | 41.565 |
| 2006 | 3810000 | 12.00 | 45.721 |
| 2007 | 3875000 | 11.20 | 43.41 |
| 2008 | 3778000 | 11.80 | 44.582 |
| 2009 | 3129030 | 11.77 | 36.822 |
| 2010 | 3481900 | 12.22 | 42.533 |
| 2011 | 3737090 | 14.02 | 52.403 |
| 2012 | 3850000 | 14.03 | 54.000 |

Source: FAOSTAT, 2016

**Morphology and Growth of Cassava**

Cassava is a perennial shrub grown mainly in the tropics for its starchy roots. It grows between latitudes $30^0$ N and $30^0$ S (Cock, 1985). Cassava is propagated mainly by stem cutting, though under natural conditions and breeding purposes seeds are used. Optimum temperature for seed germination is between 25 $^0$C and 35 $^0$C (Ellis & Roberts, 1979). Cuttings for commercial production are commonly 10-30 cm long taken from the woody part of mature plants. However, tip shoot cuttings have also been investigated and successfully used in cassava multiplication (IITA, 1990). Large cuttings give vigorous initial growth but may not necessarily correlate with final yield (Wholey, 1974).

Sprouting of cassava cuttings is sensitive to temperature, with fastest sprouts produced between 28.5-30 $^{0}C$ (Keating & Evenson, 1979). Cassava cuttings bearing nodes may be planted vertically, inclined or horizontally. Horizontally planted cuttings produce more shoots but may not necessarily translate to highest yield (Goldworthy & Fisher, 1984; Ekanayake, Osiru, & Porto, 1998). Cassava produces both nodal and basal roots and the rooting of cassava is known to be polarized. Therefore, planting the cutting upside down would increase the time of sprouting and may lead to poor establishment of the crop (Ekanayake, 1993). Generally, sprouting takes place between 5 and 6 days after planting with fresh healthy cuttings but emergence rate may be influenced by planting position of the cuttings (Ekanayake, 1996).

Axillary and adventitious roots (like fibrous root system) are produced in the first few weeks after planting and initial growth of the shoot system is relatively slow. Initiation of storage root may begin as early as 6 weeks after planting (WAP) in some cultivars, but generally it occurs from 8 to 12 WAP and continues to develop until 8 to 15 months (El-Sharkawy & Cock, 1990; Ekanayake, 1993). Cassava has a coarse, relatively thick and poorly branched root system with few root hairs while some roots extend deeply, most are shallow (Howeler, 1991).

The cassava leaves are spirally arranged on the stem and comprise of petiole, stipules, leaf blade or lamina which is usually palmate or lobed in odd numbers between 3 and 9 (IITA, 1990). The shoots and roots of the cassava plant develop simultaneously such that assimilate supplies are partitioned between them resulting in intensive competition. Leaf formation is given higher preference over storage roots for available assimilates in the twelve WAP. Leaf area index in cassava ranged from 3 to 7 depending on variety and soil fertility. However, leaf area index values of 10 or more have been obtained (Keating, 1981). Leaf area increases with age of the plant, reaching peak at 4 to 6 MAP and declining thereafter (Goldworthy & Fisher, 1984; IITA, 1990).

Some cassava varieties exhibit two types of branching, forking and lateral, while some which do not branch may produce lateral shoots. Branching in cassava can be influenced by environmental conditions and genotype; however, the plants produce forks at different heights up to four or five levels depending on the clone. Multi-level branching promotes early canopy closure which reduces weed growth (Okpara et al. 2010). Cassava is monoecious and production of flowers is also influenced by genotype, environment, altitude as well as photoperiod. Flowering is frequent and regular in some varieties, while it is rare or non-existent in others (IITA, 1990).

Cassava root is developed underground; thus, the flowering and seed production periods are less important than those of the cereal crops. Cropping periods that considerably impact on cassava production are the planting period and the harvesting period (Rijks, 2003). In Nigeria, for instance, the suitable planting period generally starts in the early rainy season and harvest begins at the late rainy season (Sriroth et al. 2003). The reason for this is that the average amount of rainfall in the early planting period determines the quality of starch content as well as the development of fresh roots (Sangpenchan, 2009). Because cassava roots have no natural dormancy, they are highly susceptible to postharvest physiological deterioration (PPD), such as discoloration, smell alteration, and microbial contamination. This results in the short storage life of fresh roots (Wenham, 1995).

**Varietal Differences in Cassava**

The International Board for Plant Genetic Resources (IBPGR) has identified a set of relatively stable morphological traits as descriptors which are useful in the classification and varietal identification of cassava (Aina, 2006). Shoot characteristics refer to above ground morphological characters such as leaf shape, petiole colour, petiole length, branching habit, plant height, stem colour, stay green and length of internodes.

Root characteristics include number of roots, root size, root shape, skin colour, peel colour, time of maturity, dry matter content, yield and hydrocyanic acid content (Ekanayake, 1996). Preference of farmers for different varieties has been on the basis of economic yield, maturity period, pest and disease resistance, organoleptic qualities, early and aggressive canopy formation to suppress weeds and compatibility with the farming system (IITA, 1990).

**Cassava Genetic Variability**

Genetic diversity of cassava in Africa has been assessed in some countries using a range of molecular markers (Fregene, Bernal, Duque, Dixon, & Tohme, 2000; Fregene et al. 2003; Zacarias, Botha, Labuschagne, & Benesi, 2004). These assessments have resulted in varying outputs, involving different analysis methods and applications. Detailed knowledge on genetic structure and variability of cassava germplasm is critically important for setting effective national and regional conservation priorities, for identifying 'gaps' in diversity and/or for defining breeding strategies (Tautz & Renz, 1984). Cassava is an outbreeding species originated in the American continent (Ceballos, Iglesias, Pérez, & Dixon, 2004). Cassava improvement has been largely limited to mass selection within genotypes collections of landraces and F1 segregation progenies due to highly heterozygous landraces and vegetative propagation. An understanding of the genetic structure of this species through molecular markers is important for guiding parental choice in breeding programs and validating a core collection (Iglesias, Calle, Hershey, Jaramillo, & Mesa, 1994). Furthermore, fingerprinting characterization of new varieties will become more and more important, particularly for cultivars used in industrial production, as a result of cultivar protection laws.

Various markers for morphological and agronomic traits are traditionally used for divergence and characterization studies of cassava cultivars (Léfèvre & Charrier, 1993). Isozyme patterns have also been used as a method to estimate genetic diversity and identification of cassava clones (Colombo et al. 1998). Few studies have been published on the use of deoxyribonucleic acid (DNA) markers in cassava. The genetic diversity of an *in vitro* germplasm collection of African cassava clones was evaluated using restriction fragment length polymorphism (RFLP) (Beeching et al. 1993) and random amplified polymorphic DNA (RAPD) markers (Marmey, Beeching, Hamon, & Charrier, 1994). This technology has already been applied to fingerprinting in a wide range of plant species, including rice (Welsh & McClelland, 1990), cocoa (Wilde *et al.* 1992), papaya (Sondur, Manshardt, & Stiles, 1996), apple (Koller, Lehmann, McDermott, & Gessler, 1993), and cotton (Multani & Lyon, 1995).

**Nutrient Requirements of Cassava**

Cassava may grow well and produce reasonable yields in poor and degraded soils where other arable crops cannot thrive. It is often called scavenger crop due to its efficiency in nutrient absorption from a low nutrient soil. Although cassava can be cultivated in impoverished, nutrient-deficient and marginal soils, the crop requires adequate quantities of nutrients to produce a good yield (Howeler, 1991, Obigbesan, 1999). It responds to generous doses of nitrogen, phosphorus and potassium as well as other micronutrients such as magnesium, calcium and sulphur.

According to Howeler (2008), cassava extracted 198 kg N, 70 kg $P_2O_5$, 220 kg $K_2O$, 47 kg MgO, 143 kg CaO and 19 kg S per hectare to produce a yield of 37.0 metric tonnes while 35 kg N, 58 kg $P_2O_5$, 7.0 kg CaO and 4.1 kg MgO per hectare is required to produced root yield of 15.0 t ha-1. Thus at lower yields, nutrient removal would be considerably lower, however, compared to other crops, nitrogen and phosphorus removal per tonne of dry matter in cassava were found to be much lower than those of other crops such as maize, rice and sweet potato (Howeler, 1991). Although yields of about 10 t $ha^{-1}$ or lower obtained in some farmers' field may not seriously deplete the nutrient level of the soil, it is advisable to apply 60 kg N, 15 kg $P_2O_5$ and 50 kg $K_2O$ to prevent further decline in nutrient levels in soil for an expected good yield (Howeler, 2002; Nweke, 2004).

Among tropical root crops, cassava has the highest ratio of potassium to nitrogen in the harvested roots and demands the largest amount of potassium from the soil. This situation makes cassava yield more closely associated with the concentrations of nitrogen and potassium in the roots than phosphorus (Howeler, 2002). Cassava root yield can generally be increased by nitrogen and potassium rather than phosphorus, since the crop has ability to adapt to low levels of available phosphorus as a result of the association of its roots with mycorrhiza which helps to solubilize and mobilize phosphorus levels as well as increase the availability in the soil (Howeler, 1993). Adequate nitrogen levels stimulate vegetative growth and production of assimilates while potassium enhances sink and dry matter accumulation in the root roots (Onwueme & Charles, 1994).

However, nutrients do not react independently but work with each other, high concentration of potassium in the soil may reduce uptake of calcium and magnesium while excess of nitrogen leads to luxuriant shoot growth at the expense of root formation (Sanchez & Miller, 1986; Howeler, 2002). Furthermore, frequent use of sulphate fertilizers is undesirable due to its ability to raise the acidity and thereby not allowing lime dressing to cause any significant increase in cassava yield (Omoti & Ataga, 1980; Ande, 2011).

Cropping systems and practices influence fertilizer requirements and recommendation for cassava. Continuous cropping without adequate soil amendment leads to faster depletion of major nutrients, especially nitrogen and potassium, which can cause yield decline from 28 to 11 t ha-1 root fresh matter after 20 years of cultivation. However, fresh root yields can be maintained at 20 t ha-1 with the application of NPK 15-15-15 at the rates of 600 kg/ha (Sittibusaya, 1993; IITA, 2005). Intercropping of cassava with legumes may reduce the requirement for nitrogen and phosphorus due to the ability of legumes to fix nitrogen for use by cassava while phosphorus is made available for plant use through mychorrhizal association (Howeler, 1994). Ayoola, (2010) working on an Alfisol (loamy sand) reported the depletion of soil P in a crop mixture involving cassava/maize/melon/okra on farmers' field in the tropics and attributed it to crop removal and fixation. Furthermore, high demand of exchangeable potassium was reported after maize/melon harvest before cassava inclusion in mixture (Adeyemi, 1991).

## Response of Cassava to Fertilizer Application

The role of fertilizer in increasing crop yield and production to feed the ever increasing population has been investigated in several studies (Agbaje & Akinlosotu, 2004; Makinde, Ayeni, Ojeniyi, & Odedina, 2010). Higher yields of cassava are usually recorded in areas where fertilizer is frequently used and increase in cassava yield due to fertilizer application has been reported several times (Obigbesan, 1977; Lema, Tata-Hangy, & Bidiaka, 2004; Fermont et al. 2010; Okpara et al. 2010).

Response of cassava to applied nutrients, however, depends to a large extent on the soil nutrient status at the time of application but higher response to a particular nutrient element is envisaged when the level of availability in the soil is low. The heterogeneous nature of soils in Africa has strong effects on the crop response to fertilizer due to difference in soil type, historical management and resource allocation (Zingore, Murwira, Delve, & Giller, 2007), soil nutrient status and rainfall regime (Vanlauwe et al.et al. 2006). There is a high variability in fertilizer response even on infertile soils, indicating interactions between factors which should be considered when choosing and developing fertilizer recommendations and models (Fermont et al. 2010).

This however requires a careful consideration of the fertilizer type, rate, as well as fertilizer materials, before application of fertilizer to cassava. Furthermore, the crop's response to fertilizer in sole cropping differs from that of cassava grown in mixed stands. Therefore, judicious management and conservation of soils for sustainable cassava-based intercropping under intensive cropping must be taken into consideration. It has been reported that crops especially under intercropping take up more nutrients than in monocrops (Howeler & Cadavid, 1983). Iwueke (1991) found that aggregate uptake of each nutrient was higher in the intercrop of cassava/maize/melon than in sole crops suggesting that soil nutrients would deplete faster under intercropping than in sole crops unless a fertilizer regime of NPK 15-15-15 at 400 kg/ha is maintained.

Fertilizer recommendations for optimum response should take into consideration the companion crops. In cassava/maize intercrop with low potassium in soil status, application of 100 kg $ha^{-1}$ annually is recommended to sustain optimum yields of cassava roots (Howeler & Cadavid, 1990). Cassava in intercrop generally responds to generous dose of organic based fertilizer complemented with inorganic fertilizer especially NPK (Ayoola & Makinde, 2011). In Southwestern Nigeria, intercropping cassava with arable crops is a common practice. Averagely 60-70% of the cropped land is devoted to growing crops in mixtures of 2-6 crops on a particular farm especially intercropping with cassava (Olukosi, Elemo, Kuman, & Ogungbile, 1991).

Makinde, Saka and Makinde (2007), obtained cassava root yield of 22.3 t $ha^{-1}$ with the application of a combination of 5 t $ha^{-1}$ of organic manure + 75kg N and 50 kg P in cassava/maize/melon/soybean intercrop which was lower than 18.2 t obtained. NPK 15-15-15 was applied to 5 t $ha^{-1}$ of organic based fertilizer + 100 kg $ha^{-1}$ NPK produced 13.9 t $ha^{-1}$ of cassava root, higher than 10.0 t $ha^{-1}$ obtained by applying 400 kg $ha^{-1}$ NPK 15-15-15 alone in a cassava/maize intercrop. Significant increase in soil nutrient status was also observed after two cropping seasons (Ayoola & Makinde, 2011).

Cassava responds promptly to both macro- and micronutrients application. Adequate level of potassium stimulates nitrogen-response while excess nitrogen suppresses response to applied potassium in soil. Although cassava is a heavy macro-nutrient feeder, it also requires other meso-/micro-nutrients to produce good yields (Nguyen, Schoenau, Nguyen, Van Rees & Boehm, 2002; Howeler 2008). The response of cassava to Agrolyser (which supplies mainly micronutrients) was investigated at IITA, Ibadan and NRCRI, Umudike in Nigeria. Results showed that an average application of 4kg $ha^{-1}$ in combination with compound or organic manure, 6 and 20% increase in root and stem yield of cassava, dense foliage and higher protein and Zinc content in leaves are most likely (Akoroda & Okechukwu, 2007).

Positive response of cassava to applied organomineral fertilizer on Alfisol has also been reported by Oluleye and Akinrinde (2009). Agbaje and Akinlosotu, (2004) observed that at late planting, high nutrient concentration of fertilizers at 400 and 800 kg NPK 20-10-10 $ha^{-1}$ depressed cassava root yield in favour of top biomass. Similar findings have been reported by Sanchez and Miller (1986). But the application of NPK 15-15-15 at the rate of 600 kg $ha^{-1}$ was found to increase the number of roots per plant as well as the overall yield (Ojeniyi et al. 2009).

The Abuja Fertilizer Summit held in 2006, agreed to the need to rapidly raise the average level of use of fertilizers from the current 8 kg $ha^{-1}$ to an average of 50 kg $ha^{-1}$ by 2015 and the Alliance for Green Revolution in Africa (AGRA) in 2008 show that there is an increasing consensus that mineral fertilizers are essential in Africa to counteract declining soil fertility and improve agricultural productivity (Adesina, 2008). Although cassava produces reasonable yields on infertile soils, there is no doubt that fertilizer can increase cassava yields. Cassava is a heavy potassium feeder, but also requires nitrogen, phosphorus and micro nutrients to produce good yields (Nguyen et al. 2002 Howeler, 2002; 2008). Nonetheless, experience with fertilizer use on cassava in Africa is limited and results are elusive. Some authors (Odurukwe & Arene, 1980, Aderi, Ndaeyo, & Edet, 2010) reported yield increases due to fertilizer use, in tropical Eastern Nigeria. Carsky and Toukourou (2005), observed an increasing response to fertilizer over time in farmers' field in Benin. Soils in Africa are highly herterogeneous, which has strong effects on crop response to fertilizer, due to differences in soil type, historical management and resource allocation (Zingore et al. 2007) or soil fertility status (Vanlauwe et al. 2006).

Cassava has numerous traits that offer comparative advantages in marginal environments where farmers often lack the resources to improve their lands through purchased inputs. Its tolerance to poor, acidic soils, high levels of exchangeable aluminium, low concentration of phosphorus in the soil solution and drought periods provides it with the ability to grow and produce reasonable yields in places where other crop do not produce well (Cock & Howeler, 1978; Fresco, 1993; Howeler, 2002). As a result, cassava is often produced on areas with soil problems, while the better soils are devoted to 'more profitable' crops (Fresco, 1993).

**Effects of Cassava Harvesting Time on Yield**

Although cassava is a perennial plant, starchy roots are commercially harvested between 6-24 MAP (El-Sharkawy, 1993). In humid lowlands in tropical countries, the roots can be harvested after 6-7 MAP while in cold and drought areas, cassava may be harvested after 18-24 MAP (Goldworthy & Fisher, 1984).

As cassava grows, the roots continue to bulk until maturity time when further growth or leaving in the soil does not result in significant sink accumulation in the roots. The time of harvesting cassava depends on the variety, socioeconomic factors and utilization (Nweke, 1994b). Improved cassava varieties mature early at about 9 MAP while others require up to 15-18 MAP to accumulate reasonable root dry matter. Most local varieties planted by farmers take a longer time to mature compared to the improved varieties. Some local cassava varieties can be left in the ground up to 24 MAP and harvested when needed in order to preserve the roots which are highly perishable.

Githunguri, Chweya, Ekanayake and Dixon 1998), obtained yield of above 25 t ha-1 in TMS 30572, TMS 4(2) 1425 and TMS 30555 cassava varieties at 8 MAP, but Ezedinma et al.et al. (1981), obtained root yield of 26 t ha-1 in TMS 30572 cassava variety up to 12 MAP and observed yield decline thereafter. Alleman and Dugmore (2004), reported significant yield increase of 43.0 t ha-1 with TMS 60444 from 15 to 21 MAP in Bathurst, South Africa. The yield obtained by Eke-Okoro (2001) with TMS 30572 was lower at harvest between 12-14 MAP.

The uses of cassava roots also determine the period of harvest. Cassava meant for flour production should be harvested before 12 MAP for better quality flour (Apea-Bah, Oduro, Ellis & Safo-Kantaka, 2011). According to Obigbesan (1999), when cassava is allowed to grow up to 15 MAP the starch yield triples the yield obtained at 9 MAP. Reduction in quality of harvested roots that has been left beyond 15 MAP has been reported (Sanni et al.2007) and most early maturing cassava varieties are prone to root rot and poor quality of harvested roots when left in the ground beyond this period, especially where fertilizer is used. Ebah-Djedji, Dje, N'Zue, Zohouri and Amani (2012), obtained peak starch content of 20.17% at 13 MAP while working with five improved cassava varieties in Cote d'Ivoire. They further found that Bonoua2 had the highest starch yield content of 20.78 at 13 MAP while 971A had 19.38% at 17 MAP.

Harvesting time affects the organoleptic qualities of cassava. Mulualem and Ayenew (2012) reported that delaying harvest of cassava beyond 18 MAP resulted in undue cellulose accumulation, low starch and high hydrocyanic acid content in the roots. Out of 10 cassava varieties evaluated in Ethiopia, 45/72NW produced the highest yield of 36 t $ha^{-1}$ when harvest was delayed up to 18 MAP. Although yield of 41 t $ha^{-1}$ was obtained for the same variety harvested at 24 MAP, problems of poor quality, pests and diseases were common within this period. Furthermore, yield related traits in most of the characters showed dramatic yield increases when harvested between 12-15 MAP. Harvesting at 12-14 MAP also ensures quality stakes (planting material) for propagation (Ezedinma et al. 1981, Mulualem & Ayenew, 2012).

The harvest time for cassava depends on the variety, ecological factors, socioeconomic factors and uses. Hence, Ngendahayo and Dixon (2001) stressed the need to determine the optimum harvesting time for cassava varieties in different ecological zones of Nigeria. This will equip farmers with the knowledge of appropriate time to harvest cassava for optimum yield and quality of roots, avoid losses and maximize the use of land.

**Bulking Rate**

Cassava possesses unique attributes, notably the ability to make returns of root yield even at extreme stress conditions (Ekwe, Nwachukwu, & Ekwe, 2008). It possesses high biological efficiency of food energy production per unit area, compared to maize (FAO, 1984) and fits with the cropping systems in Nigeria (Beeching et al. 2000). Annual cassava production has continued to increase due to the development of improved varieties with high yield, excellent culinary qualities and resistance to pests and diseases (Nwosu, 2005). The local cultivars still grown in Nigeria are low yielders that mature late (20-24 months), with yields in farmers' plot generally below 20 t ha-1 for the crop (Njoku, Egesi, Asante, Offei & Vernon, 2009; Aderi et al. 2010).

Current research efforts are geared towards developing not only high yielders but also rapid root bulking and early types (6 to 9 months) and high starch content. The early maturing cassava produce yields of 28-30 metric tons or more (Bassey & Harry, 2013). The number of roots which eventually form storage roots as well as earliness of root bulking and maturity may depend on the genotype assimilates supply, photoperiod, and temperature (Akoroda, 2005). The process of root formation and maturity may also depend on soil water supply, soil fertility and soil temperature (Ikpi, Gebremeskel, Hahn, Ezumah, & Ekpere, 1986).

There are varieties of shapes and number and form of the root produced, depending on the cassava variety. The sink is an important trait of ideotype. Actually, root yield depends not only on an adequate production of photosynthate but also on an adequate and strong sink to accept it. The sink strength is by and large determined by the root size and bulking capacity and an increase in either component could enhance the power of the sink (Sharma, 1996). The rate of root bulking for most cultivars is determined early in the growing season from both environmental and physiological factors. Environmental factors include plan temperatures at planting (both soil and air temperatures) and weather extremes. Physiological factors include cultivar, the resulting number of roots produced per unit land area.

Farmers prefer cassava varieties which have high sink power, high yielding properties and are early maturing. The desired attributes of a good early cassava types are early rooting, rapid root bulking and short maturity period, high starch accumulation before the onset of dry season, good in-ground storability, and good cooking qualities (Nnodu, Ezulike, & Asumugha, 2006). Due to long period of dry season which often cause retarded growth in cassava and reduces the strength of the source and power of the sink, the need to screen for early bulking and maturity has become necessary to increase cassava yield. This approach would enable cassava varieties to fit into the existing cropping systems and favourable cropping season and matures before serious moisture stress sets in. According to Eke-Okoro and Ekwe (2005), the early types possess unique attributes of rapid root bulking and maturity at the expense of shoot development, although both tend to work together.

According to Ekpe (1998), cassava varieties should be screened for top growth ratios and rapid root bulking potential and maturity since rapid top growth has been known to reduce root bulking irrespective of the amount of fertilizer applied to the crop. Githunguri, (2004) reported that regions with high rainfall have higher root yield, bulking rate and lower cyanogenic potential than those in drier zones. The result of their study also showed that root bulking rate at Ibadan increased from 4 to 6 months after planting, fell at 10 months and then levelled thereafter. Correlation and regression analyses suggested that root bulking rate and cyanogenic potential (CNP) were negatively correlated. Root formation begins about 8 weeks after planting. Many researchers have tried to define the optimum harvest time of cassava through experiments, determining maximum root yield (Hahn *et al.* 1979; Ashoka, Nair, & Kurian 1984; Maini, Indira, & Mandal, 1977). However, the recommendations from the studies vary. The optimum stage of harvest, according to some researchers depends on varieties and ecological factors. Root size increases with the age of cassava plant and normally reaches the peak at about 15 months, with a slowdown in root production occurring a few months before this time (Ngendahayo & Dixon, 2001).

**Root Quality of Cassava**

The economic value for cassava products for the farmer and industries is the dry matter content which is the chemical potential of the crop and reflects the true biological yield (Teye et al. 2011). The dry matter content which is also referred to as the dry weight is however controlled by polygenic additive factor (IITA, 1985; Kawano, Fukuda, & Cenpukdec, 1987c). According to Lian (1985) the dry matter is influenced by several factors such as the age of the plant, crop season, location and efficiency of the canopy to trap sunlight. Dry matter of cassava varies from one variety to another and ranged between 17% and 47% with the majority lying between 20% and 40% (Braima et al. 2000); values above 30% are considered high. The dry matter of the roots has become an important character for the acceptance of cassava by researchers and consumers who boil or process them (Teye et al.). Over 85% of root dry matter consists of highly digestible starch.

**Starch Quality**

Cassava is one of the most important sources of starch in the tropics (Sanchez et al. 2009). Cassava starch has excellent agglutinant properties which make it especially suitable for shrimp and fish feed replacing expensive artificial agglutinants. During early plant development, water stress retards growth, which will only be resumed after the immature plant has received sufficient water. Despite an increased starch yield, the effect of initial water stress on starch quality is still sustained (Sriroth, Piyachomkwan, Santisopasri, & Oates 2001). They further stressed that in mature plants, starch quality is affected by environmental conditions prior to root harvest, especially the onset of rain after a stress period as indicated by a reduced starch paste in Thailand.

Cassava starch is used directly as starch and indirectly as depolymerized products in various industries due to its high purity, low cost and unique characteristic such as high paste viscosity, high paste clarity, and high freeze-thaw stability, which are advantageous to many industries. According to Sriroth et al. (2001), cassava starch can be further processed to a variety of value added products such as sweeteners, alcohols, acids and other chemicals.

**Cyanogenic Potential (CNP)**

Cassava contains the cyanogenic glucosides, linamarin and lotaustralin, which are hydrolyzed after tissue damage, by the endogenous enzyme, linamarase to the corresponding cyanohydrins and further to hydrogen cyanide [HCN], (Conn 1969). The HCN is responsible for chronic toxicity when inadequately processed cassava products are consumed by humans and animals for prolonged periods. Therefore, traditional processing procedures must aim at reducing cyanide and improving storability, convenience and palatability.

Cassava processing procedures vary, depending on products, from simple processing (peel, boil and eat) to complicated procedures for processing into garri, for example, which involves many more processing steps, namely peeling, washing, grating, pressing, fermenting, sifting, and roasting. Some of these steps reduce cyanide more effectively than others. Processing techniques and procedures differ with countries and localities within a country according to food cultures, environmental factors such as availability of water and fuelwood, the cassava varieties used, and the types of processing equipment and technologies available.

**Cassava Biomass**

Biomass refers to the diverse materials obtained from plants and animals, which can be used as raw materials for the creation of useful energy in various forms and for other diverse purposes (Sambo, 2005). Biomass comes in variety of forms, but can be classified broadly in terms of end- use into fuel biomass, feed biomass, fibre biomass, organic fertilizer biomass and chemical biomass (Virchow, Beuchelt, Kuhn, & Denich 2016). Furthermore, the method of biomass production depends on the type of biomass. Fuel Biomass comprises all chemical energy sources in solid, liquid and gaseous forms obtained by processing plant and animal materials. These fuels can be burnt singly or in combination with conventional fossil fuels for the generation of thermal energy for purposes such as cooking, drive or the generation of electricity. One type of biomass fuel is ethanol. Ethanol is a liquid fuel that can be produced from starchy materials like cassava and sugarcane through fermentation. Other types of biomass fuel include biogas from waste and putrefying plant and animal matter in landfills or biogas digesters (Sambo, 2005).

The bias towards cassava for this purpose is informed by its abundance throughout Nigeria. An effort by Nigeria in recent years to make composite flours of wheat and cassava for food and industrial uses was to encourage farmers to produce more cassava. Currently, almost all ethanol need of Nigeria is imported. A switch to internal production of ethanol from local raw materials such as cassava is therefore more than timely. This would have the desirable effect of creating employment in the rural areas where cassava is grown.

Bioenergy production from agricultural crop biomass or residues has gained interest recently due to the escalating cost of fossil fuels and the need to mitigate global warming caused by increasing GHG emissions (Okudoh, Schmidt & Trois, 2015). Of all the different feed stocks used for bioenergy production in Africa, cassava biomass potentially offers multiple benefits for producing biofuels such as biogas (Ogwo, Dike, Mathew, & Akabuogu, 2012).

**Biomass and Production of Cassava**

Nigeria is the largest producer of cassava in the world followed by Brazil (FAO, 2000). Although Nigeria produces about 34 million metric tons annually (FAO, 2000) most of the cassava produced in Nigeria is consumed locally as food. Inspite of the high cassava production, Nigeria's output falls below total demand for the crop as food, for industry and export. Recently, Nigeria has shown interest in biofuel obtainable from cassava. This is evident in the bio-fuel policy and the ethanol fuel programme in which sites have been identified for the cultivation of cassava (Adeoti, 2010). Thus the need for intensification of the product is obvious. Nweke, Ugwu, Dixon, Asadu and Akuba (1997), noted that with increasing demand for cassava following population growth and changes in food preferences of the consuming nations as well as increase in industrial needs, subsistence operators are confronted with the challenges of increasing their output. Given the interest of more nations in buying cassava products from Nigeria, the prospect for enhanced foreign exchange is becoming significantly high. Although it has been argued that increasing the productivity of cassava is crucial for Nigeria to increase output to meet the 'actual versus potential' demand, increased production area is also essential. Given that Nigeria producers are mostly small holders, increasing the production area would imply prospective farmers joining the industry. The financial attractiveness of an enterprise is however, paramount to attracting new investors.

### Cassava Biomass Bioenergy Potential

Biomass sources and processing techniques vary in terms of the plant and animal products they use and the agricultural, agro-industrial or urban waste they recycle (Okudoh, Trois, Workneh, & Schmidt, 2014). Non-food use of biomass has become a major issue for sustainability. It concerns energy, and also clothing, materials, bioproducts (and biopolymers), fertilizers and organic ameliorators, among others. There are three potential biofuels that can be generated at an industrial scale from cassava biomass viz., bioethanol, biodiesel and biogas (Ogwo et al. 2012).

**Biofuels**

A number of transportation fuels can be produced from biomass, helping to alleviate demand for petroleum products and improve the greenhouse gas emissions profile of the transportation sector (EESI, 2016a). Ethanol from corn and sugarcane, and biodiesel from soy, rapeseed, and oil palm dominate the current market for biofuels, but a number of companies are moving forward aggressively to develop and market a number of advanced second-generation biofuels made from non-food feedstocks, such as municipal waste, algae, perennial grasses, and wood chips (EESI, 2016b). These fuels include cellulosic ethanol, bio-butanol, methanol and a number of synthetic gasoline/diesel equivalents. Until sufficient quantity of electric vehicles is produced to run on renewably-produced electricity, biofuels remain the only widely available source of clean, renewable transportation energy.

**Bioethanol**

Most countries with large potential for growing cassava such as Nigeria, Benin, Mozambique, Ghana, Indonesia and Thailand already use cassava for industrial purposes. Bioethanol initiatives have been identified in these countries and current production is approximately 100,000 l of cassava ethanol per year. This figure could rise to 2 million litres if ambitious plans by China and other developing countries like Nigeria and South Africa are implemented. On a global scale 6-106 Megaton of cassava ethanol could be produced per year (Kuiper et al.et al. 2007). The technology for producing ethanol from cassava is very well developed. Cassava is performing well on all processing steps. A study by Wang (2002) compared the yields of bioethanol from different energy crops and showed that cassava compared favourably to other crops such as maize, sugarcane and sweet sorghum. In fact, cassava had the highest annual yield of bioethanol (up to 6 t $ha^{-1}$) than any other crop including sugarcane (Wang, 2002).

A study by Nuwamanya, Chiwona-Karltun, Kawuki and Baguma (2012), investigated the feasibility of using non-food parts of cassava for energy production and the results revealed that at least 28% of peels and stems comprise dry matter, and 10 g feedstock yields >8.5 g sugar, which in turn produced >60% ethanol, with pH ≈ 2.85, 74–84% light transmittance and a conductivity of 368 mV, indicating a potential use of cassava feedstock for ethanol production. Rattanachomsri, Tanapongpipat, Eurwilaichitr and Champreda (2009), produced 14.3g/L of ethanol from 4% (w/v) cassava pulp by first using multi-enzyme from *Aspergillus niger* strain BCC17849 for pretreatment before fermenting with *Candida tropicalis*. The crude multi-enzyme composed of non-starch polysaccharide hydrolyzing enzyme activities, including cellulose, pectinase and hemicellulose resulting in high yield (716mg/glucose and 67mg/ xylose) of fermentable sugars.

# CHAPTER THREE

## MATERIALS AND METHODS

### Description of Experimental Sites

The study sites were located at Ikenne-Remo and Oke-oyi in Ogun and Kwara States, Nigeria, respectively. Ikenne Local Government Area (LGA) is one of the twenty LGAs in Ogun State, Nigeria. Ikenne is located at 06°51.218'N and 03° 42.622'E in the rainforest vegetation belt of Nigeria. It has an area of 144 km$^2$ and a population of 118,735 as at 2006 census. Oke-oyi is a town under Ilorin East LGA in Kwara State. Oke-oyi is located at an elevation of 316 meters above sea level and has a population of 113,841 as at 2006 census. Oke-oyi is located at 08°36.988'N and 04° 45.813'E.

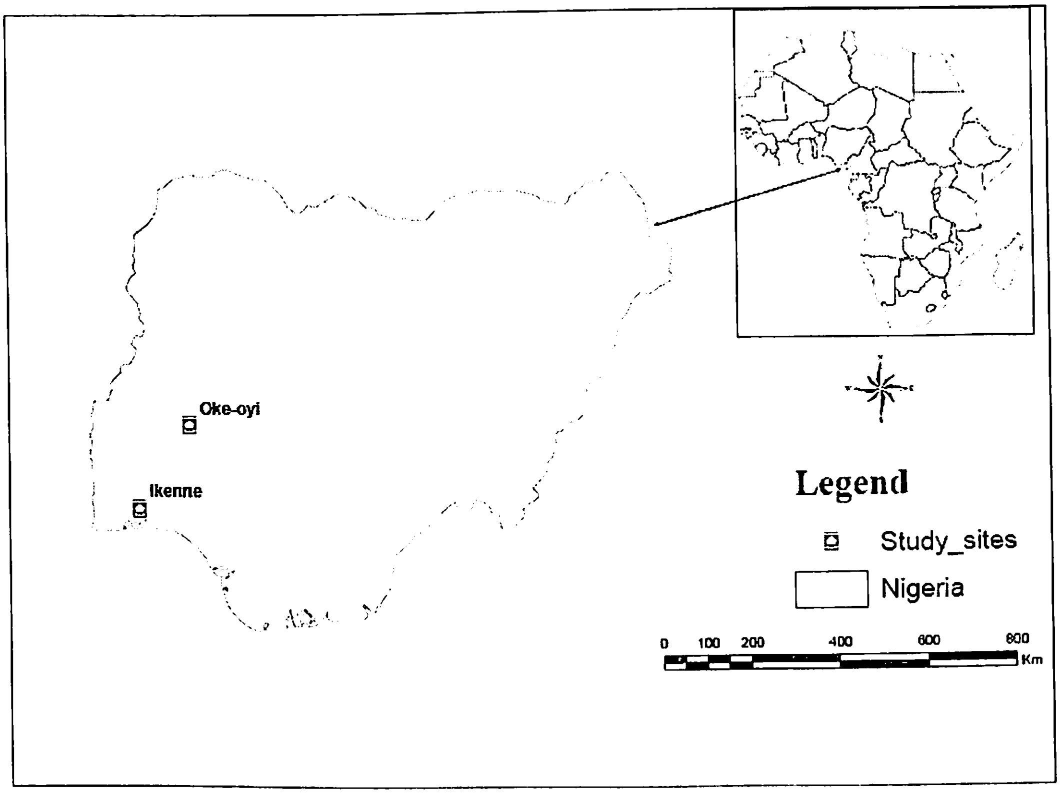


*Figure 1*: Map of Nigeria showing the two experimental sites

### Climate

Ikenne is located in the humid tropical zone with the rainy season that starts in April and ends in November, followed by a 4- month dry season (December to March). The average annual rainfall at Ikenne is 1,517mm as shown in Figure 2. It follows a pseudo bi-modal pattern, in that a decrease in rainfall in August marks the end of the major season and the beginning of minor season. The peak of the second season occurs in September and/or October. The wet season lasts for 8 months from April till November; the onset of the season is highly variable. The major season starts from April and ends in August. The minor season begins in September and ends at November. Ikenne is in the evergreen forest zone. The average monthly temperature ranges from 23°C in July to 32°C in February and its elevation is 59m above sea level.

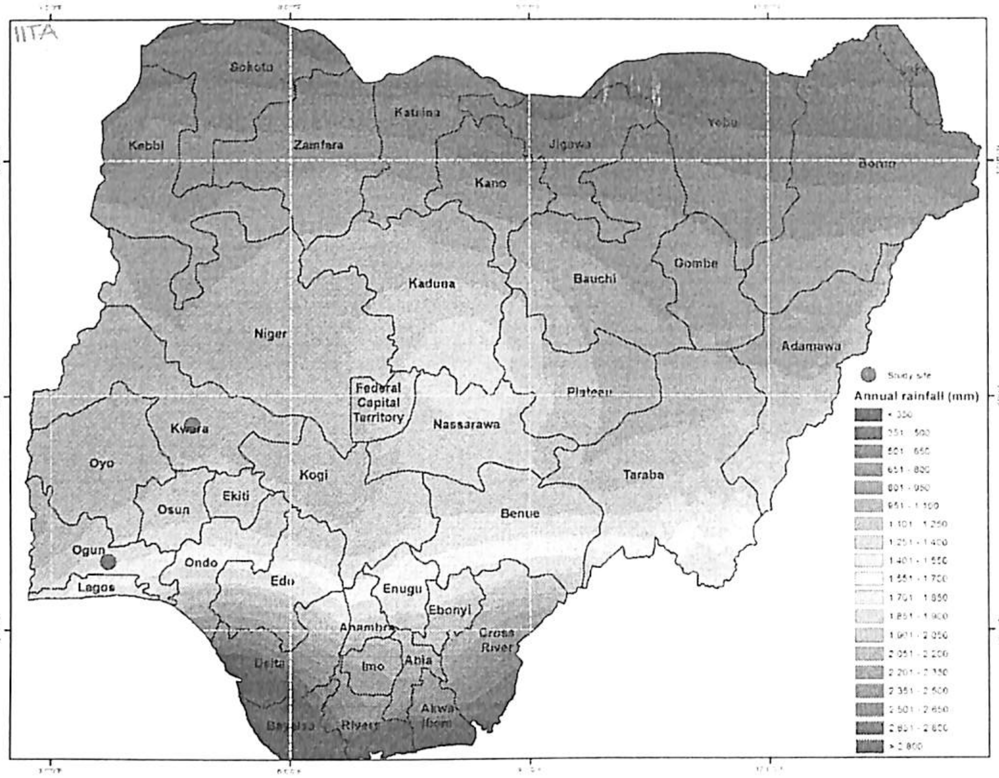


*Figure 2*: Annual rainfall regimes (mm yr$^{-1}$) of the study sites

Source: GIS Support Unit (IITA, 2015)

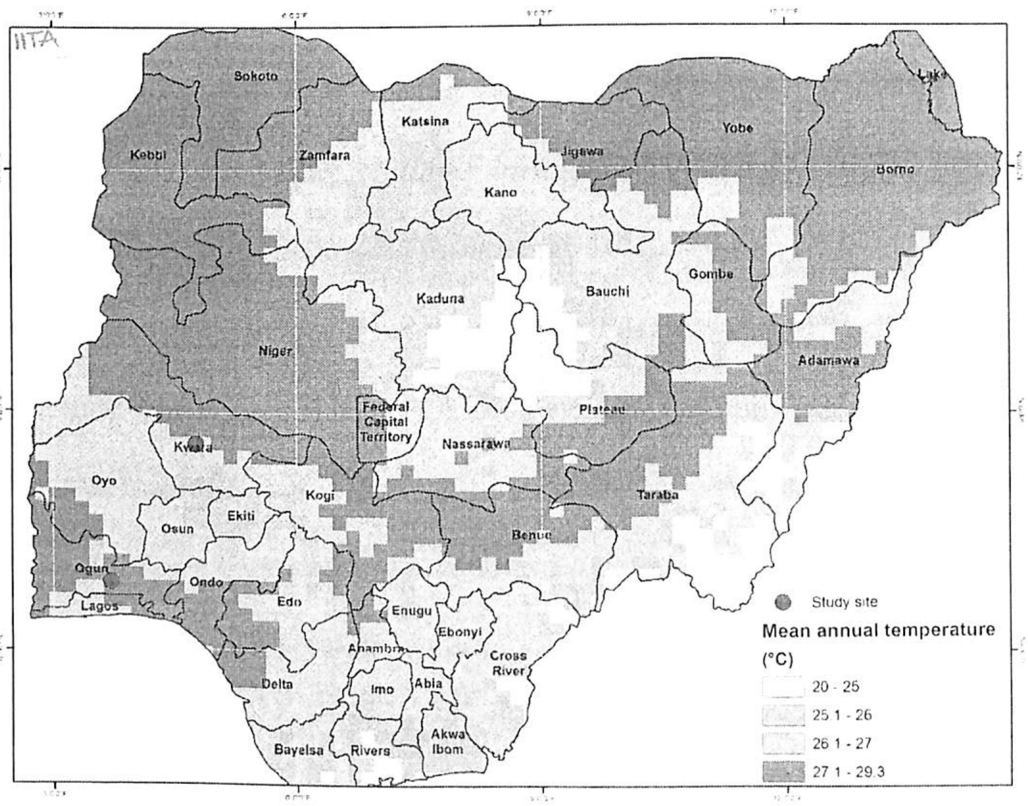


*Figure 3*: Mean annual temperature of the study sites

Source: GIS Support Unit (IITA, 2015)

Oke-oyi covers an area of about 1027 $km^2$. It falls within the southern limits of the tropical savannah zone of Nigeria with mean annual rainfall of 1,231mm, mean annual temperature of 28 $^0C$ and mean annual relative humidity of 56%. The monthly average of the relative humidity remains above 60% from July through October (Issa, Alagbe, & Garba, 2014). The Oke-oyi study area experiences high temperature all the year round, high humidity and pronounced wet and dry seasons. The wet season begins from April and terminates in October in an average year. In contrast to Ikenne, rainfall pattern at Oke-oyi follows a mono-modal distribution. However, temperature, solar radiation, and sunshine and day length are not limiting factors for the crops that are commonly grown in the area (Oriola, 2004). The elevation of Oke-oyi is 276m above sea level.

**Vegetation**

The vegetation at Ikenne consists of trees species such as *Isotonia boonei*, *Cola gigantean*, *Antiaris africana*, *Pentaclethra macrophylla*, and *Elaeis guineensis* (Adedeji & Gbadegesin, 2012). Oke-oyi vegetation is typical to the guinea savannah and consists of small deciduous fire-resistant branching trees that do not usually form a closed canopy and are often widely scattered. The arable crops grown at Oke-oyi include cassava, maize, sorghum, etc. There are also tall grass species such as *Elephant grass and Guinea grass*.

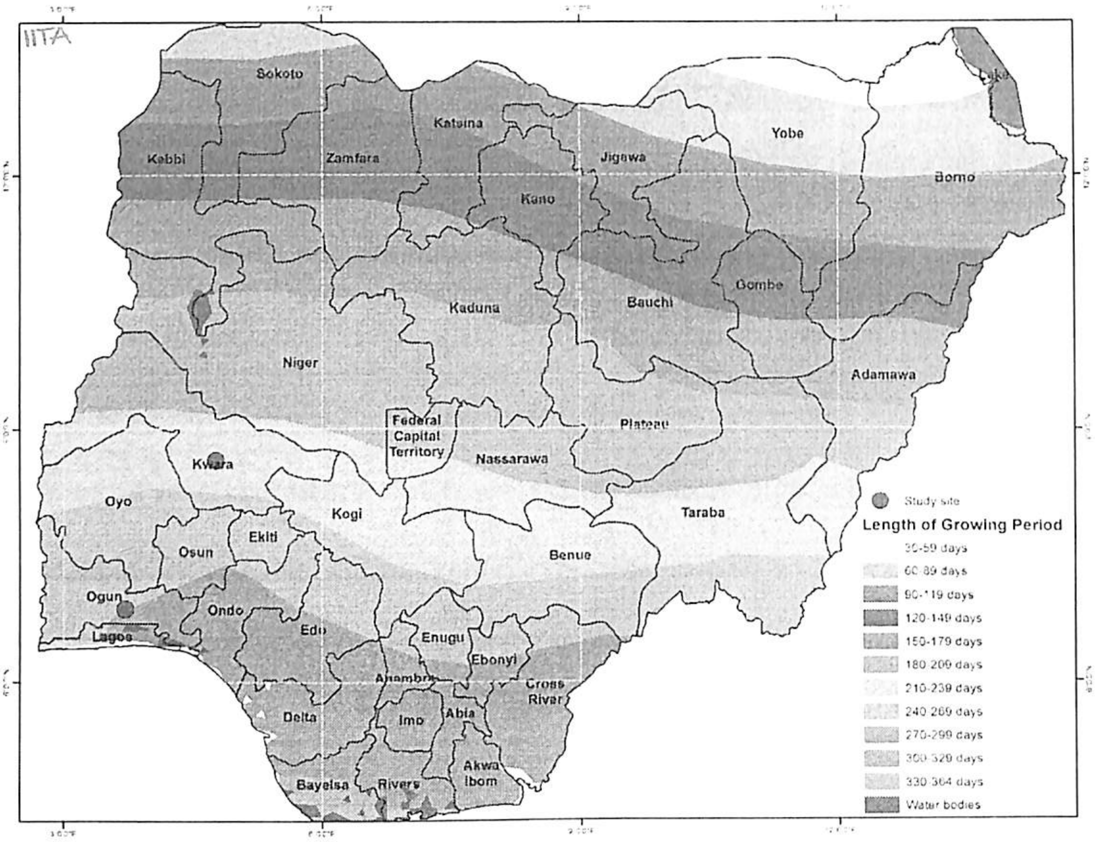


*Figure 4*: Length of growing days of the study sites

Source: GIS Support Unit (IITA, 2015)

### Geology and Soils

The soils at Ikenne experimental station belong to the *Itagunmodi* series and USDA classification of Oxic Paleustults. The soils are classified as Ultisols according to USDA classification and as Ferric Acrisols according to the FAO-UNESCO system (Nwachokor & Uzu, 2008) and developed from Amphibolite. The Ikenne soils are considered marginal for agricultural production since the soils are highly weathered, low in cation exchange capacity (CEC), base saturation and pH (Adedeji & Gbadegesin, 2012) and usually occurring in rainforest and derived savannah.

The soils of Oke-oyi are reddish in colour with an appreciable reserve of weatherable minerals (Oriola, 2004). The soil of Oke –oyi is of Woro Series and is classified as Typic Plinthic Eutrustalf (USDA, 1961).

Oke-oyi area is underlain by the rocks of the basement complex of south-western Nigeria, which is of Precambrian to Lower Palaeozoic in age (Jones & Hockey 1964; Rahaman, 1976). It comprises biotite-granite, granite-gneiss and metasediments which are mainly quartz-mica schist and quartzite (Issa, et al. 2014). The soil of Ikenne experimental site was previously planted with 'β-carotene' cassava (TMS 01/1371variety) while Oke-oyi experimental site was under fallow.

**Soil Sampling and Characterization**

Before planting the different varieties of cassava, initial soil sampling was carried out at each of the experimental sites. Soil sampling was done using stratified random sampling method. Composite soil samples were taken by driving a soil auger into the soil, and samples were taken at two soil depths (0-15 cm, 15-30 cm) and placed into sampling bags. Additional soil samples were collected at the two depths using soil cores. A total of 16 auger soil samples and 12 core samples were collected from the two locations.

The soil samples were air dried and then passed through 2 mm sieve. Routine soil tests were conducted on the 16 soil samples collected to determine the nutrient content. The analysis was carried out at the Analytical Service Laboratory (ASLAB) of the International Institute of Tropical Agriculture (IITA) Ibadan, Nigeria.

## Laboratory Analyses of Soil Samples

### Soil pH

The pH of 10 g of soil was determined in 10 ml water with soil sample to water ratio of 1:1 using Glass Electrode pH meter according to Black et al. (1965).

### Soil Organic Carbon Determination

Soil organic carbon was determined by complete oxidation procedure described by Heanes (1984). Potassium dichromate (1.0 N $K_2Cr_2O_7$) quantity of 5 ml was added to 250 mg of 0.5 mm sieved soil in 50 ml digestion tube. It was capped with a rubber stopper, and swirled on a vortex mixer until the soil sample was completely dispersed. The suspension was digested at 150 $^{o}$C for 30 minutes. The digest was allowed to cool, dilute to 50 ml volume, mix using a vortex mixture. The digest was centrifuged in 50 ml centrifuge tubes for 10 minutes at 3000 rpm. The absorbance was read on a spectrophotometer at a wavelength of 600 nm using a 1 cm cell.

### Determination of Soil Total Nitrogen

Total soil nitrogen was determined by running the samples on an auto-analyser (Technicon, 1971) after wet digestion. 0.5 g of 0.5 mm sieved soil sample was weighed into a 50 ml tubes, (5 digestion tubes was without soil samples for the preparation of standards). According to Bremner and Mulvaney, (1982), 2.5 ml of sulphuric acid-selenium mixture was poured into each tube. (Sulphuric acid-selenium mixture: Dissolve 6.25 g of selenium only in 1 litre concentrated (98%) sulphuric acid.), the sample with the acid was then mixed on a vortex mixer. Hydrogen peroxide ($H_2O_2$) 2 ml was then added into each tube. The mixture was digested at 300 $^{0}$C until the digest is clear. Each batch of digestion contained 5 check samples. The use of this method converts organic nitrogen to ammonium sulphate. Samples and checks were then run on the auto-analyzer.

### Available Phosphorus

Using a three (3.0 ml) scoop, three (3.0 ml) of soil was weighed into a 50 ml centrifuge tube,. Soil sample in the scoop was levelled. Capped securely and shake for 5 minutes allowed to stand for 10 minutes, then centrifuge for 5 minutes at 3000 rpm. The available soil P was determined using spectrophotometer after extraction with Mehlich-3. Mehlich-3 extraction solution was made by dissolving 69.45 g $NH_4F$ and 36.75 g EDTA in 250 ml distilled water which was later diluted to 500ml using a 500 ml polythene bottle. In a 10 litre jug, 8 litres of water was added and 200 g $NH_4NO_3$. This was followed by the addition of 40 ml of the EDTA/$NH_4F$ solution, 115 ml acetic acid, and 8.2 ml of 70% nitric acid was later added, the solution was diluted to 10 litres. The pH of the solution was 2.5.

### Determination of Exchangeable Calcium, Magnesium and Potassium

Calcium, Magnesium and Potassium were extracted with Mehlich 3 extractant. Three grammes of soil were weighed into a 50 ml centrifuge tube. Centrifuge at 300 rpm for 5 minutes, allowed to rest 10 minutes and centrifuged again at the same speed for another 5 minutes. For the stock solution 8.00 ml of 1000 ppm Ca, 1.6 ml of 1000 ppm Mg and 0.800 ml of 1000 ppm K were added to a 100 ml volumetric flask, and then diluted to 100 ml with distilled water. This solution contains 80.0 ppm Ca, 16.0 ppm Mg, and 8.00 ppm K. 1.00 ml of sample was added to centrifuge tubes and diluted with an additional 18.0 ml of 1000 ppm of Sr solution. Samples are read on an atomic absorption spectrophotometer and the burner head is rotated for Ca-Mg-K readings. Sample concentrations are then determined from the standard curve.

### Determination of Exchangeable Zinc, Copper, Manganese and Iron

For the Zn-Cu-Mn-Fe stock solution, 100 ml of 1000 ppm Mn, 100 ml of 1000 ppm Fe, 1.00 ml of 1000 ppm Cu and 1.00 ml of 1000 ppm Zn were added to a 250 ml volumetric flask. Distilled water was then used to dilute to the mark. This solution contains 400 ppm Mn and Fe and 8.00 ppm Cu and Zn. The sample concentrations were then determined using the AAS.

### Exchangeable Acidity

The titration method was used to determine exchangeable acidity (Al and H). Weigh three grammes of air-dried soil (grind to pass a 2mm sieve) into folded filter paper placed on the extraction cup. 50 ml of 1.0 N KCL solution was gently poured through the soil in the filter paper and the leachate collected. 5 drops of phenolphthalein indicator was added to the leachate. The leachate was titrated with 0.05 N NaOH to pink end point (Mclean, 1965).

Calculation

Exchangeable acidity (meq/100 g)

$$= \frac{V*0.05*100}{W} = V \times 1.67$$

where

V = Titre volume of NaOH used (ml)

Normality of NaOH = 0.05*N*

W = weight of soil sample used

### Effective Cation Exchange Capacity

Effective cation exchange capacity (ECEC) was calculated by the summation of exchangeable acidity and exchangeable basic cations.The pH of the extracting solution in determining the basic solution was 5.7.

### Particle Size Analysis

The composition of clay, silt and sand was determined from their settling rates in an aqueous solution using the hydrometer method. This method is based on the dispersion of soil aggregates using a sodium hexa-meta-phosphate solution and subsequent measurement based on the changes in suspension density (Landon, 1991).

The samples were pre-treated with hydrogen peroxide to remove organic matter before shaking with a dispersion agent (sodium hexa-meta-phosphate). The soils were then classified into the different textural classes using a computer program (Gerikis & Baer, 1999).

## Experimental Materials

### Cassava Varieties

Six varieties of cassava, which are described as early and late-maturity varieties, (Table 2) were obtained from the International Institute of Tropical

Agriculture in Ibadan, Nigeria and planted during the major and minor seasons in 2014. They were: TME 419, Oko-iyawo, TMS 98/0505, TMS 96/1632, TMS 30572 and TMS 91/02324. TME (Tropical *Manihot esculenta*) is a prefix for all IITA landrace accessions while TMS (Tropical *Manihot* species) is a prefix for all cassava lines developed by IITA. The pre-emptive - CMD cassava development period is a period when cassava improvement and development focused on resolving the negative production pressures of a new strain of cassava mosaic virus from east Africa pre-empted to infest Nigeria cassava farms in future. The cassava breeding programme of the International Institute of Tropical Agriculture, later in 2005 and 2006 in collaboration with the National Root Crops Research Institute, Umudike, released five new cassava varieties among which are TME 419, TMS 98/0505 and TMS 96/1632 with a view to check this new strain of virus (Eke-okoro & Njoku, 2012).

Table 2: *Description of Cassava Varieties Used in the Study*

| Variety | Year of release | Maturity type | Branching habit | Trait classification |
|---|---|---|---|---|
| TME 419 | 2005 | Early maturing 9-12 MAP | Non-branching | High Dry Matter, Multiple Pests Resistant, High yield, poundable and High Starch. |
| Oko-iyawo | Local variety | Late maturing | Branching | |
| TMS 98/0505 | 2005 | Early bulking 12 MAP | Branching | Multiple Pests Resistant, High Starch, High yield, Early bulking. |
| TMS 96/1632 | 2006 | Early maturing 9-12 MAP | Branching | High Dry Matter, Multiple Pests Resistant, High yield, stay green and drought tolerant. Fairly suitable for mixed cropping, suitable for food and industry |
| TMS 30572 | 1984 | 12 MAP | Branching | Has excellent response to fertilizer; multiple branching; early and profuse spread of canopy; high yield and moderate multiple resistances to pest and diseases. It is used as a national check in most cassava trials (IITA, 2005). High Dry Matter, Early Bulking, High starch and High yield |
| TMS 91/02324 | Not officially released | Early maturing 9-12 MAP | Branching | This variety fresh yield ranges between 17.75-28.6 t ha-1 across Nigeria, dry matter (DM) %, of 21.37-37.40 and starch content (%) of 61.64-75.15. |

### Fertilizers Used

Three inorganic fertilizers were used for the experiment at the two experimental sites. They were NPK 15:15:15, NPK 20:10:10 and NPK 12:12:17. The three different fertilizer types were applied at the rates of 150 kg $ha^{-1}$ and 300 kg $ha^{-1}$, respectively.

### Fertilizer Application

All fertilizer treatments were applied manually using the band method at 6 weeks after planting. The fertilizer was placed 5cm deep and 5 cm away from the plant, and covered with soil. Fertilizer application was carried out a day after the first weeding.

## Cultural Practices

### Land Preparation

The Oke-oyi site was previously under fallow, whereas Ikenne experimental site was previously cultivated with cassava before the establishment of the experiment. The land was prepared by spraying the fields with Glyphosate (Round-up) two weeks before ploughing to kill the weeds. The land was ploughed, harrowed and then ridged. Thereafter, the cassava was planted on ridges. The fields were divided into different (3) blocks and replicated thrice. Pre-emergence herbicide (Premextra) was sprayed two days after planting to kill emerging weeds after planting.

### Planting

Healthy mature cassava stems of the six varieties were obtained from IITA and from local farmers. They were cut at 25 cm length with 5-8 nodes. Planting at the two experimental sites was done 7 and 8 July 2014 and 9 and 10 September 2014 in Oke-oyi and Ikenne respectively. Cuttings were planted (one stem per hill) on the crest of ridges at 1m X 1m spacing to give population density of 10,000 plant stands per hectare. Four rows of 20 plants per plot were planted for each cassava variety. Replanting was done 3 weeks after planting to achieve optimum plant population.

### Weeding

Weeding was done manually with the use of hoe and with application of Paraeforce (a selective herbicide). Weeds at the borders of experimental areas were controlled by the use of broad spectrum herbicide Touch down with active ingredient Glyphosate.

## Experimental Design, Treatments and Field Layout

### Experiment 1

Preliminary field experiments were conducted at the two research sites using two cassava varieties (TME 419 and Oko-iyawo). Site selection was carried out based on differences in soil fertility levels and agroecological zones. Soil fertility level was higher at Oke-oyi while rainfall receipts were greater at Ikenne. The experiment was laid out in a split- plot arrangement with three replicates. Fertilizer and non-fertilizer treatments were the main plot while variety was the sub-plot. NPK 15:15:15 at the rate of 300 kg $ha^{-1}$ was applied. The layout of the experiment is shown in Table 3. Plant spacing was

1m x 1m with 1m within and between rows. Each row is 20m long made up of 20 plants for each variety. Each treatment is made up of 4 rows. Four plants were destructively harvested at each harvesting time, the four plants were randomly chosen within an area of 2m x 2 m.

Table 3: *Experiment 1 Field layout*

| Layout | | | | | |
|---|---|---|---|---|---|
| Rep 1 | | Rep 2 | | Rep 3 | |
| Fertilized | | Non fertilized | | Non fertilized | |
| V1 | V2 | V2 | V1 | V1 | V2 |
| Non fertilized | | Fertilized | | Fertilized | |
| V2 | V1 | V1 | V2 | V2 | V1 |

**Experiment 2**

Field experiments were conducted at the two research sites using six cassava varieties (TME 419, Oko-iyawo, TMS 98/0505, TMS 96/1632, TMS 30572 and TMS 91/02324). Two different application rates of three inorganic fertilizers were used as fertilizer treatments in a split-split plot arrangement with three replicates.

Four plants were harvested sequentially at 6, 8 10 and 12 months after planting. Plant spacing was 1m x 1m with 1m within and between rows. Each row is 20m long made up of 20 plants for each variety. Each treatment is made up of 4 rows. Each experimental unit (comprising of a fertilizer type, rate and variety) dimension was 4m x 20m = 80m$^2$, each replicate was made of 42 experimental units, total of 126 experimental units. Each experimental unit and replicate was separated from the other by 1m. There was a general 3 m boarder around the whole experimental site, giving a gross total area of 14,400 $m^2$. Table 4 shows the field layout of experiment 2.

The fertilizer types were:

(i) F1 – NPK 15:15:15

(ii) F2 – NPK 20:10:10

(iii) F3 – NPK 12:12:17

(iv) NF – No fertilizer (Control)

At the rates of:

1. 150 kg $ha^{-1}$
2. 300 kg $ha^{-1}$
3. 0 kg $ha^{-1}$

Varieties:

V1- TME 419

V2- Oko-iyawo

V3- TMS 98/0505

V4- TMS 96/1632

V5- TMS 30572

V6- TMS 91/02324

Table 4: *Experiment 2 field layout showing treatments combinations*

| Layout | | | | | | |
|---|---|---|---|---|---|---|
| | | | Rep 1 | | | |
| F1, rate1 | F2, rate1 | F3, rate1 | No fert | F1, rate2 | F2, rate2 | F3, rate2 |
| V2 | V3 | V2 | V2 | V3 | V2 | V2 |
| V4 | V5 | V1 | V5 | V5 | V1 | V5 |
| V6 | V6 | V4 | V3 | V6 | V4 | V3 |
| V5 | V4 | V6 | V4 | V4 | V6 | V4 |
| V1 | V1 | V3 | V1 | V1 | V3 | V1 |
| V3 | V2 | V5 | V6 | V2 | V5 | V6 |
| | | | Rep 2 | | | |
| No fert | F1, rate2 | F2, rate2 | F3, rate2 | F1, rate1 | F2, rate1 | F3, rate1 |
| V2 | V3 | V2 | V2 | V3 | V2 | V2 |
| V4 | V5 | V1 | V5 | V5 | V1 | V5 |
| V6 | V6 | V4 | V3 | V6 | V4 | V3 |
| V5 | V4 | V6 | V4 | V4 | V6 | V4 |
| V1 | V1 | V3 | V1 | V1 | V3 | V1 |
| V3 | V2 | V5 | V6 | V2 | V5 | V6 |
| | | | Rep 3 | | | |
| F1, rate1 | F1, rate2 | F2, rate2 | F3, rate2 | F2, rate1 | F3, rate1 | No fert |
| V2 | V3 | V2 | V2 | V3 | V2 | V2 |
| V4 | V5 | V1 | V5 | V5 | V1 | V5 |
| V6 | V6 | V4 | V3 | V6 | V4 | V3 |
| V5 | V4 | V6 | V4 | V4 | V6 | V4 |
| V1 | V1 | V3 | V1 | V1 | V3 | V1 |
| V3 | V2 | V5 | V6 | V2 | V5 | V6 |

## Field Measurement of Crop Parameters

Measurements taken in the course of the experiment included time series of biomass sampling, harvest index, starch content, HCN level, dry matter content and root dry matter yield. At each harvest time, yield and yield components were determined.

### Sprouting Data

Sprouting data for the experiment were taken three weeks after planting. Sprouting data were determined by counting the number of sprouted stems per treatment.

### Number of Leaves

The number of all fully expanded leaves per plant of the four plants to be sampled at each harvest time was counted at 2 months interval from 6 MAP to 12 MAP.

### Plant Height

Height of cassava plants was measured from the soil level to the tip of the sprout or the tallest stem of the sampled plants at 6, 8, 10 and 12 months after planting (MAP) using a meter rule.

### Plant Height at First Branching

Plant height at branching was measured with a graduated pole. The measurement was taken from soil level to the height at branching.

## Yield Parameters

### Root Yield

At each harvesting time, the four sampled plants in each treatment were harvested. The number of roots were counted and weighed and used in determining yield in tons per hectare.

The yield in t $ha^{-1}$ was calculated as follows:

Root yield ($tha^{-1}$) = $\left(\frac{Weight\ in\ Kg}{Area\ per\ stand} \times 10\right)$

### Dry Matter of Leaves and Stem

Dry matter content of the leaves and stems were determined at each harvest time using100 g sample from each treatment. The weighed sample was oven dried at 65°C to a constant weight and the percentage dry matter determined.

### Root Dry Matter Content

Dry matter content (DMC) was estimated using the well-known specific gravity methodology (Kawano et al. 1987). Approximately 5 kg of roots were weighted in a hanging scale (Wa). The same sample was weighted with the roots submerged in water (Ww). DMC was estimated with the following formula:

DMC (%) = $\left(\frac{Wa}{Wa-Ww}\ x\ 158\right) - 142$

Where:

Wa is the cassava weight in air and

Ww is the cassava weight in water.

### Dry Matter Yield

Dry matter yield (DYLD): This is a product of dry matter percentage (DMC) and fresh yield (FYLD) expressed in t ha$^{-1}$.

$$DYLD = \frac{DMC}{100} \times \frac{FYLD}{1}$$

DYLD expressed in t ha$^{-1}$

### Harvest Index

Harvest index (HI) was calculated as a ratio of dry root yield to the total dry matter production:

$$\mathrm{HI} = \left(\frac{RY}{RY+SY}\right)$$

Where RY = Fresh root yield

SY = Fresh shoot yield

## Root Quality

### Determination of Hydrogen Cyanide Content

The fresh cassava root samples in all experiments were analysed for total Hydrogen Cyanide contents. A simple picrate method was used to quantify the cyanide contents of cassava samples. The cyanide in the samples reacted with Toluene solution to produce hydrogen cyanide vapour which reacted with alkaline picrate test strips to form red colour on the test strips. The red coloured complex on the strips extracted was measured using a cyanide chart. Cyanide content was measured in ppm.

### Determination of Starch Content

Roots (3-5 kg) were weighed in air while making sure that the roots are free of debris. The weighed samples were then weighed in water with the use of Reiman Balance to determine the specific gravity. Starch content is calculated using the precision formula (%) by (Kawano *et. al.*, 1987).

$$\text{Starch content } (\%) = \left(\frac{Wa}{Wa-Ww}\ x\ 210.8\right) - 213.4$$

### Meteorological Data

Meteorological data for the two experimental sites were sourced from Lower Niger River Basin Development Authority, Ilorin and Nigerian Meteorological Agency, Oshodi, Lagos for Oke-oyi and Ikenne respectively for the period of sixteen years (2000-2015) in daily resolution.

### Statistical Analysis

The data collected were subjected to ANOVA procedure of the general linear model (GLM) of Statistical Analysis Software (SAS ® version 9.3) package to compare all observational data from the different treatments and also among the varieties. Treatment means were compared using the Least Significance Difference (LSD) at 5% level of probability.

# CHAPTER FOUR

# EFFECTS OF HARVESTING TIME ON GROWTH, YIELD AND QUALITY OF CASSAVA

## Introduction

Cassava (*Manihot esculenta* Cranzt) is a perennial crop native to tropical America, (Olsen & Schaal, 2001). Cassava plant is cultivated mainly for its storage roots and it produces potentially more calories per unit area than any other crop in the world except sugar cane (Sagrilo et al. 2003). Cassava offers the advantage of a flexible harvesting date, allowing farmers to keep the roots in the ground until needed (Chavez et al. 2005). Cassava roots are commercially harvested between 6-24 MAP depending on variety, socio-economic factors and utilization (Goldworthy & Fisher, 1984; El Sharkawy, 1993; Nweke, 1994b).

As cassava grows, the roots continue to bulk until maturity when no significant further sink accumulation occurs in the roots. Improved cassava varieties mature as early as 9 MAP while local varieties require up to 15 MAP to accumulate reasonable root dry matter (IITA, 2005). Cassava root yield also varies with variety and time of harvesting. In their study involving TMS 30572, TMS 4(2) 1425 and TMS 30555 cassava varieties in southwest Nigeria, Githunguri et al. (1998) obtained fresh root yield of above 25 t $ha^{-1}$ at 8 MAP with no fertilizer application. Ezedinma et al. (1981), obtained fresh root yield of 26 t $ha^{-1}$ from TMS 30572 cassava variety at 12 MAP and observed yield decline thereafter at southeast Nigeria under rainfed condition. Alleman and Dugmore, (2004) working under rainfed condition with no fertilizer application in South

Africa, reported significant yield increase of 32.0 t $ha^{-1}$ in eight cassava varieties when harvest was delayed to between 15 to 21 MAP. Okpara et al. (2010) in a different report stated that 12 MAP appeared to be optimum time of harvesting cassava variety TMS 98/0505 to obtain dry matter yield of 13.5 t $ha^{-1}$ with the application of 150 kg $ha^{-1}$ of K fertilizer there was no significant addition beyond this period. Fresh cassava root yield of 41.0 t $ha^{-1}$ obtained at 14 MAP with same variety was also reported but the yield obtained by Eke-Okoro (2001) with TMS 30572 was lower between 12-14 MAP.

The uses of cassava root roots also determine the period of harvest. Cassava meant for flour production should be harvested before 12 MAP for better quality flour (Apea-Bah et al.et al. 2011). According to Obigbesan (1999), when cassava is allowed to grow up to 15 MAP the starch yield could increase up to triple that obtained at 9 MAP.

Sanni et al. (2007) observed reduction in quality of harvested roots that has been left beyond 15 MAP and most early maturing cassava varieties are prone to root rot and poor quality of harvested roots when left in the ground beyond this 15 MAP, especially where fertilizer is used in its production. Ebah-Djedji et al. (2012) obtained peak starch content of 20.17% at 13 MAP while working with five improved cassava varieties. They further found that Bonoua2 had the highest starch yield content of 20.78% at 13 MAP while 971A had 19.38% at 17 MAP.

Harvesting time affects the organoleptic qualities of cassava. Mulualem and Ayenew (2012) reported that delaying harvest of cassava beyond 18 MAP resulted in undue-cellulose accumulation, low starch and high hydrocyanic acid content in the roots. Out of 10 cassava varieties evaluated, 45/72 NW produced the highest yield of 36 t $ha^{-1}$ when harvest was delayed up to 18 MAP. Although yield of 41 t $ha^{-1}$ was obtained for the same variety harvested at 24 MAP, with problems of poor quality, pests and diseases common within this period. Furthermore, yield related traits in most of the characters showed dramatic yield increases when harvested between 12-15 MAP. Harvesting at 12-14 MAP also ensures quality stakes (planting material) for propagation (Mulualem & Ayenew).

Ngendahayo and Dixon (2001) stressed the need to determine the optimum harvesting time for cassava varieties in different ecological zones of Nigeria. However, the harvest time for cassava depends on the variety, ecological factors, socioeconomic factors and uses. This will equip farmers with the knowledge of appropriate time to harvest cassava for optimum yield of high quality root roots, avoid losses and maximize the use of land. There are still researches to conduct about cassava but the most important are those which refer to differences among cultivars, as well as the harvesting period of the storage roots (Dixon et al. 2010). Therefore, the present study was conducted with the following objectives:

1. To determine the effect of different harvest periods on biomass production, fresh root yield, root dry matter content, hydrogen cyanide concentration and starch contents from the root of two cassava varieties in two agro-ecological zones.

2. To determine the interactive effect of fertilizer application with harvesting time on the above variables.

## Materials and Methods

Description of the climate, vegetation, geology and soil, at the study sites, and soil sampling and characterization are as described in Chapter 3

## Soil Chemical Analysis: as described in Chapter 3

## Materials Used

### *Cassava Varieties*

Two cassava varieties; TME 419, an improved variety and Oko-iyawo a local variety were used for the study. TME 419 was released in 2005 by IITA in collaboration with NCRI (Umudike) during the pre-emptive cassava mosaic disease (CMD) cassava development period, (Eke-okoro & Njoku, 2012). Oko-iyawo is a favourite local variety grown in the two research sites due to its adaptability to the two agroecological zone. Cassava stems cuttings used in Oke-oyi experimental site were obtained from a commercial farm in Kwara State while those used in Ikenne experimental site were sourced from IITA, Ibadan.

### *Fertilizer Used*

The inorganic (NPK 15-15-15) fertilizer used in the experiment was obtained from a commercial agrochemical shop and was applied at two research sites. Fertilizer was applied at the rate of 300 kg $ha^{-1}$ at both sites. The fertilizer was applied manually using the band method at 6 weeks after planting.

## Cultural Practices

All cultural practices were as described in Chapter 3.

## Experimental Design, Treatments and Field Layout

The experiment was conducted at the two research sites using two cassava varieties TME 419 and Oko-iyawo. The NPK 15-15-15 fertilizer was applied at 300 kg $ha^{-1}$. The treatment included a control experiment with no fertilizer application. The experimental design was a split plot with three replications. Each experimental unit had 4 rows of 20 metres length (20 plant stands per row separated by 1m within ridge and across ridge). Harvesting was done sequentially at 6 months, 8 months, 10 months, and 12 months, respectively.

## Field Measurement of Crop Parameters

As described in Chapter 3

## Root Quality

As described in Chapter 3

## Statistical Analysis

The data collected were subjected to ANOVA procedure of the general linear model (GLM) of Genstat statistical package ($9^{th}$ Edition) to compare yield and total biomass data from the different treatments and also among the varieties. Treatment means were compared using the Least Significance Differences of means (LSD) at 5% level of probability.

## Results

### Physical and chemical characteristics of soil at the two experimental sites

The physical and chemical characteristics of the soils at the two experimental sites are presented in Table 5. Result from the initial laboratory analysis of the soils used in the study showed that the pH ranged (4.6-7.8) of the soil were within the optimum range for cassava production (Howeler, 2002). Organic carbon, nitrogen, calcium, magnesium and potassium were all below the critical level for cassava production in both experimental soils (Howeler 2002). Phosphorus concentration was below the critical level in Ikenne while it was within the optimum range in Oke-oyi top soil. The rootable soil depths according to the soil profile descriptions are 115 cm and 180 cm for Oke-oyi and Ikenne respectively.

Table 5: *Physical and Chemical Characteristics of Ikenne and Oke-oyi experimental soils*

| | Soil depth (cm)/ Values | | | | |
|---|---|---|---|---|---|
| | Ikenne | | Recommended values (Howeler (2002) | Oke-oyi | |
| Elements | 0-15 | 15-30 | | 0-15 | 15-30 |
| pH($H_2O$) | 5.7 | 5.8 | 4.6-7.8 | 5.4 | 6.2 |
| OC (g $kg^{-1}$) | 12.30 | 9.30 | 17.98 | 5.30 | 4.50 |
| N (g $kg^{-1}$) | 0.98 | 0.74 | 4.2 | 0.26 | 0.20 |
| P (mg $kg^{-1}$) | 3.63 | 1.57 | 8 | 13.8 | 4.68 |
| Exchangeable Cations (cmol $kg^{-1}$) | | | | | |
| Ca | 3.00 | 2.74 | 1.0-5.0 | 1.26 | 3.00 |
| Mg | 0.81 | 0.88 | 0.4-1.0 | 0.28 | 0.50 |
| K | 0.08 | 0.16 | 0.15-0.25 | 0.20 | 0.17 |
| Na | 0.07 | 0.07 | <0.5 | 0.06 | 0.07 |
| Exchangeable Acidity | 0.42 | 0.42 | | 0.17 | 0.33 |
| ECEC | 4.38 | 4.26 | | 1.96 | 4.08 |
| Exchangeable micronutrients (cmol $kg^{-1}$) | | | | | |
| Zn | 0.30 | 0.09 | 1.0-5.0 | 0.67 | 0.21 |
| Cu | < 0.01 | < 0.01 | 0.3-1.0 | < 0.01 | < 0.01 |
| Mn | 0.13 | 0.14 | 0.1-1.0 | 0.16 | 0.17 |
| Fe | 0.59 | 0.81 | 0.1-1.0 | 0.55 | 0.69 |
| Particle size distribution (g $kg^{-1}$) | | | | | |
| Gravel content (%) | No stone | No stone | | 2-5 | 10-15 |
| Sand | 730 | 710 | | 850 | 830 |
| Silt | 60 | 60 | | 50 | 50 |
| Clay | 210 | 230 | | 100 | 120 |
| Textural class | Sandy clay loam | Sandy clay loam | | Loamy Sand | Loamy Sand |

**Effects of Harvesting Time on Growth and Yield Parameters of the Two Cassava Varieties**

The above ground biomass, fresh weight of root yield, dry matter production of leaves, and root measured at different harvesting times are presented in Table 6 and Figures 4 to 8.

**Above Ground Biomass at Both Experimental Sites**

The above ground biomass of cassava varieties measured at 8 MAP did not differ significantly among the cassava varieties at Oke-oyi experimental site. Fertilizer application also did not cause any significant increases in the above ground biomass of the different cassava varieties. At Ikenne, however, the above ground biomass of cassava varieties at 8 MAP showed significant difference ($p < 0.05$) in their response to fertilizer application as shown in Figure 4. (TME 419 fertilized with 300 kg $ha^{-1}$ was significantly different from Oko-iyawo with the same fertilizer rate treatment TME 419 with fertilizer application was significantly different ($p<0.05$) from TME 419 non-fertilized and similar trend was observed with Oko-iyawo.

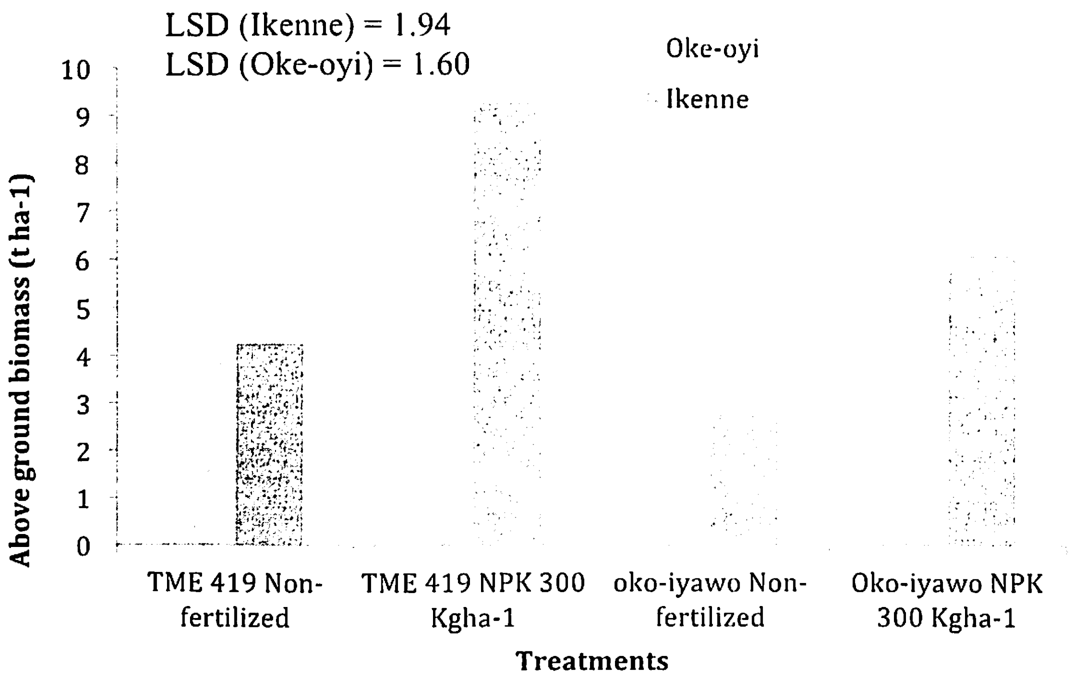


*Figure 5*: Effect of fertilizer application on above ground biomass of two cassava varieties at 8 MAP

**Dry Weights of Foliage**

There was no significant treatment in the dry matter of foliage of cassava varieties at each experimental site at 10 and 12 MAP. Comparing the two experimental sites, it was observed that cassava varieties performed better at Oke-oyi than at Ikenne at 10 and 12 MAP in the amount of foliage dry matter. Fertilizer application did not cause any significant difference in dry matter accumulation of cassava varieties foliage at the two experimental sites at all harvesting time as presented in Table 6.

Table 6: *Effect of Fertilizer Application on Dry Matter Foliage ($t\ ha^{-1}$) of two Cassava Varieties at both Experimental Sites*

| | | Oke-oyi | | Ikenne | |
|---|---|---|---|---|---|
| | | Cassava varieties | | | |
| Harvest time MAP | Treatment | TME 419 | Oko-iyawo | TME 419 | Oko-iyawo |
| 10 | Non-fertilized | 1.26$^{a}$ | 0.59$^{a}$ | 0.04$^{a}$ | 0.40$^{a}$ |
| | NPK 300 $kgha^{-1}$ | 0.63$^{a}$ | 0.97$^{a}$ | 0.40$^{a}$ | 0.77$^{a}$ |
| LSD | | 0.86 | | 0.38 | |
| 12 | Non-fertilized | 1.78$^{a}$ | 1.43$^{a}$ | 0.30$^{a}$ | 0.19$^{a}$ |
| | NPK 300 $kgha^{-1}$ | 1.39$^{a}$ | 2.65$^{a}$ | 0.35$^{a}$ | 0.33$^{a}$ |
| LSD | | 1.25 | | 0.32 | |

Means followed by the same letters in a column are not significantly different at $p< 0.05$ using LSD

**Fresh Weight of Root Yield**

Fresh weight of storage root of cassava varieties did not differ significantly ($p>0.05$) at Oke-oyi across the four harvesting periods (Figure 5). Fertilizer application did not cause significant difference at all harvest periods at Oke-oyi. Though no significant difference was observed Oko-iyawo performed better than TME 419 at 12 MAP at Oke-oyi. However, at Ikenne there was a significant difference in the fresh weight of cassava roots harvested at 8 and 12 MAP, which is indicative of the cassava varieties responding differently to fertilizer application at the different harvesting periods. At 12 MAP, TME 419 with fertilizer application was significantly different ($p<0.05$) from the other treatments. TME 419 performed significantly better than Oko-iyawo at Ikenne. The result is presented in Figure 5and 6.

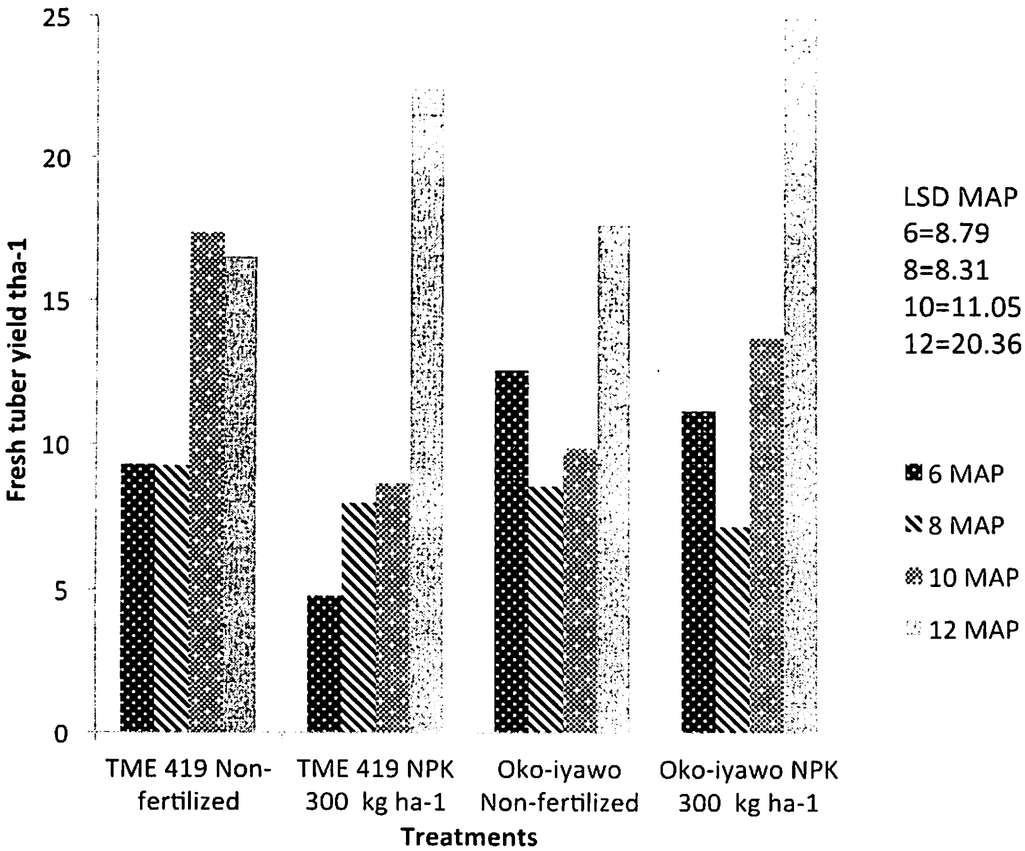


*Figure 6*: Effect of harvesting time and fertilizer application on fresh root yield weight (t $ha^{-1}$) of cassava varieties at Oke-oyi

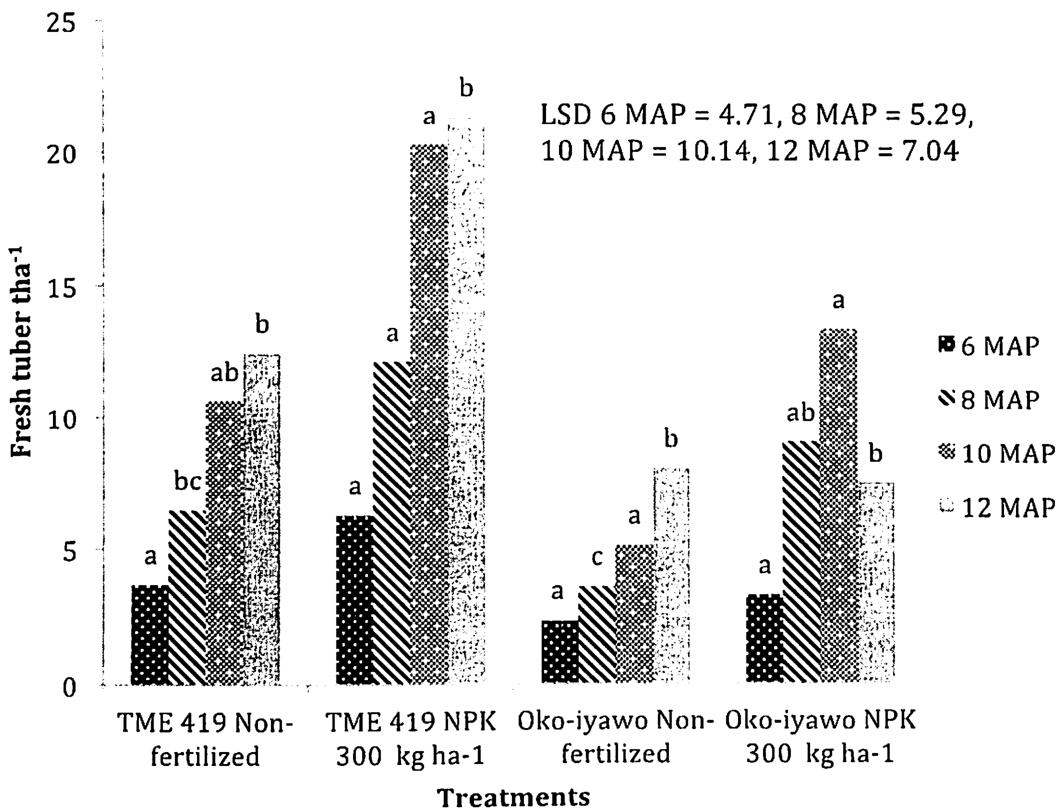


Figure 7: *Effect of harvesting time on fresh root yield (t ha$^{-1}$) of cassava varieties at Ikenne*

**Root Dry Matter Yield**

There was no significant difference (p>0.05) between the cassava varieties and harvesting periods at Oke-oyi experimental site. At Ikenne, there was significant difference (p<0.05) at 8 and 12 MAP. At 12 MAP, TME 419 with fertilizer application was significantly higher than Oko-iyawo with or without fertilizer application as presented in Figures 7 and 8.

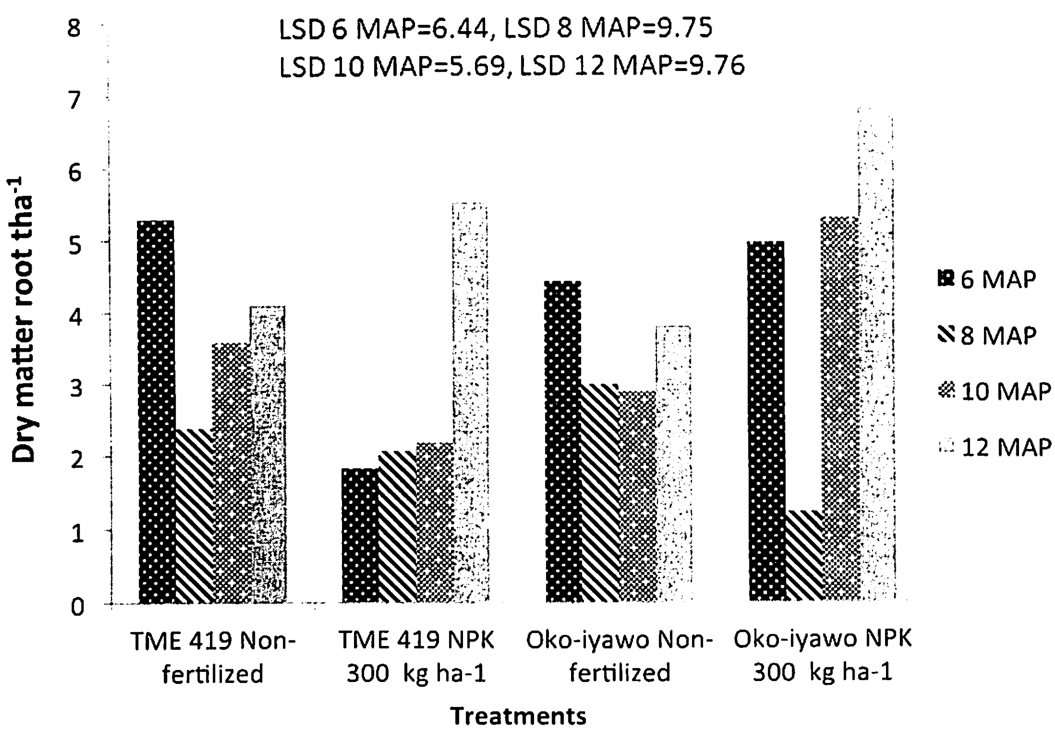


*Figure 8*: Effect of harvesting times on dry matter yield of root at Oke-oyi

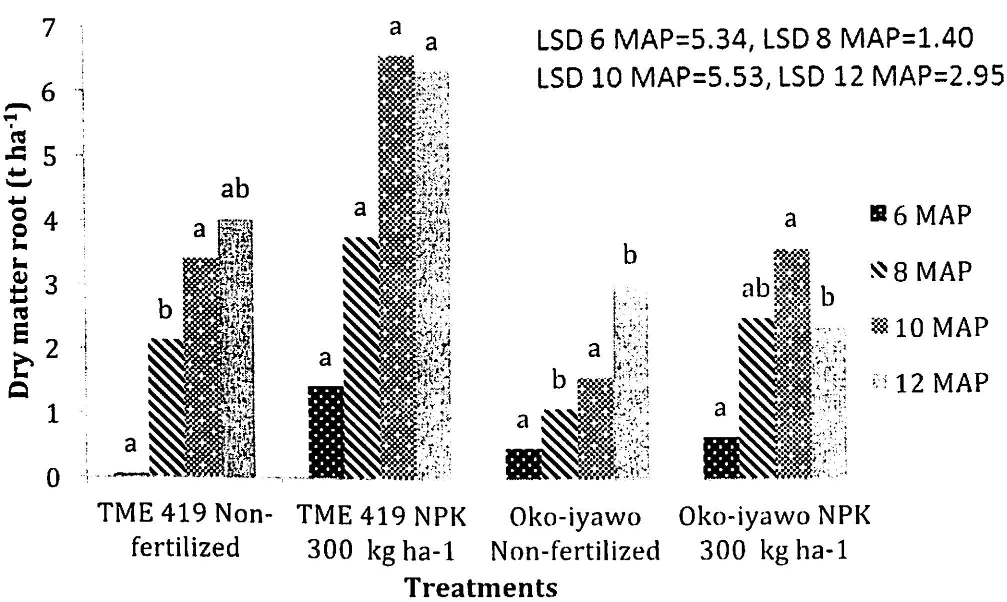


*Figure 9*: Effect of harvesting times on dry matter yield of root at Ikenne

## Effects of Harvesting Time on Cassava Root Quality

The results of the effect of harvesting time on starch content and cyanide concentration of the varieties of cassava at Ikenne and Oke-oyi are presented in Figures 9 to 11

## Cyanide Potential

Cyanide potential of cassava varieties did not differ significantly between the two cassava varieties across harvesting times at Ikenne. At Oke-oyi, there was no significant difference ($p>0.05$) at 10 MAP and fertilizer application also did not cause significant difference. However, at 12 MAP, Oko-iyawo without fertilizer application differed significantly ($p<0.05$) from the other treatments. Oko-iyawo without fertilizer at both experimental sites had higher HCN than other treatments.

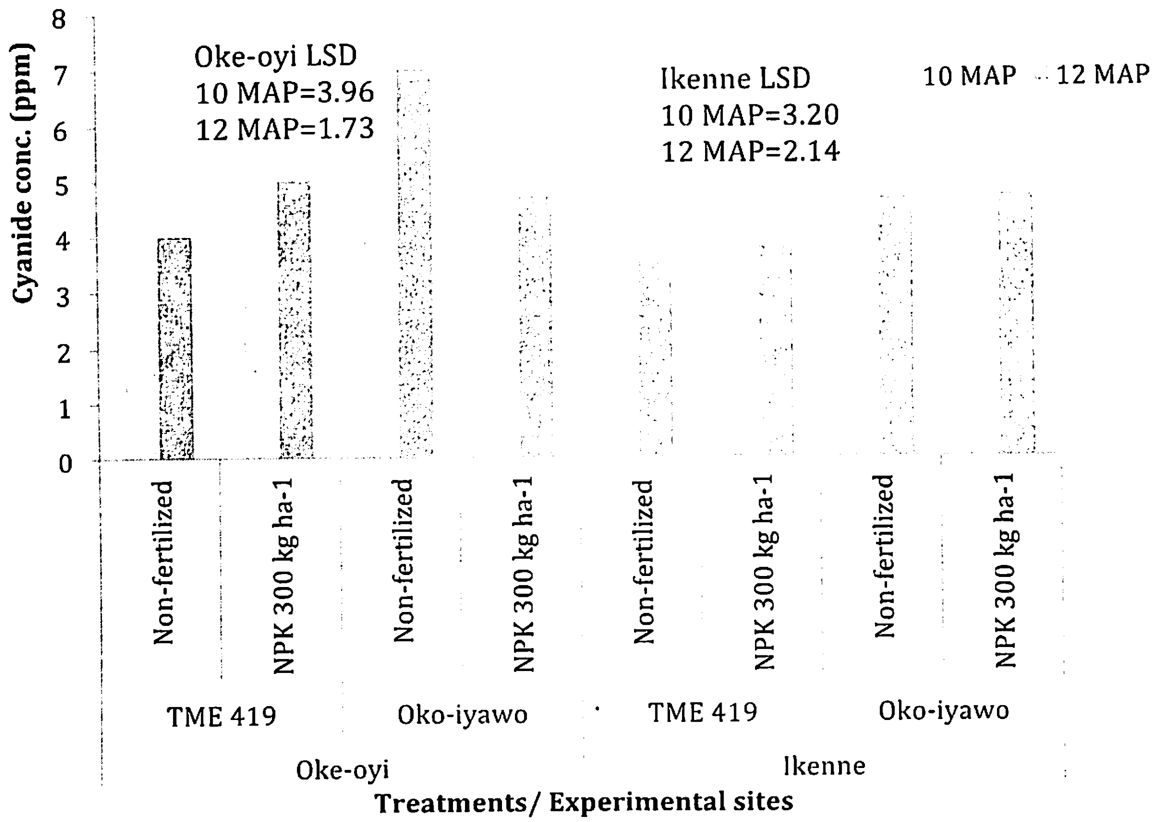


*Figure 10*: Effect of harvesting time on cyanide potential of cassava varieties at both experimental sites

**Cassava Starch Content**

At Oke-oyi the Oko-iyawo variety treated with NPK 15:15:15 fertilizer at a rate of 300 kg ha$^{-1}$ t had highest starch content of 27.7 % at 10 MAP at Oke-oyi . At Ikenne, the result showed that Oko-iyawo non-fertilized had higher starch content at 12 MAP but this was statistically different from the other fertilizer treatments.

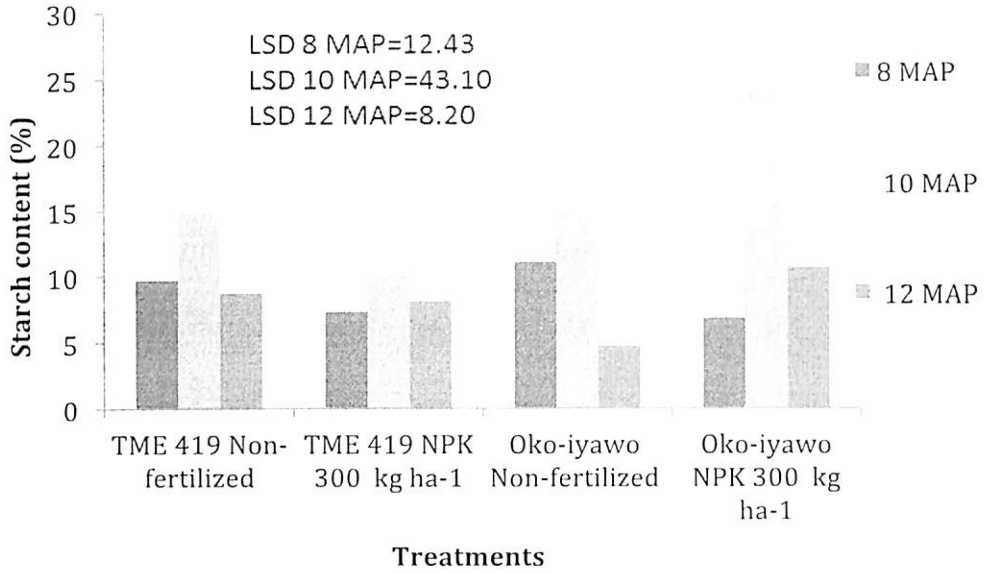


*Figure 11*: Effect of harvesting time on starch content of cassava varieties at Oke-oyi

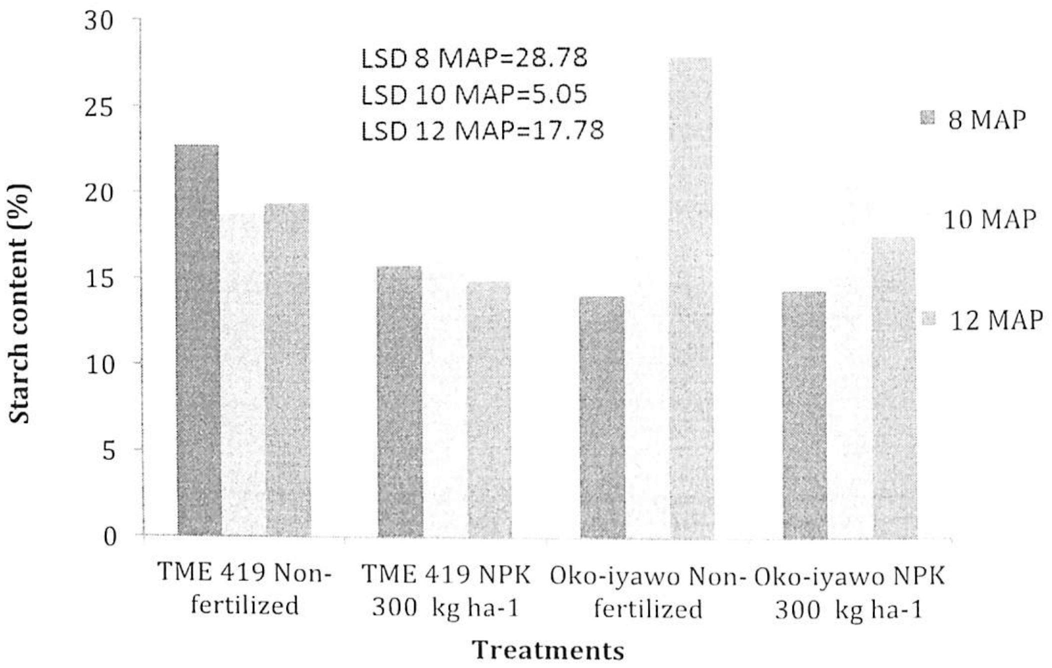


*Figure 12*: Effect of harvesting time on starch content of cassava varieties at Ikenne

## Discussion

The study was carried out to determine the effect of different harvest periods on biomass production, fresh root yield, root dry matter content, hydrogen cyanide concentration and starch contents from the root of two cassava varieties in two agro-ecological zones. It is also to determine the interactive effect of fertilizer application with harvesting time on the above variables. Two cassava varieties were used in this study; TME 419 is an improved variety while Oko-iyawo is a preferred local variety by farmers at the two experimental sites. These varieties exhibited different responses to the various treatments in the study at the two experimental sites.

Oko-iyawo grew faster and produced more biomass at Oke-oyi than TME 419 while TME 419 performed better than Oko-iyawo in biomass production in Ikenne. Fresh root yield at Oke-oyi showed that the two cassava varieties were similar and also followed similar trend at the two locations. TME 419 yielded better than Oko-iyawo at Ikenne. These disparities could also be attributed to inherent varietal differences (IITA, 1990) in these two cassava varieties. This result supports FAO (2013) that niche varieties need to be developed and deployed.

## Above Ground Biomass

The result of above ground biomass of cassava varieties at Ikenne at harvesting times and with fertilizer application agreed with the result of Aderi et al. (2010). At Oke-oyi, harvesting times and fertilizer application were not significant. This result could be due to higher amount of nitrogen in Ikenne soils as shown in Table 5. Nitrogen fertilizers application have been reported to result in increased foliage weight and longer shoot (Wang & Li, 2004; Liu, Sung, Chen, & Lai, 2014).

**Dry Weight of Foliage**

The two cassava varieties showed similar trend at both experimental site as observed in Table 6 for both harvesting times and interaction of harvest time with fertilizer. Though the results were not significant, dry foliage weight was higher at Oke-oyi than at Ikenne.

**Fresh Root Yield**

The fresh root yield of cassava varieties at Oke-oyi were not significant at all harvesting time and with fertilizer application. However, all treatment with fertilizer application performed better at 12 MAP. The result of fresh root yield at Oke-oyi could be due to the fact that cassava varieties are bred without fertilizer application and this can lead to their non-response to fertilizers (Fermont, 2009). This observation has also been reported from other trials (Nnodu et al. 1992; Nnodu & Dixon, 2001; Aderi *et al.* 2010). This is in contrast with the result of Ojeniyi et al. (2009); Ojeniyi et al. (2012), where there was increase in fresh root yield as a result of fertilizer application. At Ikenne harvesting at 8 and 12 MAP were significant with fertilizer application (Ojeniyi et al. (2009); Ojeniyi et al. (2012) for both cassava varieties. TME 419 performed better than Oko-iyawo at all harvest time at Ikenne (FAO, 2013).

### Root Dry Matter Yield

Root dry matter yield at Oke-oyi was not significant at all harvest time and with fertilizer application. Though not significant, dry matter yield was highest at 12 MAP for both cassava varieties with fertilizer application, Oko-iyawo had higher dry matter yield than TME 419 at Oke-oyi.

Root dry matter yield at Ikenne was significant at 8 and 12 MAP. TME 419 with fertilizer application had higher dry matter yield than Oko-iyawo with or without fertilizer application. This result showed that TME 419 at Ikenne partitioned higher dry matter to the root during the growth period as also reported by Connor & Cock (1981); Ekanayake (1993).

### Starch Content

Starch content of cassava varieties showed that Oko-iyawo had higher starch content at both experimental sites. Though not significantly different, the highest starch content at Oke-oyi was at 10 MAP. At Ikenne, the starch content was higher at 12 MAP. Generally, the two cassava varieties produced more starch content at Ikenne than at Oke-oyi.

### Cyanide Concentration

Cyanide concentration of cassava varieties at both sites showed that Oko-iyawo with no fertilizer application had higher HCN. concentration. Sanchez et al. (2009) found out that landraces have higher HCN concentration than improved varieties and in contrast with the conclusion of Raji et al. (2007). At Oke-oyi, Oko-iyawo with no fertilizer application was significant at 12 MAP but was not significant at harvest times at Ikenne. Fertilizer application in this experiment caused a reduced HCN concentration at both experimental sites. This result supports the findings of Bokanga, Ekanayake, Dixon and Porto (1994), that the location effect on cyanogenic potential of cassava varieties is very pronounced.

Fertilizer application caused an increase in the number of storage roots per plant. The response to fertilizer application has also been observed (Kasele, 1980, Fermont, 2009) which also translated to higher cassava yield components, dry matter and fresh root weight. Fertilizer application caused a reduction in cyanogenic potential at both experimental sites, increased in starch content at Oke-oyi and had no effect on starch content at Ikenne.

**Conclusions**

The TME 419 cassava is a better yielding variety at Ikenne (forest-savanna transition agro-ecological zone) while Oko-iyawo is a better yielding variety at Oke-oyi (Southern-guinea savanna agro-ecological zone) in this study.

Harvesting time of cassava has an effect on root quality (starch content and cyanogenic potential) at both agro-ecological zones. Harvesting fresh cassava root at 12 MAP is optimum from this study, for root dry matter yield at Oke-oyi, 12 MAP was optimum while for Ikenne experimental site harvesting can be done between 10 and 12 MAP. Fertilizer application caused increased in parameters measured in this study.

# CHAPTER FIVE

# EFFECTS OF VARIETY, FERTILIZER TYPE AND RATE ON BIOMASS PRODUCTION AND ROOT YIELD OF CASSAVA

## Introduction

Traditionally, in sub-Saharan Africa (SSA), fields have been left to fallow for a number of years, so that the natural vegetation can regrow and for soil fertility to be restored (Vanlauwe et al.et al. 2015), but this practice is no longer feasible. Consequently, the use of external inputs such as fertilizer for soil fertility maintenance in these systems seems inevitable. Fermont (2009) reported that as a result of the growing demand for cassava in the food, fodder and industrial (starch and biofuel) markets, farmers are likely to adopt fertilizer to improve cassava productivity in their farms. Soil fertility depletion has been described as one of the most important constraint to food security in SSA (Vanlauwe et al.). Nutrients are commonly not replaced to the degree that they are removed in crop harvesting and other losses, resulting in highly negative nutrient balances (Fermont et al. 2007).

In Africa, smallholder farmers use little or no fertilizer at all. According to Kelly (2006), smallholder farmers in Africa use an average of 9 kg $ha^{-1}yr^{-1}$ compared with 73 and 135 kg $ha^{-1}yr^{-1}$used in Latin-America and Asia, respectively. Fertilizer is rarely used on cassava due to a common belief that cassava does not need fertilizer. This belief is based on the ability of cassava to yield in areas with low soil fertility where other crops fail. The role of fertilizer in increasing crop yield to feed the ever increasing population has been severally investigated (Agbaje & Akinlosotu, 2004; Makinde et al. 2010). Many authors have found increases in cassava yields due to fertilizer application and they have often recorded higher cassava yields in areas where fertilizer is frequently used (Fermont, 2009; Okpara et al. 2010).

Response of cassava to applied nutrients depends to a large extent on the soil nutrient status at the time of application and a higher response to a particular nutrient element is envisaged when its level in the soil is low (Howeler, 2002). The heterogeneous nature of soils in Africa has strong effects on the crop response to fertilizer due to difference in soil type, historical management and resource allocation (Zingore et al. 2007), soil nutrient status and rainfall regime (Vanlauwe et al. 2006).

The FAO (2013) stated that the full potential of cassava will not be realized until production constraints are mitigated in higher-yielding varieties and cassava growers have access to disease-free planting material. Current average yields are still far lower than cassava's potential. A study by the International Center for Tropical Agriculture (CIAT) in the 1990s estimated conservatively that – with improved crop and soil management, and the use of higher yielding varieties more resistant to drought, pests and diseases – cassava could produce an average of 23.2 tonnes of roots/ ha (FAO, 2013) which will amount to 450 million tonnes a year on the current harvested area. With the growing importance worldwide of cassava as a source of food, animal feed and industrial feedstock, there is increasing demand for cultivars with specific characteristics and adaptation to different ecologies. Niche varieties need to be developed and deployed to cater to increasingly diverse and competing end uses.

Although the landraces gave lower yields than the elite cultivars, they carried genes for adaptation to local conditions, and have preferred root quality attributes that can be introgressed into elite germplasm development (Raji, Ladeinde, & Dixon, 2007). Some African germplasm also have been used as sources of resistance to major pest and diseases particularly the cassava mosaic disease (CMD), cassava bacterial blight (Mignouna & Dixon, 1997) and more recently, the cassava brown streak disease (CBSD). However, these landraces are often low yielding and thus cannot compete with improved cultivars of major crops for arable lands. Nonetheless, a number of African cassava landraces have been reported to possess certain agronomic and food quality characteristics that could be potentially utilized for root quality and productivity improvement (Raji, 2003).

Scientific improvement of cassava started some few decades ago thus, the divergence between landraces and improved germplasm is not wide as in other crops (FAO, 2007). Strong emphasis is placed on heritable traits such as plant type, branching habits and reaction to disease, harvest index and dry matter content (Hahn *et al.* 1979) and later low heritability traits as root yield (Eke-okoro & Njoku, 2012). The genetic diversity and observed herozygosity in landraces were slightly higher than in elite accessions (Turyagyenda et al. 2012).

The current research efforts are geared towards developing not only high yielders but also rapid tuber bulking and early types (6 to 9 months) and high starch content. The early maturing types produce yields of 28-30 tonnes or more (Chadha, 2007). The number of roots which eventually form tubers as well as earliness of tuber bulking and maturity may depend on the genotype assimilates supply, photoperiod, and temperature (Akoroda, 2005). The process of tuber formation and maturity may also depend on soil water supply, soil fertility and soil temperature (Ikpi et al. 1986).

There are varieties of shapes and number and form of the root tubers produced, depending on the cassava variety. The sink is an important trait of ideotype. Actually, tuber yield depends not only on an adequate production of photosynthate but also on an adequate and strong sink to accept it. The sink strength is by and large determined by the tuber size and bulking capacity and an increase in either component could enhance the power of the sink (Sharma, 1996). The rate of tuber bulking for most cultivars is determined early in the growing season from both environmental and physiological factors.

There is a high variability in cassava response to fertilizer application even on infertile soils, indicating interactions between factors which should be considered when choosing and developing fertilizer recommendations and models (Fermont et al. 2010). This however requires a careful consideration of the fertilizer type, rate, as well as fertilizer materials, before application of fertilizer to cassava.

The specific objective of the study is to:

- Determine yield and total dry matter responses of different cassava varieties to the application of different fertilizer types and rates in two agro-ecological zones

## Materials and Methods

### Experimental Sites

Description of the study sites, climate, vegetation, geology and soil, soil sampling and characterization are as described in Chapter 3

### Soil Chemical Analysis: as described in Chapter 3

### Experimental Materials

#### *Cassava Varieties: as described in Chapter 3 and table 4*

#### *Fertilizers Used*

In this experiment, three inorganic NPK fertilizers (NPK 15-15-15, NPK 20-10-10 and NPK 12-12-17) were applied at two rates (150 kg $ha^{-1}$ and 300 kg $ha^{-1}$) as described in Chapter 3

### Cultural Practices

All cultural practices were as described in Chapter 3.

### Experimental Design, Treatments and Field Layout: as described in Chapter 3

### Field Measurement of Crop Parameters

As described in Chapter 3

**Statistical Analysis: as described in Chapter 3**

**Results**

The results of the interactive effect of variety, fertilizer type and rate on growth rate, bulking rate and yield of cassava on dry biomass productivity of foliage, stem, above ground biomass and root at the two experimental sites are shown in Tables 7 to 31and Figures 13 to 16.

**Dry Matter of Foliage (%)**

***Variety***

The results presented in Tables 7 and 8 showed the effect of cassava varieties on dry matter of foliage. At Oke-oyi, there was no significant difference among the cassava varieties at 10 and 12 MAP. At 10 MAP, TMS 98/0505 had the highest while TMS 91/02324 had the lowest dry matter accumulation in foliage. The reverse was observed at 12 MAP where TMS 91/02324 has the highest dry matter in the foliage and TMS 98/0505 has the lowest dry matter. At Ikenne, cassava varieties were significantly different only at 10 and 12 MAP. TMS 96/1632 and TME 419 gave the highest dry matter accumulation at 10 and 12 MAP respectively. There was an observed gradual reduction in the dry matter of foliage from 6 to 12 MAP at Ikenne.

Table 7: *Effect of Variety on Dry Matter Content of Cassava Foliage at Oke-oyi*

| | Months after planting | | | |
|---|---|---|---|---|
| | Dry matter foliage (%) | | Dry matter stem (%) | |
| Variety | 10 | 12 | 10 | 12 |
| TME 419 | 29.77[a] | 34.93[a] | 30.43[ab] | 27.13[a] |
| Oko-iyawo | 29.59[a] | 36.19[a] | 25.96[c] | 23.64[b] |
| TMS 98/0505 | 31.22[a] | 33.17[a] | 28.72[b] | 26.63[a] |
| TMS 96/1632 | 30.62[a] | 36.15[a] | 30.71[ab] | 25.25[ab] |
| TMS 30572 | 30.33[a] | 34.89[a] | 31.39[a] | 25.03[ab] |
| TMS 91/02324 | 29.16[a] | 37.26[a] | 25.20[c] | 25.27[ab] |
| LSD | 2.13 | 5.28 | 2.58 | 2.91 |

Means followed by the same letter (s) in a column are not significantly different (p> 0.05) level of probability using LSD

Table 8: *Effect of Varieties on Foliage Dry Matter (%) at Ikenne*

| | Months after planting | | | |
|---|---|---|---|---|
| Variety | 6 | 8 | 10 | 12 |
| TME 419 | 37.93[a] | 33.89[a] | 33.72[bc] | 26.03[a] |
| Oko-iyawo | 35.10[a] | 34.76[a] | 30.55[d] | 23.43[ab] |
| TMS 98/0505 | 39.39[a] | 34.78[b] | 34.11[bc] | 24.82[ab] |
| TMS 96/1632 | 35.99[a] | 34.86[a] | 36.52[a] | 18.85[b] |
| TMS 30572 | 36.14[a] | 36.36[a] | 34.93[ab] | 22.69[ab] |
| TMS 91/02324 | 36.86[a] | 38.65[a] | 32.42[cd] | 22.68[ab] |
| LSD | 4.81 | 6.70 | 1.97 | 6.25 |

Means followed by the same letter (s) in a column are not significantly different (p> 0.05) level of probability using LSD

*Fertilizer Rate and Fertilizer Type*

The results presented in Tables 9 and 10 show the effect of fertilizer rate and fertilizer type on dry matter of cassava foliage. No significant difference was observed in the cassava foliage following application of different rates of fertilizer; however, at an application rate of 300 kg $ha^{-1}$ the fertilizer treated cassava had the highest dry matter of foliage at all harvesting times at Oke-oyi. At Ikenne, there was no significant difference in plant foliage in terms of the rates of fertilizer applied at 6, 8 and 12 MAP, but foliage in the NPK 300 kg $ha^{-1}$ treatment was significantly different from the non-fertilized at 10 MAP.

At Oke-oyi, NPK 15-15-15 was significantly different from all the other fertilizer treatment at 10 MAP. At 12 MAP, NPK 15-15-15 differ significantly from NPK 12-12-17 and non-fertilized. At Ikenne, fertilizer type did not show any significant difference at all harvesting times. However, NPK 15-15-15 performed better than the other fertilizer type at 6, 10 and 12 MAP. At Ikenne, interaction between fertilizer type and fertilizer rate was significant only at 10 MAP ($p < 0.01$). Fertilizer type x fertilizer rate x variety interaction was significant only at 10 MAP. Fertilizer type x variety and fertilizer rate x variety did not show any significant difference at all the harvesting periods. There was no observed interaction among fertilizer rate, fertilizer type and variety at Oke-oyi.

Table 9: *Effect of Fertilizer Rate and Fertilizer Type on Dry Matter of Foliage and Stem at Oke-oyi*

| | Months after planting | | | |
|---|---|---|---|---|
| | Dry Matter Leaves (%) | | Dry Matter Stem (%) | |
| Fertilizer Rate | 10 | 12 | 10 | 12 |
| Non-fertilized | 29.40[a] | 34.54[a] | 31.72[a] | 24.47[a] |
| NPK 150kg $ha^{-1}$ | 29.86[a] | 34.95[a] | 27.83[b] | 26.25[a] |
| NPK 300kg $ha^{-1}$ | 30.93[a] | 36.42[a] | 29.25[b] | 25.14[a] |
| LSD | 1.65 | 3.77 | 2.09 | 2.24 |
| Fertilizer Type | 10 | 12 | 10 | 12 |
| Non-fertilized | 29.41[b] | 34.54[b] | 31.73[a] | 24.47[a] |
| NPK 15-15-15 | 32.00[a] | 39.26[a] | 26.04[b] | 25.76[a] |
| NPK 20-10-10 | 29.89[b] | 35.76[ab] | 29.83[a] | 26.12[a] |
| NPK 12-12-17 | 29.32[b] | 33.52[b] | 29.69[a] | 25.35[a] |
| LSD | 1.77 | 4.36 | 2.19 | 2.41 |

Means followed by the same letter (s) in a column for the same factor are not significantly different p> 0.05 level of probability using LSD

Table 10: *Effect of Fertilizer Rate and Fertilizer Type on Foliage Dry Matter (%) at Ikenne*

| | Months after planting | | | |
|---|---|---|---|---|
| Fertilizer rate | 6 | 8 | 10 | 12 |
| Non-fertilized | 37.41[a] | 38.56[a] | 33.33[ab] | 20.30[a] |
| NPK 150kg $ha^{-1}$ | 38.67[a] | 35.85[a] | 32.75[b] | 23.14[a] |
| NPK 300kg $ha^{-1}$ | 34.77[a] | 34.49[a] | 34.85[a] | 23.93[a] |
| LSD | 4.02 | 5.13 | 1.58 | 5.03 |
| Fertilizer Type | 6 | 8 | 10 | 12 |
| Non-fertilized | 37.42[a] | 38.56[a] | 33.34[a] | 20.30[a] |
| NPK 15-15-15 | 37.49[a] | 35.30[a] | 34.30[a] | 24.04[a] |
| NPK 20-10-10 | 35.14[a] | 35.56[a] | 33.78[a] | 23.85[a] |
| NPK 12-12-17 | 37.40[a] | 34.36[a] | 33.04[a] | 22.56[a] |
| LSD | 4.18 | 5.54 | 1.68 | 5.34 |

Means followed by the same letter (s) in a column for the same factor are not significantly different p> 0.05 level of probability using LSD.

**Dry Matter Stem (%)**

***Variety***

The result presented in Tables 7 and 10 shows the effect of varieties on dry matter of cassava stem. At Oke-oyi, dry matter accumulations of cassava varieties stem differ significantly at 10 and 12 MAP. At 10 MAP, TMS 30572 had the highest dry matter accumulation in the stem followed by TMS 96/96/1632, TME 419, TMS 98/0505, Oko-iyawo and TMS 91/02324 in descending order. TMS 30572 was significantly difference from TMS 98/0505. At 12 MAP, TME 419 had the highest dry matter stem was significantly different only from Oko-iyawo. At Ikenne, there was significant difference observed with dry weight of cassava varieties stem at all harvesting time. Dry weight of stem gradually decreased from 6 to 10 MAP and then increased at 12 MAP for all cassava varieties. TMS 98/0505 was significantly different from TMS 30572 at 6 MAP, TMS 30572 was significantly different from TMS 98/0505 at 8 MAP, TMS 96/1632 differ significantly from TME 419 at 10 MAP and TMS 98/0505 was significantly different from TMS 91/02324 at 12 MAP.

Table 10: *Effect of Cassava Varieties on Stem Dry Matter (%) at Ikenne*

| | Months after planting | | | |
|---|---|---|---|---|
| Variety | 6 | 8 | 10 | 12 |
| TME 419 | $34.83^{ab}$ | $28.55^{ab}$ | $23.70^{bc}$ | $26.03^{a}$ |
| Oko-iyawo | $34.67^{ab}$ | $27.02^{c}$ | $23.13^{c}$ | $24.82^{c}$ |
| TMS 98/0505 | $35.43^{a}$ | $27.81^{b}$ | $24.28^{ab}$ | $27.92^{a}$ |
| TMS 96/1632 | $35.82^{a}$ | $29.80^{ab}$ | $25.18^{a}$ | $26.05^{ab}$ |
| TMS 30572 | $32.81^{bc}$ | $30.87^{a}$ | $21.70^{d}$ | $27.77^{ab}$ |
| TMS 91/02324 | $31.59^{c}$ | $26.90^{c}$ | $21.55^{c}$ | $25.91^{b}$ |
| LSD | 2.48 | 2.66 | 1.12 | 1.90 |

Means followed by the same letter (s) in a column are not significantly different $p > 0.05$ level of probability using LSD.

### ***Fertilizer Rate and Fertilizer Type***

The results presented in Tables 9 and 11 show the effect of fertilizer rate and fertilizer types on dry matter of cassava stem. Non-fertilized (control) was significantly different from the other rates of fertilizer application at 10 MAP. There was no significant difference at 12 MAP but it was observed that NPK 150 kg $ha^{-1}$ gave the highest stem dry matter at Oke-oyi. At Ikenne, there was no significant difference in the rate of fertilizer applied at 6 to 10 MAP. At 12 MAP, NPK 150 kg $ha^{-1}$ differs significantly from non-fertilized.

At Oke-oyi, Fertilizer type follows a similar trend as fertilizer rate in stem dry matter. Non-fertilized was significantly different from NPK 15-15-15 at 10 MAP. Though not significantly different, NPK 20-10-10 gave the highest dry matter yield at 12 MAP while at Ikenne, there was significant difference with fertilizer type at 6, 10 and 12 MAP. At 6 MAP, non-fertilized gave the highest stem dry matter and significantly difference from NPK fertilizers. NPK 20-10-10 was significantly difference from NPK 12-12-17 while NPK 15-15-15 was significantly different from non-fertilized at 10 and 12 MAP respectively. There was no observed interaction among fertilizer type, fertilizer rate and variety at all harvesting times at both experimental sites.

Table 11: *Effect of Fertilizer Rate and Fertilizer Type on Stem Dry Matter (%) at Ikenne*

| | Months after planting | | | |
|---|---|---|---|---|
| Fertilizer rate | 6 | 8 | 10 | 12 |
| Non-fertilized | 37.67[a] | 27.66[a] | 23.25[a] | 25.33[b] |
| NPK 150kg $ha^{-1}$ | 33.73[b] | 29.16[a] | 23.11[a] | 26.97[a] |
| NPK 300kg $ha^{-1}$ | 33.51[b] | 28.34[a] | 23.26[a] | 26.60[ab] |
| LSD | 1.98 | 2.14 | 0.91 | 1.50 |
| | | | | |
| Fertilizer Type | 6 | 8 | 10 | 12 |
| Non-fertilized | 37.68[a] | 27.66[a] | 23.25[ab] | 25.34[b] |
| NPK 15-15-15 | 35.27[b] | 29.76[a] | 22.97[ab] | 27.30[a] |
| NPK 20-10-10 | 33.33[bc] | 28.60[a] | 23.89[a] | 26.43[ab] |
| NPK 12-12-17 | 32.28[c] | 28.02[a] | 22.71[b] | 26.68[ab] |
| LSD | 2.11 | 2.26 | 0.96 | 1.60 |

Means followed by the same letter (s) in a column for the same factor are not significantly different p> 0.05 level of probability using LSD.

## Above Ground Biomass

### *Variety*

The above ground biomass weight at Oke-oyi (Table 12) for varieties was significant at all harvesting times. TMS 98/0505 had the highest above ground biomass weight at 6 and 8 MAP; TMS 30572 had the highest weight at 10 and 12 MAP respectively. TMS 91/02324 had the lowest above ground weight and was significantly lower than TMS 98/0505 and TMS 30572 at all harvesting times. At Ikenne, however, TME 419 had the highest above ground biomass at 8 and 12 MAP while TMS 98/0505 had the highest above ground biomass weight at 10 MAP. TMS 91/02324 had the lowest above ground biomass weight and was significantly lower than TME 419 at 8 and 12 MAP as presented in table 13.

Table 12: *Effect of Variety on Fresh Above Ground Biomass ($t\ ha^{-1}$) at Oke-oyi*

| | Months after planting | | | |
|---|---|---|---|---|
| Variety | 6 | 8 | 10 | 12 |
| TME 419 | $4.35^{ab}$ | $4.18^{bc}$ | $6.29^{abc}$ | $13.95^{ab}$ |
| Oko-iyawo | $4.03^{ab}$ | $4.37^{ab}$ | $6.39^{abc}$ | $15.50^{a}$ |
| TMS 98/0505 | $5.64^{a}$ | $5.25^{a}$ | $7.42^{ab}$ | $13.96^{ab}$ |
| TMS 96/1632 | $4.43^{ab}$ | $3.25^{d}$ | $5.68^{bc}$ | $11.06^{b}$ |
| TMS 30572 | $5.43^{a}$ | $5.00^{ab}$ | $8.25^{a}$ | $17.50^{a}$ |
| TMS 91/02324 | $3.15^{b}$ | $3.43^{cd}$ | $4.99^{c}$ | $10.62^{b}$ |
| LSD | 1.87 | 0.88 | 2.25 | 3.62 |

Means followed by the same letter (s) in a column are not significantly different p> 0.05 level of probability using LSD.

Table 13: *Effect of Cassava Varieties on Fresh Above Ground Biomass ($t\ ha^{-1}$) at Ikenne*

| | Months after planting | | | |
|---|---|---|---|---|
| Variety | 6 | 8 | 10 | 12 |
| TME 419 | $4.54^{ab}$ | $4.80^{a}$ | $8.64^{a}$ | $7.52^{a}$ |
| Oko-iyawo | $4.06^{ab}$ | $3.91^{ab}$ | $8.56^{a}$ | $5.79^{ab}$ |
| TMS 98/0505 | $4.83^{a}$ | $3.69^{b}$ | $9.14^{a}$ | $6.60^{ab}$ |
| TMS 96/1632 | $3.65^{b}$ | $2.50^{c}$ | $6.88^{a}$ | $5.05^{b}$ |
| TMS 30572 | $3.75^{b}$ | $4.60^{ab}$ | $7.74^{a}$ | $6.66^{ab}$ |
| TMS 91/02324 | $3.99^{ab}$ | $4.56^{ab}$ | $8.32^{a}$ | $6.06^{ab}$ |
| LSD | 1.02 | 1.02 | 2.87 | 1.79 |

Means followed by the same letter (s) in a column for the same factor are not significantly different $p > 0.05$ level of probability using LSD.

***Fertilizer Rate and Fertilizer Type***

There was no significant difference observed among the different rates of fertilizer applied at 6, 10 and 12 MAP however; NPK 300 kg $ha^{-1}$ had the highest above ground biomass at all harvest times. NPK 300 kg $ha^{-1}$ was significantly different from non-fertilized at 8 MAP at Oke-oyi as shown in Table 14. At Ikenne, NPK 300 kg $ha^{-1}$ and was significantly different from non-fertilized at 8 MAP. Though not significantly different, NPK 150 kg $ha^{-1}$ had higher weighs than other rates at 10 and 12 MAP (Table 15).

Fertilizer type did not differ significantly at 6 and 12 MAP. NPK 12-12-17 was significantly different from non-fertilized at 8 MAP and all the other fertilizer types at 10 MAP, however, there was significant difference between NPK 12-12-17 and non-fertilized at 8 MAP (Table 14). However, at Ikenne, all NPK fertilizer treatments were significantly different from non-fertilized at 8 MAP. (Table 15) There was no significant difference among the fertilizer types at 10 MAP while

NPK 12-12-17 was significantly different from non-fertilized treatment. There was no significant interaction among fertilizer type, fertilizer rate and cassava varieties at both experimental sites at the four harvesting times.

Table 14: *Effect of Fertilizer Rate and Type on Fresh above Ground Biomass at Oke-oyi*

| | Months after planting | | | |
|---|---|---|---|---|
| Fertilizer rate | 6 | 8 | 10 | 12 |
| Non-fertilized | 4.62ᵃ | 3.60ᵇ | 6.50ᵃ | 13.77ᵃ |
| NPK 150kg $ha^{-1}$ | 4.53ᵃ | 4.24ᵃᵇ | 6.21ᵃ | 12.80ᵃ |
| NPK 300kg $ha^{-1}$ | 4.63ᵃ | 4.43ᵃ | 6.80ᵃ | 14.73ᵃ |
| LSD | 1.49 | 0.71 | 1.83 | 3.54 |
| | | | | |
| Fertilizer Type | 6 | 8 | 10 | 12 |
| Non-fertilized | 4.63ᵃ | 3.61ᵇ | 5.81ᵇ | 14.59ᵃ |
| NPK 15-15-15 | 4.99ᵃ | 4.16ᵃᵇ | 6.33ᵇ | 12.81ᵃ |
| NPK 20-10-10 | 3.82ᵃ | 4.11ᵃᵇ | 6.07ᵇ | 13.39ᵃ |
| NPK 12-12-17 | 4.95ᵃ | 4.73ᵃ | 7.46ᵃ | 14.63ᵃ |
| LSD | 1.58 | 0.76 | 1.12 | 6.55 |

Means followed by the same letter (s) in a column for the same factor are not significantly different p> 0.05 level of probability using LSD

Table 15: *Effect of Fertilizer Rate and Type on Fresh Above Ground Biomass at Ikenne*

| | Months after planting | | |
|---|---|---|---|
| Fertilizer rate | 8 | 10 | 12 |
| Non-fertilized | $3.08^{b}$ | $8.21^{a}$ | $6.28^{a}$ |
| NPK 150kg $ha^{-1}$ | $4.36^{a}$ | $8.58^{a}$ | $6.46^{a}$ |
| NPK 300kg $ha^{-1}$ | $3.94^{a}$ | $7.85^{a}$ | $6.09^{a}$ |
| LSD | 0.81 | 2.07 | 1.45 |
| Fertilizer Type | 8 | 10 | 12 |
| Non-fertilized | $3.08^{b}$ | $8.51^{a}$ | $5.37^{b}$ |
| NPK 15-15-15 | $3.99^{a}$ | $8.23^{a}$ | $6.16^{ab}$ |
| NPK 20-10-10 | $4.33^{a}$ | $7.80^{a}$ | $6.63^{a}$ |
| NPK 12-12-17 | $4.16^{a}$ | $8.46^{a}$ | $6.50^{a}$ |
| LSD | 0.86 | 2.81 | 1.11 |

Means followed by the same letter(s) in a column for the same factor are not significantly different p> 0.05 level of probability using LSD.

## Harvest Index (HI)

### *Variety*

Cassava varieties at Oke-oyi as shown in Table 16 were significantly different ($p<0.05$) at all harvesting times. TME 419 had the highest HI at 6 MAP, TMS 98/0505 at 10 MAP and TMS 96/1632, had the highest HI at 8 and 12 MAP. They were all significantly different from TMS 91/02324 which had the lowest harvest index at all harvesting times at Oke-oyi. The result presented in table 17 shows the effect of cassava varieties on HI at Ikenne, TMS 98/0505, TMS 96/1632 had the highest HI at 6 and 8 MAP respectively while TMS 91/02324 had the highest HI at 10 and 12 MAP and are all significantly different from Oko-iyawo which had the lowest HI at harvesting times.

Table 16: *Effect of Cassava Varieties on Harvest Index at Oke-oyi*

| | Months after planting | | | |
|---|---|---|---|---|
| Variety | 6 | 8 | 10 | 12 |
| TME 419 | $0.64^{a}$ | $0.68^{a}$ | $0.57^{ab}$ | $0.60^{a}$ |
| Oko-iyawo | $0.54^{ab}$ | $0.62^{ab}$ | $0.55^{ab}$ | $0.52^{b}$ |
| TMS 98/0505 | $0.56^{a}$ | $0.70^{a}$ | $0.63^{a}$ | $0.62^{a}$ |
| TMS 96/1632 | $0.56^{a}$ | $0.72^{a}$ | $0.59^{a}$ | $0.65^{a}$ |
| TMS 30572 | $0.58^{a}$ | $0.70^{a}$ | $0.46^{b}$ | $0.51^{bc}$ |
| TMS 91/02324 | $0.39^{b}$ | $0.54^{b}$ | $0.33^{c}$ | $0.45^{c}$ |
| LSD | 0.16 | 0.12 | 0.12 | 0.07 |

Means followed by the same letter (s) in a column are not significantly different $p > 0.05$ level of probability using LSD.

Table 17: *Effect of Cassava Varieties on Harvest Index at Ikenne*

| | Months after planting | | | |
|---|---|---|---|---|
| Variety | 6 | 8 | 10 | 12 |
| TME 419 | $0.44^{bc}$ | $0.52^{c}$ | $0.55^{a}$ | $0.59^{a}$ |
| Oko-iyawo | $0.38^{c}$ | $0.53^{c}$ | $0.39^{b}$ | $0.57^{a}$ |
| TMS 98/0505 | $0.56^{a}$ | $0.63^{ab}$ | $0.57^{a}$ | $0.64^{a}$ |
| TMS 96/1632 | $0.48^{b}$ | $0.70^{a}$ | $0.51^{a}$ | $0.66^{a}$ |
| TMS 30572 | $0.42^{bc}$ | $0.57^{bc}$ | $0.54^{a}$ | $0.66^{a}$ |
| TMS 91/02324 | $0.42^{bc}$ | $0.57^{bc}$ | $0.57^{a}$ | $0.67^{a}$ |
| LSD | 0.08 | 0.09 | 0.10 | 0.11 |

Means followed by the same letter (s) in a column are not significantly different $p > 0.05$ level of probability using LSD.

***Fertilizer Rates and Fertilizer Types***

There was no significant difference among the different fertilizer rates at both experimental locations. However, 300 kg $ha^{-1}$ had the highest HI at harvest times at both locations (Tables 18 and 19).

At Oke-oyi, fertilizer types did not show any significant difference at harvesting times except at 10 MAP (Table 18). NPK 20-10-10 had the highest HI among the fertilizer types at harvesting times though not significantly different however, NPK 12-12-17 at 10 MAP had the highest HI and was significantly different from NPK 20-10-10. In table 19, at Ikenne, there was no significant difference among the fertilizer types except at 8 MAP where non-fertilized was significantly different from NPK 20-10-10. Though not significantly different, NPK 12-12-17 had the highest HI at 6 and 12 MAP respectively. There was no interaction observed among the factors under study.

Table 18: *Effect of Fertilizer Rate and Fertilizer Type on Harvest Index at Oke-oyi*

| | Months after planting | | | |
|---|---|---|---|---|
| Fertilizer rate | 6 | 8 | 10 | 12 |
| Non-fertilized | 0.54[a] | 0.66[a] | 0.52[a] | 0.56[a] |
| NPK 150kg ha$^{-1}$ | 0.56[a] | 0.63[a] | 0.50[a] | 0.55[a] |
| NPK 300kg ha$^{-1}$ | 0.53[a] | 0.69[a] | 0.54[a] | 0.57[a] |
| LSD | 0.11 | 0.16 | 0.11 | 0.07 |
| Fertilizer Type | 6 | 8 | 10 | 12 |
| Non-fertilized | 0.55[a] | 0.65[a] | 0.48[b] | 0.56[a] |
| NPK 15-15-15 | 0.57[a] | 0.68[a] | 0.53[ab] | 0.54[a] |
| NPK 20-10-10 | 0.57[a] | 0.69[a] | 0.48[b] | 0.59[a] |
| NPK 12-12-17 | 0.49[a] | 0.62[a] | 0.56[a] | 0.54[a] |
| LSD | 0.25 | 0.18 | 0.07 | 0.08 |

Means followed by the same letter (s) in a column are not significantly different p> 0.05 level of probability using LSD.

Table 19: *Effect of Fertilizer Rate and Fertilizer Type on Harvest Index at Ikenne*

| | Months after planting | | | |
|---|---|---|---|---|
| Fertilizer rate | 6 | 8 | 10 | 12 |
| Non-fertilized | 0.45[a] | 0.60[a] | 0.52[a] | 0.63[a] |
| NPK 150kg ha$^{-1}$ | 0.44[a] | 0.61[a] | 0.52[a] | 0.61[a] |
| NPK 300kg ha$^{-1}$ | 0.47[a] | 0.56[a] | 0.53[a] | 0.65[a] |
| LSD | 0.06 | 0.11 | 0.09 | 0.11 |
| Fertilizer Type | 6 | 8 | 10 | 12 |
| Non-fertilized | 0.44[a] | 0.63[a] | 0.47[a] | 0.60[a] |
| NPK 15-15-15 | 0.46[a] | 0.61[ab] | 0.56[a] | 0.64[a] |
| NPK 20-10-10 | 0.43[a] | 0.56[b] | 0.49[a] | 0.61[a] |
| NPK 12-12-17 | 0.48[a] | 0.56[b] | 0.55[a] | 0.66[a] |
| LSD | 0.11 | 0.05 | 0.11 | 0.09 |

Means followed by the same letter (s) in a column are not significantly different p> 0.05 level of probability using LSD.

**Fresh Storage Root Yield**

***Variety***

At Oke-oyi, there was significant difference for fresh storage root yield among the varieties ($p<0.05$) at 6 to 12 MAP (Table 20). The highest fresh storage tuber yield was observed in TMS 98/0505 at 6, 8 and 12 MAP. The difference in weight gain among the cassava varieties between 8 and 10 MAP was small. All cassava varieties tend to double storage root yield weight from 10 to 12 MAP as shown in Table 20. At Ikenne, Fresh storage root yield of cassava varieties showed significant difference ($p<0.05$) at 8 and 10 MAP (Table 21). TMS 98/0505 gave the highest storage root weight at 6, 8 and 10 MAP while TMS 91/02324 had the highest storage root yield at 12 MAP. Oko-iyawo had the lowest storage root yield at harvesting times at Ikenne (Table 21).

Table 20: *Effect of Variety on Storage Root Yield of Cassava (t ha$^{-1}$) at Oke-oyi*

| | Months after planting | | | |
|---|---|---|---|---|
| Variety | 6 | 8 | 10 | 12 |
| TME 419 | $11.08^{b}$ | $10.60^{ab}$ | $10.75^{bc}$ | $21.54^{ab}$ |
| Oko-iyawo | $8.15^{c}$ | $8.85^{bc}$ | $9.38^{c}$ | $19.90^{ab}$ |
| TMS 98/0505 | $13.40^{a}$ | $12.32^{a}$ | $12.85^{ab}$ | 23.98a |
| TMS 96/1632 | $9.00^{bc}$ | $9.88^{bc}$ | $11.54^{bc}$ | $20.61^{ab}$ |
| TMS 30572 | $10.01^{bc}$ | $9.21^{bc}$ | $10.68^{bc}$ | $17.77^{b}$ |
| TMS 91/02324 | $7.97^{c}$ | $7.85^{c}$ | $15.36^{a}$ | $22.28^{ab}$ |
| LSD | 2.30 | 2.13 | 3.38 | 5.21 |

Means followed by the same letter (s) in a column are not significantly different p> 0.05 level of probability using LSD.

Table 21: *Effect of Varieties on Storage Root Yield (t ha$^{-1}$) at Ikenne*

| | Months after planting | | | |
|---|---|---|---|---|
| Variety | 6 | 8 | 10 | 12 |
| TME 419 | $4.31^{bc}$ | $6.13^{bc}$ | $10.95^{bc}$ | $12.76^{b}$ |
| Oko-iyawo | $2.93^{d}$ | $5.02^{c}$ | $9.96^{c}$ | $11.28^{c}$ |
| TMS 98/0505 | $6.37^{a}$ | $8.79^{a}$ | $16.24^{a}$ | $14.19^{ab}$ |
| TMS 96/1632 | $3.49^{cd}$ | $5.52^{c}$ | $8.29^{c}$ | $12.29^{b}$ |
| TMS 30572 | $3.39^{cd}$ | $7.58^{ab}$ | $11.10^{bc}$ | $13.00^{ab}$ |
| TMS 91/02324 | $4.73^{b}$ | $8.24^{a}$ | $13.94^{ab}$ | $15.50^{a}$ |
| LSD | 1.19 | 1.99 | 3.45 | 2.69 |

Means followed by the same letter (s) in a column are not significantly different p> 0.05 level of probability using LSD.

***Fertilizer Rate and Fertilizer Type***

The results presented in Figures 12 and 13 show the effect of fertilizer rate on storage root weight at Oke-oyi and Ikenne respectively. At Oke-oyi, there was significant difference among the fertilizer rates only at 6 and 8 MAP. The NPK 300 kg $ha^{-1}$ gave the highest fresh storage tuber yield weight at 12 MAP (Figure 12). At Ikenne, NPK 150 kg $ha^{-1}$ and NPK 300 kg $ha^{-1}$ (Figure 14) did not differ significantly from each other but both were significantly higher than non-fertilized at all harvesting time.

There was no significant difference ($p>0.05$) in the type of fertilizer on the fresh storage tuber yield weights observed at 6, 8 and 12 MAP at Oke-oyi as depicted in Figure 14, while at Ikenne, (Figure 15) NPK 12-12-17 gave the highest yield at 6, 8 and 12 MAP while non-fertilized had the lowest yield at all harvesting point.

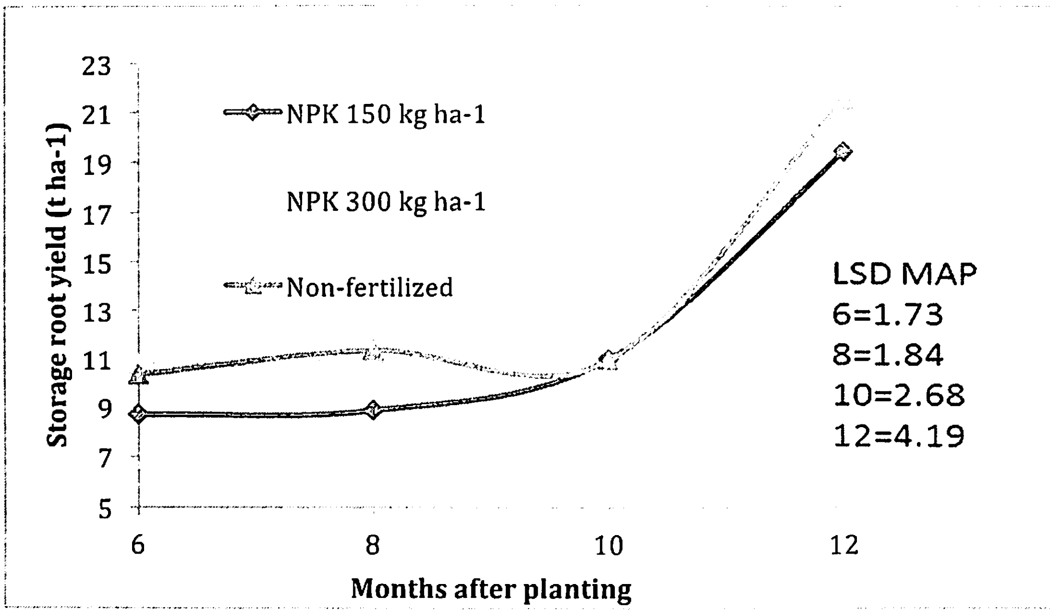


*Figure 13*: Effect of fertilizer rate on cassava storage root yield at Oke-oyi

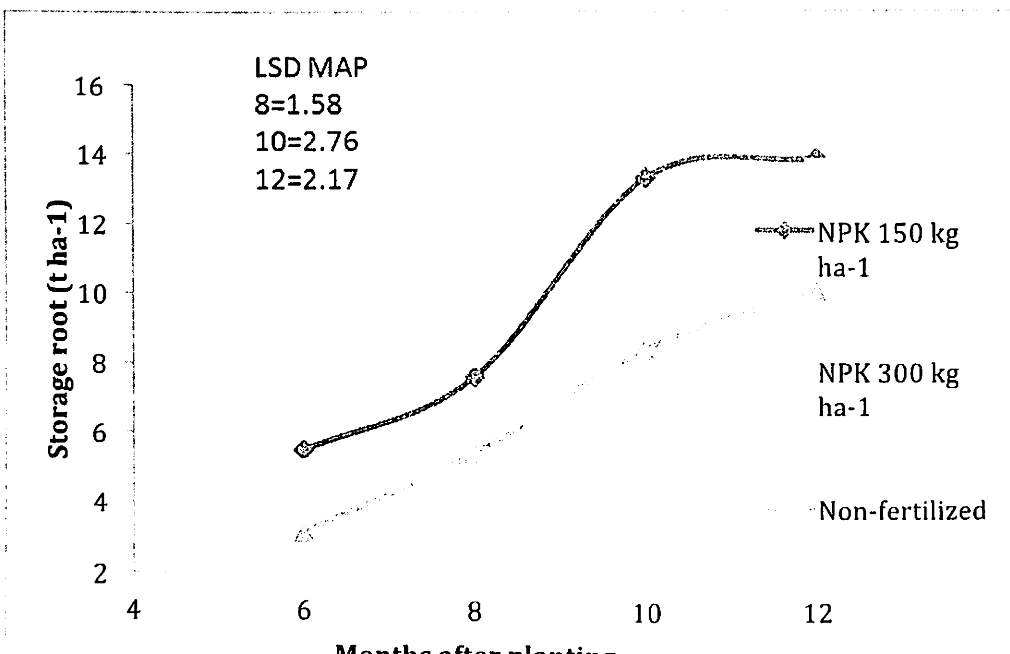


*Figure 14*: Effect of fertilizer rate on cassava storage root yield at Ikenne

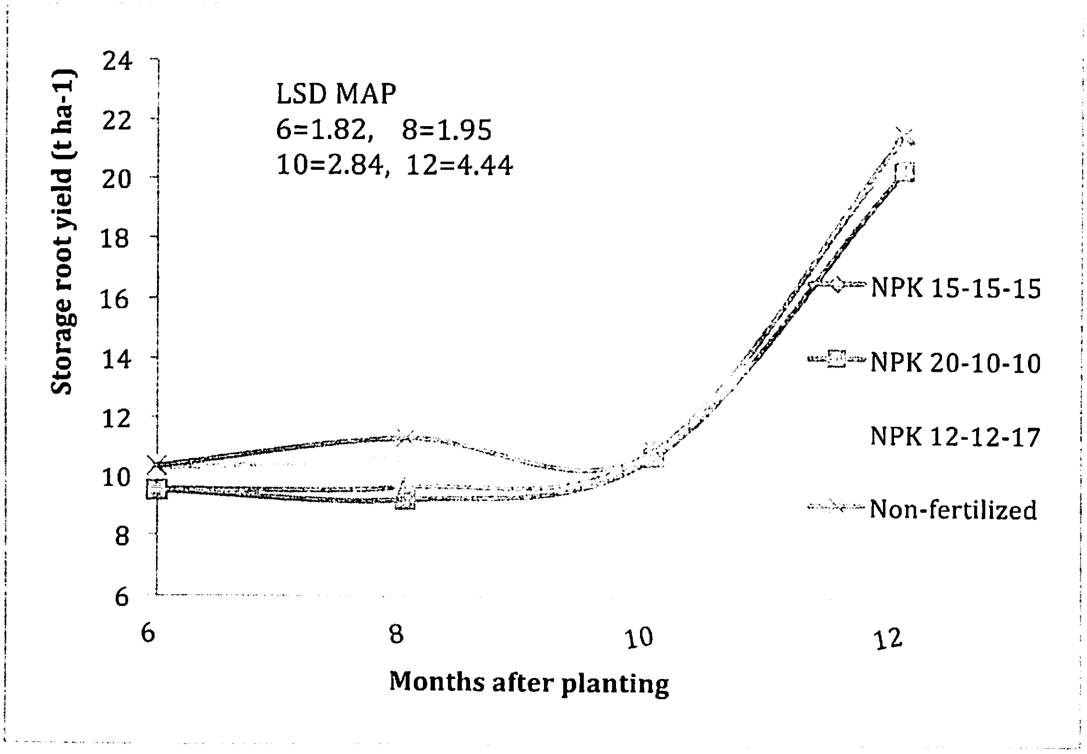


*Figure 15*: Effect of fertilizer type on cassava storage root yield at Oke-oyi

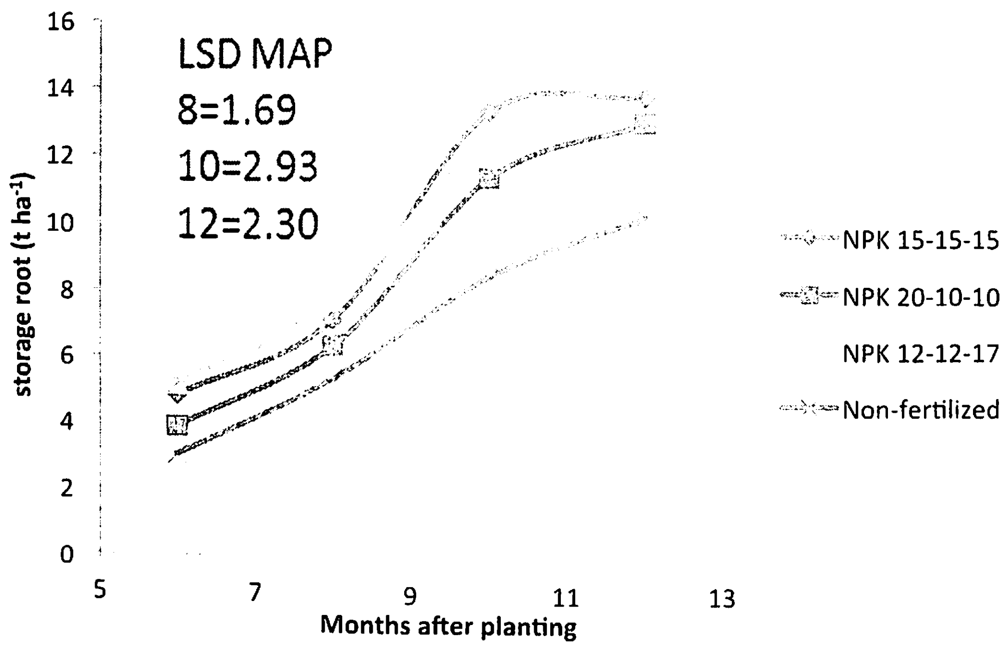


*Figure 16*: Effect of fertilizer type on cassava storage root yield at Ikenne

Table 22: *ANOVA Table of Fresh Storage Tuber Yields Showing the Non-Interactive Nature of the Factors at Oke-oyi at 12 MAP*

| Source | DF | Sum of Square | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Fertilizer type | 2 | 20.584544 | 10.292272 | 0.15 | 0.8594 |
| Fertilizer rate | 1 | 247.514806 | 247.514806 | 3.65 | 0.0605 |
| Fertilizer type*Fertilizer rate | 2 | 170.120254 | 85.060127 | 1.25 | 0.2920 |
| Variety | 5 | 205.016074 | 41.003215 | 0.60 | 0.6963 |
| Fertilizer type*Variety | 10 | 630.767816 | 63.076782 | 0.93 | 0.5116 |
| Fertilizer rate*Variety | 5 | 183.392820 | 36.678564 | 0.54 | 0.7444 |
| Fertilizer type * Fertilizer rate *Variety | 10 | 297.835702 | 29.783570 | 0.44 | 0.9214 |

Table 23: *ANOVA Table of Fresh Storage Tuber Yields Showing the Non-Interactive Nature of the Factors at Ikenne at 12 MAP*

| Source | DF | Sum of Square | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Fertilizer type | 2 | 41.0380993 | 20.5190496 | 1.13 | 0.3305 |
| Fertilizer rate | 1 | 4.7280778 | 4.7280778 | 0.26 | 0.6121 |
| Fertilizer type*Fertilizer rate | 2 | 79.0992432 | 39.5496216 | 2.17 | 0.1223 |
| Variety | 5 | 153.6741426 | 30.7348285 | 1.69 | 0.1504 |
| Fertilizer type*Variety | 10 | 227.4724141 | 22.7472414 | 1.25 | 0.2783 |
| Fertilizer rate*Variety | 5 | 47.3740028 | 9.4748006 | 0.52 | 0.7600 |
| Fertilizer type * Fertilizer rate *Variety | 10 | 199.4179615 | 19.9417962 | 1.09 | 0.3796 |

**Root Dry Matter Content (%)**

***Variety***

The dry matter contents from roots of cassava varieties harvested at different periods are shown in Table 24 for Oke-oyi. The values range from 21.59-27.45%, 25.00-29.27.23%, 27.69-29.29.79% and 32.38-51.48% for 6, 8, 10 and 12 MAP respectively. The root of TMS 96/1632 gave the highest dry matter content at 6, 8 and 10 while TMS 91/02324 gave the highest dry matter at 12 MAP. TMS 91/02324 had the lowest dry matter contents at 6 and 10 MAP, TME 419 at 8 MAP and TMS 98/0505 at 12 MAP. Statistical analysis revealed that there was significant difference between TMS 96/1632 and TMS 91/02324 at 6 and 10 MAP. There was no significant difference observed at 8 and 12 MAP. Table 25 shows the result for Ikenne experimental site. At

Ikenne, The TMS 91/02324 gave the highest root dry matter at 6 MAP while TME 419 gave the highest root dry matter at 8, 10 and 12 MAP. TME 419 was significantly different from Oko-iyawo at 8 and 12 MAP and TMS 30572 at 10 MAP.

Table 24: *Effect of Variety on Root Dry Matter Content (%) of Cassava at Oke-oyi*

| | Months after planting | | | |
|---|---|---|---|---|
| Variety | 6 | 8 | 10 | 12 |
| TME 419 | 36.35[a] | 25.88[ab] | 25.01[a] | 29.72[a] |
| Oko-iyawo | 22.97[a] | 22.83[ab] | 26.05[a] | 28.90[ab] |
| TMS 98/0505 | 32.38[a] | 22.33[ab] | 27.24[a] | 28.00[ab] |
| TMS 96/1632 | 35.17[a] | 27.45[a] | 29.28[a] | 29.79[a] |
| TMS 30572 | 36.12[a] | 24.67[ab] | 26.18[a] | 28.25[ab] |
| TMS 91/02324 | 51.48[a] | 21.60[b] | 29.10[a] | 27.70[b] |
| LSD | 19.75 | 5.59 | 6.15 | 1.81 |

Means followed by the same letter (s) in a column are not significantly different p> 0.05 level of probability using LSD

Table 25: *Effect of Varieties Root Dry Matter Content (%) of Cassava at Ikenne*

| | Months after planting | | | |
|---|---|---|---|---|
| Variety | 6 | 8 | 10 | 12 |
| TME 419 | 18.37[b] | 35.43[a] | 34.01[a] | 42.69[a] |
| Oko-iyawo | 20.33[ab] | 34.14[ab] | 32.33[b] | 35.87[c] |
| TMS 98/0505 | 18.90[b] | 33.96[ab] | 30.53[c] | 39.35[ab] |
| TMS 96/1632 | 19.71[b] | 32.87[ab] | 32.94[ab] | 38.53[b] |
| TMS 30572 | 19.98[b] | 30.36[b] | 30.90c | 39.77[ab] |
| TMS 91/02324 | 22.46[a] | 29.12[c] | 30.52[c] | 41.66[ab] |
| LSD | 2.46 | 4.82 | 1.08 | 3.70 |

Means followed by the same letter (s) in a column are not significantly different p> 0.05 level of probability using LSD

***Fertilizer Rate and Fertilizer Type***

At Oke-oyi, the fertilizer rates did not differ significantly ($p>0.05$) at the different harvesting periods, though; NPK 150 kg $ha^{-1}$ gave the highest root dry matter content at 12 MAP (Table 26) while at Ikenne, fertilizer rate did not differ significantly at all harvesting time; however, NPK 150 kg $ha^{-1}$ gave the highest root dry matter yield at 12 MAP (Table 27).

At Oke-oyi, (Table 26) there was no significant difference among the fertilizer types at the different harvest periods but NPK 15-15-15 gave the highest dry matter at 12 MAP. There was no observed interaction of fertilizer type, fertilizer rate and variety at the different harvest period at Oke-oyi. At Ikenne, fertilizer type did not have significant difference on dry matter yield of cassava root at 8 and 12 MAP. NPK 20-10-10 was significantly higher than NPK 12-12-17 at 6 and 10 MAP (Table 27). There was no interaction among the various factors considered in this study at the different harvesting times.

Table 26: *Effect of Fertilizer Rate and Fertilizer Type on Root Dry Matter Content (%) at Oke-oyi*

| | Months after planting | | | |
|---|---|---|---|---|
| Fertilizer rate | 6 | 8 | 10 | 12 |
| Non-fertilized | 36.59[a] | 22.41[a] | 27.75[a] | 29.25[a] |
| NPK 150kg $ha^{-1}$ | 37.94[a] | 24.23[a] | 27.53[a] | 28.44[a] |
| NPK 300kg $ha^{-1}$ | 34.42[a] | 24.79[a] | 26.39[a] | 28.93[a] |
| LSD | 16.23 | 4.43 | 4.95 | 1.44 |
| Fertilizer Type | 6 | 8 | 10 | 12 |
| Non-fertilized | 36.60[a] | 22.41[a] | 27.75[a] | 29.25[a] |
| NPK 15-15-15 | 39.00[a] | 24.52[a] | 27.24[a] | 29.33[a] |
| NPK 20-10-10 | 33.16[a] | 25.68[a] | 26.64[a] | 28.10[a] |
| NPK 12-12-17 | 35.33[a] | 23.35[a] | 26.99[a] | 28.67[a] |
| LSD | 17.29 | 4.72 | 5.24 | 1.53 |

Means followed by the same letter (s) in a column are not significantly different p> 0.05 level of probability using LSD

Table 27: *Effect of Fertilizer Rate and Fertilizer Type on Root Dry Matter Content (%) at Ikenne*

| | Months after planting | | | |
|---|---|---|---|---|
| Fertilizer rate | 6 | 8 | 10 | 12 |
| Non-fertilized | 19.10[a] | 34.06[a] | 31.83[a] | 38.29[a] |
| NPK 150kg $ha^{-1}$ | 20.53[a] | 33.89[a] | 31.82[a] | 40.18[a] |
| NPK 300kg $ha^{-1}$ | 19.31[a] | 30.98[a] | 31.92[a] | 39.57[a] |
| LSD | 2.07 | 3.83 | 0.86 | 2.96 |
| Fertilizer Type | 6 | 8 | 10 | 12 |
| Non-fertilized | 19.12[ab] | 34.06[a] | 31.83[a] | 39.48[a] |
| NPK 15-15-15 | 19.73[ab] | 32.55[a] | 32.28[a] | 39.48[a] |
| NPK 20-10-10 | 21.21[a] | 35.36[a] | 31.44[a] | 39.85[a] |
| NPK 12-12-17 | 18.85[b] | 29.02[a] | 31.89[a] | 40.26[a] |
| LSD | 2.15 | 4.09 | 0.91 | 3.15 |

Means followed by the same letter (s) in a column are not significantly different p> 0.05 level of probability using LSD

## Root Dry Matter Yield

### *Variety*

The results presented in Tables 28 and 29 shows the effect of variety on dry matter yield of cassava at Oke-oyi and Ikenne respectively. Cassava varieties at Oke-oyi differ significantly ($p<0.05$) at all harvesting time. TMS 30572 had the highest root dry matter yield at 6 MAP, TMS 98/0505 at 8 and 12 MAP and TME 419 at 10 MAP and were all significantly different ($p<0.05$) from TMS 91/02324. The highest dry matter yield for the varieties was at 12 MAP with TMS 98/0505 (6.58 t $ha^{-1}$). TMS 91/02324 had the lowest dry matter yield across all harvesting times except at 10 MAP. At Ikenne, there was significant difference in dry matter yield of all cassava varieties. At 6 to 10 MAP TMS 98/0505 had the highest dry matter yield; TMS 91/02324 had the highest dry matter yield at 12 MAP while Oko-iyawo and TMS 96/1632 had the lowest dry matter yield at all harvesting time. TMS 98/0505 and TMS 91/02324 were significantly different from Oko-iyawo and TMS 96/1632 at all harvest time. At Ikenne, there was a progressive increase of DYLD from 6 to 12 MAP.

Table 28: *Effect of Varieties Root Dry Matter Yield (t $ha^{-1}$) of Cassava at Oke-oyi*

| | Months after planting | | | |
|---|---|---|---|---|
| Variety | 6 | 8 | 10 | 12 |
| TME 419 | $1.76^{a}$ | $2.07^{ab}$ | $2.91^{a}$ | $6.19^{ab}$ |
| Oko-iyawo | $2.01^{a}$ | $1.57^{ab}$ | $1.77^{bc}$ | $5.62^{ab}$ |
| TMS 98/0505 | $1.39^{ab}$ | $2.32^{a}$ | $2.52^{ab}$ | $6.58^{a}$ |
| TMS 96/1632 | $1.69^{a}$ | $1.67^{ab}$ | $2.1^{abc}$ | $6.11^{ab}$ |
| TMS 30572 | $2.29^{a}$ | $1.75^{ab}$ | $1.36_{c}$ | $4.48^{bc}$ |
| TMS 91/02324 | $0.28^{b}$ | $1.32^{b}$ | $2.08^{abc}$ | $3.51^{c}$ |
| LSD | 1.22 | 0.77 | 1.12 | 1.78 |

Means followed by the same letter (s) in a column are not significantly different p> 0.05 level of probability using LSD

Table 29: *Effect of Varieties Root Dry Matter Yield (t ha$^{-1}$) of Cassava at Ikenne*

| | Months after planting | | | |
|---|---|---|---|---|
| Variety | 6 | 8 | 10 | 12 |
| TME 419 | 0.74$^{b}$ | 1.98$^{ab}$ | 3.48$^{bc}$ | 5.27$^{ab}$ |
| Oko-iyawo | 0.51$^{b}$ | 1.62$^{b}$ | 2.41$^{c}$ | 3.73$^{c}$ |
| TMS 98/0505 | 1.09$^{a}$ | 2.86$^{a}$ | 4.92$^{a}$ | 5.21$^{ab}$ |
| TMS 96/1632 | 0.55$^{b}$ | 1.77$^{b}$ | 2.37$^{c}$ | 4.34$^{bc}$ |
| TMS 30572 | 0.54$^{b}$ | 2.15$^{ab}$ | 3.25$^{bc}$ | 5.32$^{ab}$ |
| TMS 91/02324 | 0.68$^{b}$ | 2.22$^{ab}$ | 4.11$^{ab}$ | 6.23$^{a}$ |
| LSD | 0.29 | 1.06 | 1.24 | 1.33 |

Means followed by the same letter (s) in a column are not significantly different p> 0.05 level of probability using LSD.

***Fertilizer Rate and Fertilizer Type***

The results presented in tables 30 and 31 shows the effect of fertilizer rates and fertilizer types on cassava at Oke-oyi and Ikenne respectively. There was no significant difference ($p>0.05$) among the different fertilizer rate at both experimental sites. However, the fertilizer treatments at Oke-oyi performed better (Table 30) than the non-fertilized treatment. NPK 150 kg ha$^{1}$, at Ikenne performed better at all harvest times (Table 31).

The effect of fertilizer type on dry matter yield of cassava varieties at Oke-oyi did not differ significantly ($p>0.05$) at all harvesting times. At Ikenne, however, fertilizer type differ significantly ($p<0.05$) at 10 and 12 MAP. At 10

MAP, NPK 15-15-15 was significantly different from the non-fertilized and NPK 12-12-17 was significantly different from the non-fertilized treatment at 12 MAP at Ikenne.

Table 30: *Effect Of Fertilizer Rate and Fertilizer Type on Root Dry Matter Yield (t $ha^{-1}$) of Cassava at Oke-oyi*

| | Months after planting | | | |
|---|---|---|---|---|
| Fertilizer rate | 6 | 8 | 10 | 12 |
| Non-fertilized | $1.57^a$ | $1.78^a$ | $2.12^a$ | $5.42^a$ |
| NPK 150kg $ha^{-1}$ | $1.61^a$ | $1.45^a$ | $2.13^a$ | $5.00^a$ |
| NPK 300kg $ha^{-1}$ | $1.53^a$ | $2.12^a$ | $2.12^a$ | $5.83^a$ |
| LSD | 1.02 | 0.97 | 0.93 | 1.94 |
| Fertilizer Type | 6 | 8 | 10 | 12 |
| Non-fertilized | $1.69^a$ | $1.85^a$ | $1.43^a$ | $5.86^a$ |
| NPK 15-15-15 | $1.56^a$ | $2.00^a$ | $2.29^a$ | $5.35^a$ |
| NPK 20-10-10 | $1.41^a$ | $1.52^a$ | $1.72^a$ | $5.96^a$ |
| NPK 12-12-17 | $1.68^a$ | $1.80^a$ | $2.71^a$ | $5.21^a$ |
| LSD | 0.94 | 1.07 | 1.54 | 2.62 |

Means followed by the same letter (s) in a column are not significantly different p> 0.05 level of probability using LSD.

Table 31: *Effect Of Fertilizer Rate and Fertilizer Type on Root Dry Matter Yield (t $ha^{-1}$) of Cassava at Ikenne*

| | Months after planting | | | |
|---|---|---|---|---|
| Fertilizer rate | 6 | 8 | 10 | 12 |
| Non-fertilized | $0.68^a$ | $2.10^a$ | $3.42^a$ | $5.02^a$ |
| NPK 150kg $ha^{-1}$ | $0.69^a$ | $2.26^a$ | $3.65^a$ | $5.05^a$ |
| NPK 300kg $ha^{-1}$ | $0.68^a$ | $1.94^a$ | $3.19^a$ | $4.99^a$ |
| LSD | 0.25 | 0.98 | 1.20 | 1.35 |
| Fertilizer Type | 6 | 8 | 10 | 12 |
| Non-fertilized | $0.63^a$ | $1.97^a$ | $2.63^b$ | $3.74^b$ |
| NPK 15-15-15 | $0.61^a$ | $2.33^a$ | $3.90^a$ | $4.95^{ab}$ |
| NPK 20-10-10 | $0.67^a$ | $1.90^a$ | $3.06^{ab}$ | $4.97^{ab}$ |
| NPK 12-12-17 | $0.80^a$ | $2.14^a$ | $3.71^{ab}$ | $5.77^a$ |
| LSD | 0.32 | 0.69 | 1.22 | 1.77 |

Means followed by the same letter (s) in a column are not significantly different p> 0.05 level of probability using LSD.

**Discussion**

The objective of this study was to determine yield and total dry matter responses of different cassava varieties to the application of different fertilizer types and rates in two agro-ecological zones. To achieve this objective six cassava varieties were used in this study, five (TME 419, TMS 98/0505, TMS 96/1632, TMS 30572 and TMS 91/02324) were improved cassava varieties and the last one (Oko-iyawo), a local variety.

These varieties exhibited different responses to the various treatments in the trial. Oke-oyi experimental site was under fallow before the establishment of the experiment while Ikenne experimental site was under cultivation of cassava but fertilizer was not applied. This led to different varietal response to fertilizer treatment at the experimental sites. All improved cassava varieties performed better than the local variety in all parameters measured except stem yield at Ikenne.

The non-fertilizer response of cassava varieties at Oke-oyi could be due to the inherent soil nutrient status as a result of the fallow period and also because cassava breeding was always conducted at non-fertilized plots creating varieties that are sturdy in a large range of conditions but that do not give an optimal response to fertilizer usage (Fermont et al. 2007). This could also be due to fertilizer leaching as described by Aderi et al. (2010). Response of cassava varieties to fertilizer application in Ikenne was supported by the work of Obigbesan (1999).

Foliage dry matter increased due to fertilizer application. TMS 91/02324 and TME 419 had the highest dry matter of foliage in Oke-oyi and Ikenne respectively. Fertilizer rate 300 kg $ha^{-1}$ and fertilizer type NPK 15-15-15 had the highest dry matter foliage at both experimental sites. Meanwhile Oke-oyi experimental site had higher dry matter of foliage than Ikenne.

Dry stem weight responded to fertilizer application at both experimental sites. TME 419 responded to NPK 20-10-10 at 150 kg $ha^{-1}$ while TMS 98/0505 responded to NPK 15-15-15 at 150 kg $ha^{-1}$ at Oke-oyi and Ikenne respectively. The differences in varietal response could be due to inherent varietal ability, different edaphic factors and different weather characteristics of the two experimental sites.

The above ground biomass of cassava varieties showed TMS 98/0505, rate of 300 kg $ha^{-1}$ and NPK 12-12-17 had the highest weight at Oke-oyi. While at Ikenne, TME 419 had the highest above ground weight, NPK 12-12-17 and rate 150 kg $ha^{-1}$. Oke-oyi experimental site had higher above ground weight than Ikenne. Fresh storage root tuber yields of cassava varieties shown that TMS 91/02324 had the best root yield. Fertilizer type NPK 12-12-17 and fertilizer rate 150 kg $ha^{-1}$at Ikenne also had high fresh storage root tuber yield. At Oke-oyi TMS 98/0505 had the highest tuber yield weight. Cassava varieties at Oke-oyi had higher fresh storage root tuber weight at 12 MAP than Ikenne. Higher cassava top in response to fertilizer application has also been reported by Kang and Okeke (1983).

At Oke-oyi, root dry matter contents of TMS 96/1632 cassava variety, had the highest dry matter content among the cassava varieties. Fertilizer type NPK 15-15-15 and fertilizer rate of 150 kg $ha^{-1}$ while at Ikenne, TME 419, fertilizer type NPK 12-12-17 and fertilizer rate 150 kg $ha^{-1}$ had the higher dry matter content in their categories.

Though the fresh storage weight of cassava varieties at Oke-oyi at 12 MAP are higher than those from Ikenne, the dry matter content of cassava varieties at Ikenne are higher (Safo-kantanka & Osei-Minta, 1996), than those from Oke-oyi. TME 419 and TMS 96/1632 high dry matter content was a major requirement for their choice of release as improved cassava varieties (Howeler & Cadavid, 1983; Okechukwu, Akoroda, Ogbe, & Dixon, 2010).

Dry matter yield (DYLD) of cassava varieties showed **that** TMS 98/0505 at Oke-oyi at 12 MAP had the highest DYLD and from 6 to 10 MAP at Ikenne experimental site as shown in Tables 23 and 24. DYLD production responded to fertilizer application. At Oke-oyi, 300 kg $ha^{-1}$ fertilizer rate gave the highest DYLD while 150 kg $ha^{-1}$ at Ikenne gave the highest DYLD. NPK 15-15-15 and 12-12-17 at Oke-oyi and Ikenne respectively gave the highest DYLD among the fertilizer types. This result collaborates with the results of others (Okechukwu & Dixon, 2009; Okechukwu et al. 2010) on the importance of DYLD in cassava variety improvement.

Fresh storage root yield of cassava varieties as presented in tables 15 and 16, showed that TMS 98/0505 had the highest fresh root yield at 6, 8 and 12 MAP at Oke-oyi and 6, 8 and 10 at Ikenne. Fertilizer rate 300 kg $ha^{-1}$ and 150 kg $ha^{-1}$ at Oke-oyi and Ikenne respectively gave the highest root weight (Agwu, Nwachukwu, & Anyanwu, 2012; Ganiyu, Akinniran, & Adeyemo, 2013). While the non-fertilized treatment gave the highest storage root weight at Oke-oyi (Aderi et al. 2010), NPK 12-12-17 gave the highest storage root weight at Ikenne.

The interaction of fertilizer type and variety, fertilizer rate and variety, fertilizer type and fertilizer rate as well as fertilizer type and fertilizer rate and variety were not significant in this trial.

Evidently from this study, the serial harvesting times for the two experimental sites have showed that harvesting the cassava varieties under study in this trial at 6 MAP at Oke-oyi will give the highest dry matter content while harvest at 12 MAP at Ikenne gave the highest dry matter content. This is due to greater partitioning of assimilates to the roots tubers at Ikenne than Oke-oyi. This result is in agreement with the work of Mulualem and Ayenew, (2012).

**Conclusions**

Cassava is one of the most important food crops in Nigerian agricultural systems. The performance and productivity of the crop is influenced by the fertility status of the soil and the harvesting time.

The major findings of this study are summarized as follows:

1. TME 419 performed statistically significantly better than all the other cassava varieties at Ikenne on stem dry matter, above ground biomass, fresh storage root weight and dry matter content.
2. Of the three fertilizer types used in this study NPK 12-12-17 had the highest storage root yield, dry matter content, harvest

index, root dry matter yield and above ground biomass at Ikenne from trend observation.

3. 150 kg ha$^{-1}$ fertilizer rate performed better (though not significant) than 300 kg ha$^{-1}$ at Ikenne.
4. Optimum harvest time depends on the end use of cassava tuber and environment.
5. Response to fertilizer of cassava at Oke-oyi depends on the initial soil properties.
6. Cassava varieties used in this experiment at Oke-oyi were diverse in their response to fertilizer application.
7. TMS 30572 and TMS 98/0505 at Oke-oyi performed better than the other cassava varieties.
8. The application of NPK 12-12-17 at 150kgha$^{-1}$ produced the highest fresh storage root yield, dry matter content and root dry matter at Ikenne
9. NPK 15-15-15 at 150 kgha$^{-1}$ produced the highest dry matter content of cassava; TMS 96/1632 with no fertilizer application has the highest fresh storage root yield at 12 MAP at Oke-oyi.

# CHAPTER SIX

# EFFECTS OF VARIETY, FERTILIZER TYPE AND RATE ON THE QUALITY OF CASSAVA ROOTS

## Introduction

Cassava (*Manihot esculentus* Crantz) is a staple food for approximately 800 million people in tropical countries (Iwuoha, Ubeng, & Onwuachu, 2013). Cassava is grown primarily for its starchy tuberous roots, which are important staple for more than 800 million people, mostly in sub-Saharan Africa (SSA) but also in other parts of Africa, Asia and South America (Burns et al. 2011). It contributes significantly to the economy of most tropical countries through processing into various products (Assanvo 2008, Apea-Bah et al. 2009). Due to its importance research has been undertaken to improve cassava productivity and to produce superior varieties that not only guarantee food security but also provide good quality raw material for several industries (FAO, 2008).

Cassava is a rich source of dietary energy. Its energy yield per hectare is often very high, and potentially much higher than that of cereals (FAO, 1997a). In many countries of SSA, it is the cheapest source of calories available. In addition, the roots contain significant amounts of vitamin C, thiamine, riboflavin and niacin (FAO. 1997b). Its root starch can also be used in a wide array of industries, including food manufacturing, pharmaceuticals, textiles, plywood, paper and adhesives, and as feedstock for the production of ethanol biofuel (FAO, 2013).

Dry matter production and partitioning is an important determinant of storage root yield in cassava and could be an important selection criterion in breeding programmes for enhanced yield. Total dry matter production is a good estimator of the degree of adaptation of a genotype to the environment in which it is grown (Kamara, Menkir, Badu-Apraku, & Ibikunle, 2003). Partitioning of dry matter is particularly important in cassava because the crop has simultaneous development of leaves, stems and storage roots and the supply of assimilate is partitioned between these parts (Ekanayake et al. 1998). Generally, genotypes that allocate higher proportion of dry matter to storage roots than the stems and leaves give higher yields (Osiru & Hahn, 1998). Dry matter and starch yield are two important parameters which affect the use of cassava both as food and an industrial raw material (Hahn et al. 1989). Dry matter is the key trait farmers and processors use for selecting appropriate genotypes that are good for food, industry, and livestock (Okechukwu & Dickson, 2009).

Cassava roots contain more than 60% water (FAO, 2013), but the dry matter is very rich in carbohydrates, amounting to about 250 to 300 kg for every tonne of fresh roots. When the root is used as food, the best time to harvest is at about 8 to 10 months after planting; a longer growing period generally produces a higher starch yield. Cassava root starch is an important raw material for food, pharmaceuticals, textiles, plywood, paper and adhesives, and as feedstock for the production of ethanol biofuel. However, a major drawback in the use of cassava is the cyanogenic glucosides which upon hydrolysis produce toxic hydrogen cyanide (HCN). Cassava contains naturally occurring, but potentially toxic compounds called cyanogenic glycosides, primarily linamarin and a small amount of lotaustralin (Uyoh, Udensi, Natui, & Urua, 2007). They release hydrogen cyanide (HCN) as a result of enzymatic hydrolysis following maceration of the plant tissue. According to Codex Alimentarius Commission (2003), cassava product having high cyanide content more than 10 $mgkg^{-1}$ should be labelled as bitter cassava and not safe for human consumption in a ready to eat cassava chips. Consumption of improperly processed cassava food may lead to goitre and cretinism (Rosling, 1987). Hence, selection of cassava varieties that are acyanogenic or low in cyanogenic content is important.

Cardoso et al. (2005), stated that all cassava cultivars contain cyanogenic glucosides however a wide variation in the concentration of cyanogens exists among different cultivars. This can range from 1 to 2,000 mg $kg^{-1}$. Cultivars with <100 mg $kg^{-1}$ hydrogen cyanide are called sweet while those >100 mg $kg^{-1}$ are called bitter (Wheatley et al. 1993). Studies in the Philippines by Rolinda, Talatala, Ma and Loreto (2008), reported that application of fertilizer does not significantly affect cyanide content. It further suggested that the amount of nutrient in the soil does not considerably contribute to the cyanogenic character of the cultivar. In Ethiopia, Endris (2006) suggested that the cyanogenic content of cassava roots were significantly reduced by potassium application. The genotype-environment interactions are less pronounced but significant; some genotypes maintain the same cyanogenic potential ranking when planted in various agro-ecological zones, even though the absolute values of cyanogenic potential may be increased or decreased.

Therefore the specific objectives of this study are to:

1. Evaluate the continuum effect of variety on starch content and cyanogenic potential of cassava tubers.
2. Determine the starch content and cyanogenic potential of cassava varieties in response to different fertilizer types and rates.
3. Evaluate age of harvesting of cassava on root quality indicators.

## Materials and Methods

### Experimental Sites

Description of the study sites, climate, vegetation, geology and soil, soil sampling and characterization are as described in Chapter 3

### Soil Chemical Analysis: as described in Chapter 3

### Experimental Materials

#### *Cassava Varieties: as described in Chapter 3and Table 4*

#### *Fertilizers Used*

Three inorganic NPK fertilizers (NPK 15-15-15, NPK 20-10-10 and NPK 12-12-17) at two rates (150 kg $ha^{-1}$ and 300kg $ha^{-1}$) of applications were used in this experiment as described in 3.3.2 See previous edits

**Parameter Measurements And Determinations: as described in Chapter 3**

**Statistical Analysis: as described in Chapter 3**

**Results**

The results of the interactive effects of variety, fertilizer type and rate on starch content and cyanogenic potential at the two experimental sites are shown in figures below.

**Starch Content**

***Variety***

At Oke-oyi, (Table 32) there was no significant difference in the starch content of cassava varieties at the first harvesting time. All cassava varieties had the highest starch content at 12 MAP. TMS 96/1632 had the highest starch content at 8, 10 and 12 MAP though it was only significantly different ($p<0.05$) at 8 and 12 MAP from TMS 91/02324 (Table 32). Oko-iyawo (local variety) had its highest starch content (18.4%) at 6 MAP. At Ikenne, starch content of cassava varieties was significant ($p<0.05$) at all harvesting period (Table 33). Starch content of cassava increased from 6 to 8 MAP, decreased at 10 and increased again at 12 MAP. TME 419 had the highest starch content from 8 to 12 MAP and was significantly different from TMS 30572, Oko-iyawo and TMS 96/1632 at 8, 10 and 12 MAP (Table 33).

Table 32: *Effect of Varieties on Cassava Starch (%) at Oke-oyi*

| | Months after planting |
|---|---|

| Variety | 6 | 8 | 10 | 12 |
|---|---|---|---|---|
| TME 419 | 9.4[a] | 10.16[ab] | 9.00[a] | 15.27[a] |
| Oko-iyawo | 18.4[a] | 6.09[ab] | 10.38[a] | 14.19[ab] |
| TMS 98/0505 | 7.5[a] | 5.43[ab] | 11.96[a] | 12.98[ab] |
| TMS 96/1632 | 11.5[a] | 12.25[a] | 14.68[a] | 15.36[a] |
| TMS 30572 | 15.7[a] | 8.55[ab] | 10.55[a] | 13.31[ab] |
| TMS 91/02324 | 13.4[a] | 4.46[b] | 14.44[a] | 12.56[b] |
| LSD | 11.98 | 7.45 | 8.19 | 2.41 |

Means followed by the same letter (s) in a column are not significantly different p> 0.05 level of probability using LSD.

Table 33: *Effect of Cassava Varieties on Starch Content (%) at Ikenne*

| | Months after planting | | | |
|---|---|---|---|---|
| Variety | 6 | 8 | 10 | 12 |
| TME 419 | 0.15[b] | 22.87[a] | 20.99[a] | 32.55[a] |
| Oko-iyawo | 2.78[ab] | 21.15[ab] | 18.74[b] | 23.46[c] |
| TMS 98/0505 | 0.87[b] | 20.91[ab] | 16.35[c] | 28.09[ab] |
| TMS 96/1632 | 1.94[b] | 19.46[ab] | 19.56[ab] | 27.01[b] |
| TMS 30572 | 2.30[b] | 16.13[b] | 16.70[c] | 28.66[ab] |
| TMS 91/02324 | 5.60[a] | 14.46[c] | 16.34[c] | 31.16[ab] |
| LSD | 3.28 | 6.42 | 1.43 | 4.93 |

Means followed by the same letter (s) in a column are not significantly different p> 0.05 level of probability using LSD.

*Fertilizer Rate and Fertilizer Type*

At Oke-oyi, fertilizer rates did not differ significantly ($p>0.05$) at the different harvesting times. NPK 150 kg $ha^{-1}$, and NPK 300 kg $ha^{-1}$ gave the highest starch content at 6 and 8 MAP respectively while non-fertilized had the highest starch content at 10 and 12 MAP (Table 34) while at Ikenne, there was no significant difference among fertilizer rates at all harvesting times. NPK 150 kg $ha^{-1}$ had the highest starch content while non-fertilized had the lowest starch content at the same time at 12 MAP (Table 36).

There was no significant difference observed at Oke-oyi throughout the harvesting times among the fertilizer types as shown on Table 34. However, NPK 15-15-15 performed better at 6 and 12 MAP, NPK 20-10-10 at 8 MAP and non-fertilized at 10 MAP. At Ikenne, (Table 36) fertilizer types did differ significantly at 6 and 8 MAP. NPK 20-10-10 gave the highest starch content at 6 and 8 MAP and was significantly different from NPK 12-12-17 at the same harvesting time. NPK 12-12-17, however, gave the highest starch content at 12 MAP. There was no observed interaction among fertilizer type, fertilizer rate and variety at all harvesting times as seen in the ANOVA tables on Table 35 and 37.

Table 34: *Effect of Fertilizer Rate and Fertilizer Type on Cassava Starch Content (%) at Oke-oyi*

| | Months after planting | | | |
|---|---|---|---|---|
| Fertilizer rate | 6 | 8 | 10 | 12 |
| Non-fertilized | 12.7[a] | 5.53[a] | 12.65[a] | 14.63[a] |
| NPK 150kg $ha^{-1}$ | 15.1[a] | 7.96[a] | 12.35[a] | 13.57[a] |
| NPK 300kg $ha^{-1}$ | 10.2[a] | 8.70[a] | 10.84[a] | 14.21[a] |
| LSD | 15.00 | 5.90 | 6.59 | 1.92 |
| Fertilizer Type | 6 | 8 | 10 | 12 |
| Non-fertilized | 10.6[a] | 5.53[a] | 12.65[a] | 14.63[a] |
| NPK 15-15-15 | 11.6[a] | 8.34[a] | 11.97[a] | 14.74[a] |
| NPK 20-10-10 | 9.7[a] | 9.89[a] | 11.16[a] | 13.11[a] |
| NPK 12-12-17 | 17.6[a] | 6.78[a] | 11.63[a] | 13.87[a] |
| LSD | 11.69 | 6.29 | 6.97 | 2.04 |

Means followed by the same letter (s) in a column are not significantly different p> 0.05 level of probability using LSD.

Table 35: *ANOVA Table for Starch at 12 MAP at Oke-oyi*

| Source | DF | Sum of Square | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Fert_type | 2 | 35.9444575 | 17.9722288 | 1.29 | 0.2835 |
| Fert_rate | 1 | 27.7779415 | 27.7779415 | 1.99 | 0.1635 |
| Fert_type*Fert_rate | 2 | 33.4937452 | 16.7468726 | 1.20 | 0.3084 |
| Variety | 5 | 132.5190251 | 26.5038050 | 1.90 | 0.1080 |
| Fert_type*Variety | 10 | 148.4580176 | 14.8458018 | 1.06 | 0.4041 |
| Fert_rate*Variety | 5 | 56.4792126 | 11.2958425 | 0.81 | 0.5478 |
| Fert_t*Fert_r*Variet | 10 | 107.9259519 | 10.7925952 | 0.77 | 0.6538 |

Table 36: *Effect of Fertilizer Rate and Fertilizer Type on Cassava Starch Content (%) at Ikenne*

| | Months after planting | | | |
|---|---|---|---|---|
| Fertilizer rate | 6 | 8 | 10 | 12 |
| Non-fertilized | 1.13[a] | 21.05[a] | 18.08[a] | 26.68[a] |
| NPK 150kg $ha^{-1}$ | 3.04[a] | 20.83[a] | 18.06[a] | 29.20[a] |
| NPK 300kg $ha^{-1}$ | 1.41[a] | 16.94[a] | 18.19[a] | 27.74[a] |
| LSD | 2.76 | 5.11 | 1.14 | 3.94 |
| Fertilizer Type | 6 | 8 | 10 | 12 |
| Non-fertilized | 1.13[ab] | 21.05a | 18.08[a] | 26.68[a] |
| NPK 15-15-15 | 1.96[ab] | 19.04[a] | 18.68[a] | 28.26[a] |
| NPK 20-10-10 | 3.93[a] | 22.78[a] | 17.55[a] | 28.76[a] |
| NPK 12-12-17 | 0.78[b] | 15.00[a] | 18.15[a] | 29.30[a] |
| LSD | 2.87 | 5.44 | 1.22 | 4.19 |

Means followed by the same letter (s) in a column are not significantly different p> 0.05 level of probability using LSD.

Table 37: *ANOVA Table for Starch at 12 MAP at Ikenne*

| Source | DF | Sum of Square | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Fert_type | 2 | 45.213645 | 22.606822 | 0.36 | 0.6964 |
| Fert_rate | 1 | 3.995035 | 3.995035 | 0.06 | 0.8006 |
| Fert_type*Fert_rate | 2 | 1.370717 | 0.685359 | 0.01 | 0.9890 |
| Variety | 5 | 872.986289 | 174.597258 | 2.81 | 0.0232 |
| Fert_type*Variety | 10 | 609.619649 | 60.961965 | 0.98 | 0.4684 |
| Fert_rate*Variety | 5 | 249.271351 | 49.854270 | 0.80 | 0.5520 |
| Fert_t*Fert_r*Variet | 10 | 428.261049 | 42.826105 | 0.69 | 0.7307 |

**Cyanogenic Potential**

***Variety***

At Oke-oyi, (Table 38) there was a significant difference on cyanogenic potential content of cassava varieties at all the harvesting period except at 10 MAP. TME 419 had the lowest cyanogenic potential across all the harvesting period. TMS 91/02324 had the highest cyanogenic concentration at 6, 8 and 10 MAP. TMS 96/1632 had the highest cyanide concentration at 12 MAP while at Ikenne, cassava varieties were significantly different at all harvesting times (Table 39). TME 419 had the lowest cyanide potential at 6, 8 and 10 MAP while TMS 96/1632 had the highest cyanide potential at 6 and 8 MAP. TMS 91/02324 had the lowest cyanide potential at 12 MAP. TMS 91/02324 and TMS 30572 had the highest cyanide potential at 10 and 12 MAP respectively.

Table 38: *Effect of Varieties on Cassava Cyanide Potential (ppm) at Oke-oyi*

| | Months after planting | | | |
|---|---|---|---|---|
| Variety | 6 | 8 | 10 | 12 |
| TME 419 | 4.07$^{b}$ | 3.80$^{b}$ | 3.79$^{a}$ | 3.95$^{c}$ |
| Oko-iyawo | 5.07$^{ab}$ | 4.20$^{ab}$ | 4.10$^{a}$ | 6.25$^{b}$ |
| TMS 98/0505 | 5.25$^{a}$ | 5.00$^{ab}$ | 4.63$^{a}$ | 5.33$^{b}$ |
| TMS 96/1632 | 5.53$^{a}$ | 5.33$^{ab}$ | 4.56$^{a}$ | 7.50$^{a}$ |
| TMS 30572 | 4.53$^{ab}$ | 4.27$^{ab}$ | 3.94$^{a}$ | 6.15$^{b}$ |
| TMS 91/02324 | 5.38$^{a}$ | 5.40$^{a}$ | 4.59$^{a}$ | 6.25$^{b}$ |
| LSD | 1.08 | 1.54 | 0.87 | 1.05 |

Means followed by the same letter (s) in a column are not significantly different p> 0.05 level of probability using LSD.

Table 39: *Effect of Cassava Varieties on Cyanide Potential (ppm) at Ikenne*

| | Months after planting | | | |
|---|---|---|---|---|
| Variety | 6 | 8 | 10 | 12 |
| TME 419 | 3.88[d] | 3.42[b] | 4.14[c] | 4.52[ab] |
| Oko-iyawo | 4.33[cd] | 5.00[a] | 5.10[ab] | 4.37[ab] |
| TMS 98/0505 | 4.94[bc] | 4.06[b] | 5.00[ab] | 4.00[b] |
| TMS 96/1632 | 5.81[a] | 5.47[a] | 5.21[ab] | 4.37[ab] |
| TMS 30572 | 5.25[ab] | 4.05[b] | 4.65[b] | 4.79[a] |
| TMS 91/02324 | 5.24[ab] | 5.20[a] | 5.63[a] | 3.94[b] |
| LSD | 0.84 | 0.82 | 0.90 | 0.72 |

Means followed by the same letter (s) in a column are not significantly different p> 0.05 level of probability using LSD.

***Fertilizer Rate and Fertilizer Type***

Fertilizer rate did not have any significant effect on cyanide potential across the different harvest periods at Oke-oyi as shown in Table 40. At Ikenne, there was no significant difference among the fertilizer rates except at 12 MAP. NPK 150 kg $ha^{-1}$ was significantly different from NPK 300 kg $ha^{-1}$ at 12 MAP (Table 42).

At Oke-oyi, there was no significant difference among the fertilizer type on cassava cyanide potential during the harvest times. NPK 12-12-17 had the highest cyanogenic potential across the harvesting times except at 12 MAP. NPK 12-12-17 had the highest cyanide potential at 12 MAP (Table 40).

At Ikenne, (Table 42) also there was no observed significant difference among the different fertilizer types at all harvesting times. However, NPK 20-10-10 gave the lowest cyanide potential at 12 MAP. There was no significant difference observed among fertilizer type, fertilizer rate and variety at all harvesting time as shown on Tables 41 and 43 for 12 MAP.

Table 40: *Effect of Fertilizer Rate and Fertilizer Type on Cyanide Potential at Oke-oyi*

| | Months after planting | | | |
|---|---|---|---|---|
| Fertilizer rate | 6 | 8 | 10 | 12 |
| Non-fertilized | 4.90a | 4.87a | 4.14a | 5.64a |
| NPK 150kg $ha^{-1}$ | 4.77a | 4.50a | 4.19a | 5.75a |
| NPK 300kg $ha^{-1}$ | 5.11a | 4.63a | 4.36a | 6.04a |
| LSD | 0.86 | 1.15 | 0.71 | 0.82 |
| | | | | |
| Fertilizer Type | 6 | 8 | 10 | 12 |
| Non-fertilized | 4.91a | 4.87a | 4.14a | 5.64a |
| NPK 15-15-15 | 4.90a | 5.00a | 4.20a | 5.80a |
| NPK 20-10-10 | 4.91a | 4.00a | 4.30a | 6.18a |
| NPK 12-12-17 | 5.05a | 4.66a | 4.31a | 5.70a |
| LSD | 0.92 | 1.24 | 0.75 | 0.88 |

Means followed by the same letter (s) in a column for the same factor are not significantly different p> 0.05 level of probability using LSD

Table 41: *ANOVA Table for Cyanide Potential at Oke-oyi at 12 MAP*

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Fert_type | 2 | 1.6261069 | 0.8130535 | 0.32 | 0.7248 |
| Fert_rate | 1 | 1.4496719 | 1.4496719 | 0.58 | 0.4507 |
| Fert_type*Fert_rate | 2 | 2.7372241 | 1.3686120 | 0.54 | 0.5830 |
| Variety | 5 | 111.3688934 | 22.2737787 | 8.87 | <.0001 |
| Fert_type*Variety | 10 | 7.0214903 | 0.7021490 | 0.28 | 0.9832 |
| Fert_rate*Variety | 5 | 25.8193523 | 5.1638705 | 2.06 | 0.0850 |
| Fert_t*Fert_r*Variet | 9 | 32.6800332 | 3.6311148 | 1.45 | 0.1918 |

Table 42: *Effect of Fertilizer Rate and Fertilizer Type on Cyanide Potential at Ikenne*

| | Months after planting | | | |
|---|---|---|---|---|
| Fertilizer rate | 6 | 8 | 10 | 12 |
| Non-fertilized | 5.15a | 4.70a | 5.22a | 4.68a |
| NPK 150kg $ha^{-1}$ | 4.82a | 4.46a | 4.91a | 4.61a |
| NPK 300kg $ha^{-1}$ | 4.93a | 4.48a | 4.86a | 3.91b |
| LSD | 0.69 | 0.64 | 0.71 | 0.56 |
| **Fertilizer Type** | **6** | **8** | **10** | **12** |
| Non-fertilized | 5.15a | 4.70a | 5.22a | 4.61a |
| NPK 15-15-15 | 7.77a | 4.46a | 4.94a | 4.50a |
| NPK 20-10-10 | 5.03a | 4.43a | 4.94a | 4.06a |
| NPK 12-12-17 | 4.81a | 4.53a | 4.79a | 4.28a |
| LSD | 0.73 | 0.69 | 0.76 | 0.60 |

Means followed by the same letter (s) in a column for the same factor are not significantly different p> 0.05 level of probability using LSD

Table 43: *ANOVA Table for Cyanide Potential at Ikenne at 12 MAP*

| Source | DF | Sum of Square | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Fert_type | 2 | 3.41436260 | 1.70718130 | 1.41 | 0.2532 |
| Fert_rate | 1 | 9.71045198 | 9.71045198 | 8.01 | 0.0065 |
| Fert_type*Fert_rate | 2 | 0.61236962 | 0.30618481 | 0.25 | 0.7776 |
| Variety | 5 | 8.66246504 | 1.73249301 | 1.43 | 0.2282 |
| Fert_type*Variety | 10 | 11.59542820 | 1.15954282 | 0.96 | 0.4907 |
| Fert_rate*Variety | 5 | 3.42510144 | 0.68502029 | 0.57 | 0.7262 |
| Fert_t*Fert_r*Variet | 10 | 13.52754463 | 1.35275446 | 1.12 | 0.3671 |

**Discussion**

This experiment was set up to determine the interactive effect of variety, fertilizer type and fertilizer rate on cassava root quality and the specific objectives were to evaluate the continuum effect of variety on starch content and cyanogenic potential of cassava tubers, determine the starch content and cyanogenic potential of cassava varieties in response to different fertilizer types and rates and to evaluate age of harvesting of cassava tubers on root quality indicators.

Starch content of cassava varieties at the two experiment sites showed different characteristics. TMS 96/1632 and TME 419 had the highest starch content at 12 MAP at Oke-oyi and Ikenne respectively. This result agrees with Okechukwu et al. (2010). TME 419 was the most stable of the cassava varieties used in this experiment at both locations in term of starch content, this also confirm the result of Okechukwu et al. during a multi-locational trials in Nigeria.

Cyanogenic potential of cassava varieties was higher at Oke-oyi and lower at Ikenne. This result showed that Cyanogenic potential of cassava varieties varies with the environment. At 12 MAP, TMS 96/1632 and TMS 30572 had the highest concentration of cyanide at Oke-oyi and Ikenne respectively. This shows the inherent varietal ability of cassava (Dixon et al. 2010) to exhibit a trait based on the environment. TME 419, among the six cassava varieties at both experimental sites had the lowest cyanogenic potential.

NPK 15-15-15 at 300 kg $ha^{-1}$ had the highest starch content at Oke-oyi at 12 MAP. The highest starch content of cassava varieties, not significant ($p>0.05$), throughout the harvest times at Oke-oyi was obtained at 6 MAP with TMS 91/02324 in response to NPK 15-15-15. This showed that starch content of cassava varieties responded to fertilizer application at Oke-oyi.

Starch content of cassava varieties at Ikenne increased gradually from 6 to 12 MAP. NPK 12-12-17 at 150kg $ha^{-1}$ had the highest starch content at 12 MAP. TME 419, performed best at Ikenne and had the second highest starch content at Oke-oyi. This result further corroborates with Okechukwu et al. (2010) on the stability of TME 419 in a multi-locational trial. At 6 MAP (Ikenne), cassava generally is not physiologically matured so the starch readings are poor. As the crop matures starch percentage increases. Another explanation is the time of starch test; 6 MAP evaluations in this study fell into the period of onset of rains (Moreno & Gourdji 2015), at this time cassava starch reading is known to be extremely poor.

Harvesting any of the cassava varieties at 12 MAP at Oke-oyi and especially TMS 96/1632 will give the highest amount of starch content. Harvesting of cassava varieties at 12 MAP (Benesi, Labuschagne, Dixon, & Mahungu, 2004; Ebah-Djedji et al. 2012) at Ikenne will give the highest starch content especially for TME 419.

Cyanide potential of cassava tubers at Oke-oyi was lowest at 10 MAP increased slightly at 12 MAP (Hidayat, Zuraida, & Hararida 2002) while cyanide potential of cassava varieties at Ikenne leveled throughout the harvesting times (Bokanga et al. 1994, Githunguri, 2004).

## Conclusions

The following conclusions were drawn from this study:

A. Starch content of cassava varieties at Oke-oyi was highest at 6 MAP

B. TMS 91/02324 had the highest starch content among cassava varieties at 6 MAP at Oke-oyi in response to NPK 15-15-15 at 300 kg $ha^{-1}$ though not significantly different.

C. TME 419 had the highest starch content and was significantly different from other cassava varieties at 12 MAP at Ikenne in response to NPK 12-12-17 at 150kg $ha^{-1}$.

D. Harvesting cassava varieties at 10 MAP had the lowest cyanogenic potential at Oke-oyi while harvesting of cassava varieties can be done at any time at Ikenne with little change on the cyanogenic potential.

E. Harvesting of cassava for starch at the onset of the rainy season resulted in extremely low content (as seen at 6 MAP at Ikenne) while harvesting during the dry season (6 MAP at Oke-oyi) resulted in high starch content.

# CHAPTER SEVEN

# EFFECTS OF INTRA-SEASONAL RAINFALL VARIABILITY ON YIELD AND QUALITY OF CASSAVA

## Introduction

Climate change is an important environmental, social and economic issue. Such issues are particularly important for sub-Saharan Africa (SSA) where many people depend on agriculture for subsistence and incomes (Badiane & Delgado, 1995). Agriculture and especially crop production, in SSA is heavily dependent on weather events as 97% of agricultural production in the region is rain fed (Rockstrom et al. 2004). A study by Jarvis, Ramirez-Villegas, Herrera, & Navarro-Racines, (2012) on the impacts of climate change on major staple crops in Africa found that cassava was the least sensitive to the climatic conditions predicted in 2030, and that its suitability would actually increase in most of the 5.5 million $km^2$ area surveyed while all other major food crops in the region, including maize, sorghum, millet, beans, potatoes and bananas, were expected to suffer largely negative impacts.

According to Rosenthal and Ort, (2012) approximately 925 million people are under nourished and almost 90% of these people live in SSA, Asia and the Pacific. SSA, in particular, continues to have the highest proportion of chronically hungry individuals, where 1 in 3 is under nourished in terms of both food quantity and nutrition. The threat of substantial changes in climate raises concern about future capacity to sustain even current levels of food availability because climate change will impact food security most severely in regions where undernourishment is already a problem.

While rice, wheat and maize account for roughly half of the world's human caloric intake, many of the undernourished rely on other crops for subsistence. In SSA, the starchy root crop cassava is the most important in terms of caloric intake. Rice, wheat and maize account for only one third of total calories consumed in the region (FAO, 2011). Climate affects the various aspects of plant growth and yield. The effect of climatic elements and their extremes include the significant alteration of crop production. Temperature and rainfall pattern provide major constraint on productivity. Generally, rainfall regime is the most important climatic factor influencing agricultural activities particularly in the tropical region. Rainfall can vary considerably even within a few kilometers and on different time scale (Ayanlade, Odekunle, & Orimoogunje, 2010). This implies that crop yield is exceedingly variable over space and time. It has biggest effect in determining the crops that can be grown, the farming system, the sequence and timing of farming operations (Adejuwon, 2005).

De tafur, El-Sharkawy and Cadavid (1998), reported that early and mid-season stress significantly reduce top and root biomass than late or terminal stress which occurred during tuber maturity in cassava. Rainfall in the rain forest areas of Nigeria is erratic, unpredictable and it is the most critical factor that determines yield in rain-fed agricultural system (Agbaje & Akinlosotu, 2004). Water stress during root and tuber formation reduced cassava yield significantly while that after seven months of planting had no influence on yield (De tafur et al. (1998). This indicated that stress at vegetative and growth stages rather than at post maturity stage caused lower yield in cassava.

Agwu et al. (2012), assessed the relative effect of climate variability on cassava production and the result showed that the climate variables had no significant effect on cassava production which has been attributed to the nature of the crop especially in the area of withstanding extreme weather conditions. According to FAO, (2013), once established, cassava can grow in areas that receive just 400 mm of average annual rainfall. In Nigeria, root yields increased sixfold when the quantity of water supplied by supplementary drip irrigation was equal to that of the season's rainfall (FAO, 2013). Ganiyu et al. (2013), observed no nexus between cassava output and annual rainfall distribution. The results of time trend analysis by Nwaobiala and Nottidge, (2013) showed that the coefficient for rainfall was negatively signed and had effects on the output of cassava between1980-2011.

The Little Dry Season (LDS) of West Africa is manifested as a decline in both the frequency and amount of daily rainfall for a number of weeks halfway through the rainy season (Adejuwon & Odekunle, 2006). The occurrence of the LDS in space and time is explained by the movements of the intertropical discontinuity and its associated zone of rainfall (Ilesanmi 1981). Variability in the severity of the LDS has mixed implications for agricultural practices. Omotosho, (1988) showed that the phenomenon is peculiar to the part of West Africa lying between 4° and 9°N and 7°E and 12°W. This means that the area of occurrence of this phenomenon in Nigeria is limited and peculiar to the southwestern part between 4°–9°N and 3°–7°E as shown in Figure. 16

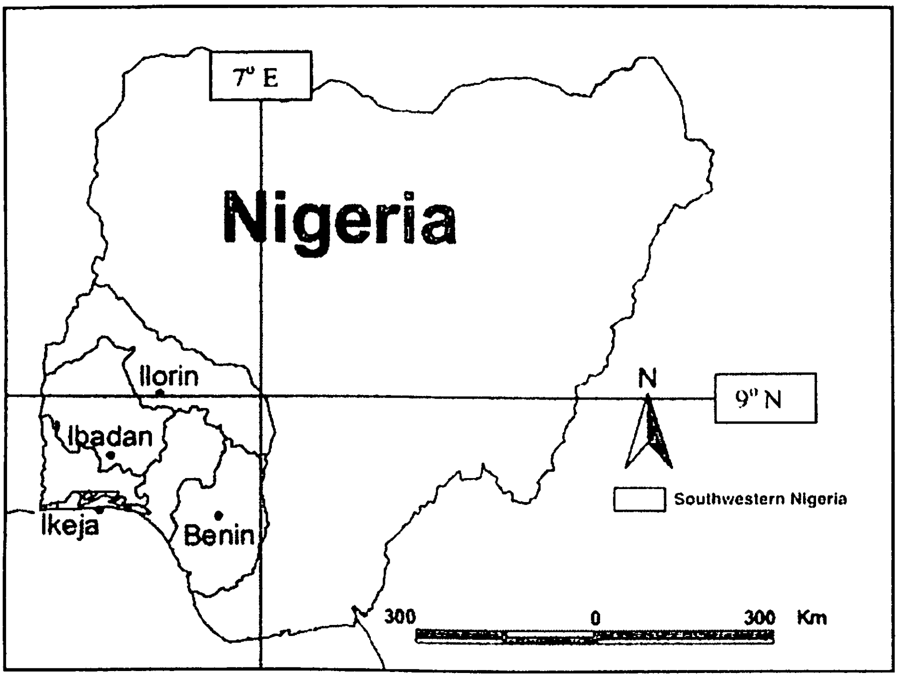


Figure 17: *Southwestern Nigeria, source: Adejumo and Odekunle, (2006)*

A study conducted by Moreno and Gourdji (2015), in Colombia concluded that increased rainfall after a dry period during the last three months before harvest results in lower starch content in cassava due to an increase in translocation (movement of assimilates from the root to the top of the plant). This is further exacerbated at the start of the rainy season as new shoots sprouts as soon as water is available. The distribution of the cyanogenic potential in cassava germplasm has been found to be a continuum from very low values to high levels. Within the same genotype, the cyanogenic potential is affected by the planting season; it is low when planted at the beginning of the rainy season, and high when planted at the end of the rainy season (Bokanga et al. 1994). They further stated that water stress is known to increase the cyanogenic potential and that the cyanogenic potential of a genotype can increase up to five-fold when planted in a different location. The genotype-environment interactions are less pronounced but significant; some genotypes maintain the same cyanogenic potential ranking when planted in various agroecological zones, even though the absolute values of cyanogenic potential may be increased or decreased (Bokanga et al.).

The specific objectives of this study are to:

1. Determine the effect of intra-annual rainfall variability on the starch content of cassava harvested at two experimental sites (Oke-oyi and Ikenne)

2. Determine the effect of intra-annual rainfall variability on (sequential) yield of cassava harvested at different times at the two experimental sites

3. Determine the effect of intra-annual rainfall variability on cyanogenic potential content of cassava

## Materials and Methods

### Experimental Sites

Description of the study sites, climate, vegetation, geology and soil, soil sampling and characterization are as described in 3.1

### Experimental Materials

***Cassava varieties: as described in 3.3.1 and table 4***

### Cultural Practices

All cultural practices were as described in Chapter 3.

### Experimental Design, Treatments and Field Layout: as described in Chapter 3

### Field Measurement of Crop Parameters

As described in Chapter 3

### Meteorological Data

Meteorological data for the two experimental sites were sourced from Lower Niger River Basin Development Authority, Ilorin and Nigerian Meteorological Agency, Oshodi, Lagos for Oke-oyi and Ikenne respectively for the period of sixteen years (2000-2015).

### Statistical Analysis

Data were analyzed using the summary statistics from Microsoft excel 2007 Windows 7.

## Results

### Weather Data

Rainfall and temperature data obtained for Oke-oyi and Ikenne are presented in Figures 17 and 18. Total annual rainfall values obtained during the growing period were 1282.10 mm and 1789.1 mm for Oke-oyi and Ikenne respectively. The highest monthly amount of rain received at Oke-oyi during the planting season was 391.6 mm in September 2014 while Ikenne received its highest amount of rainfall of 333.9, July 2014. The cassava plants did not receive any rains in November and December at Oke-oyi and January at Ikenne.

Highest monthly maximum temperatures (35.96 $^{o}$C and 34.5 $^{o}$C) and lowest monthly minimum temperatures (18.55$^{o}$C and 21.5$^{o}$C) were recorded in the same months (February and January) at both experimental sites (Oke-oyi and Ikenne) respectively.

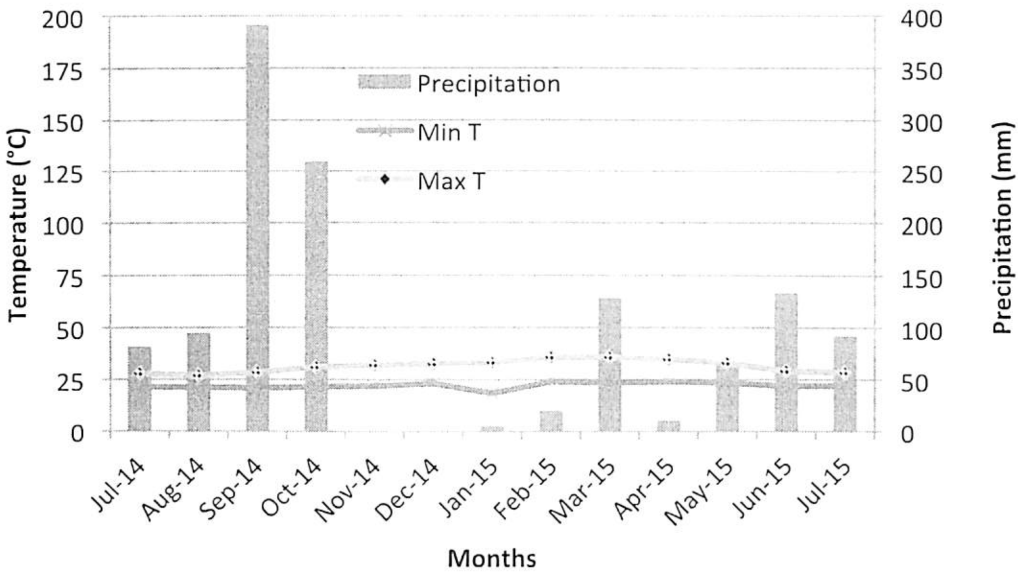


*Figure 18*: Rainfall and temperature at Oke-oyi during the planting period

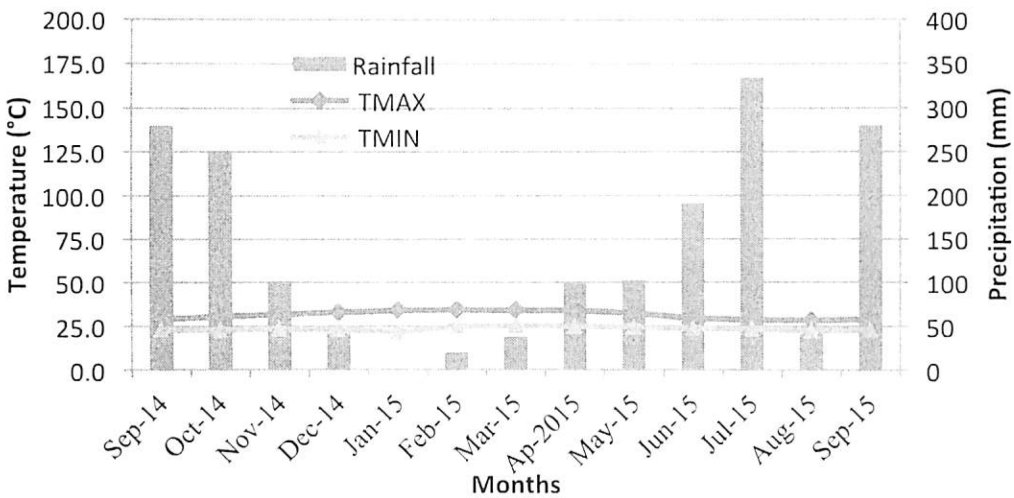


*Figure 19*: Rainfall and temperature at Ikenne during the planting period

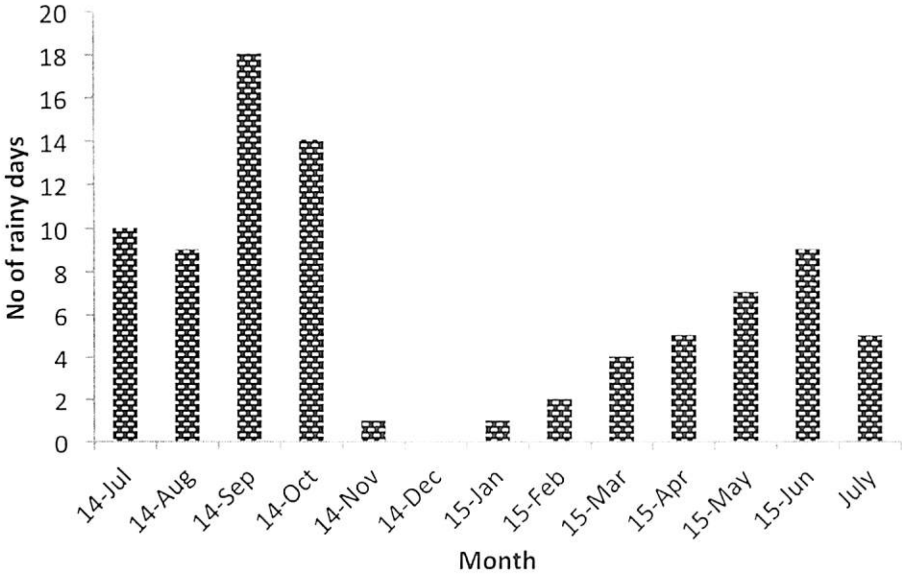


*Figure 20*: Number of raining days per month during the study period at Oke-oyi

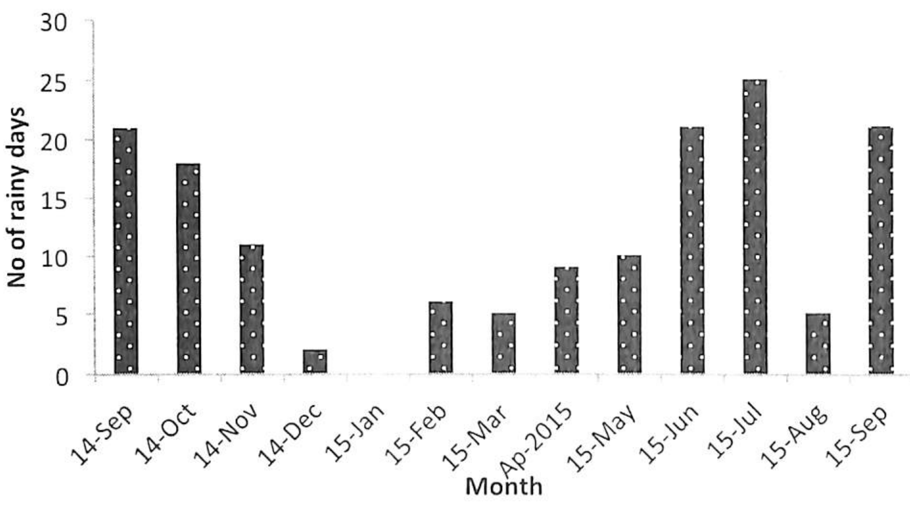


*Figure 21*: Number of raining days per month during the study period at Ikenne

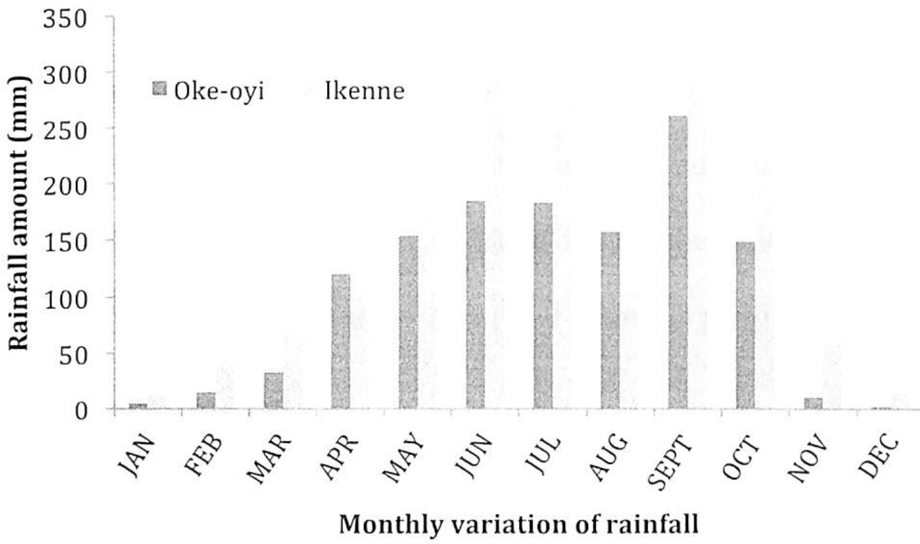


*Figure 22*: Average monthly trend in rainfall pattern 2000-2015 showing the bi-modal rainfall pattern in Ikenne and uni-modal rainfall pattern in Oke-oyi

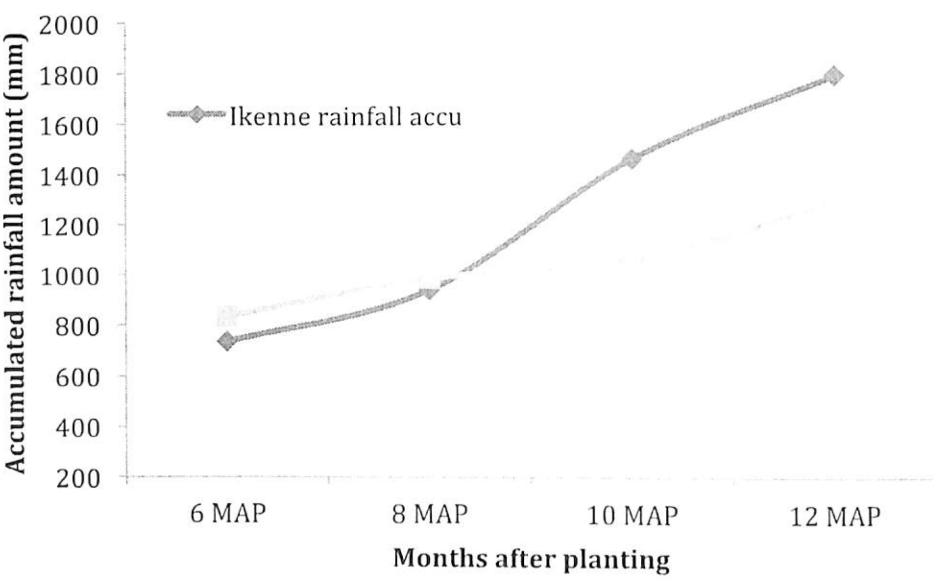


*Figure 23*: Accumulated rainfall at each harvest time at both experimental sites

## Effect of Intra-Seasonal Rainfall Variability on Total Dry Matter and Quality of Cassava Varieties

The results of location specific intra-seasonal rainfall variability on root dry matter content, root dry matter yield, cyanide concentration and starch content at both experimental sites are shown in Figures 23 to 30.

### Root Dry Matter Yield

The effect of intra-seasonal rainfall variability on root dry matter yield of cassava varieties are presented in Fig. 23 and 24 for Oke-oyi and Ikenne experimental sites respectively. At Oke-oyi, cassava varieties were different in their response to accumulated rainfall amount. At 6 MAP, TMS 30572 with a rainfall total of 833 mm had the highest root dry matter yield and was significantly different from TMS 91/02324. At 8 MAP, with an increase of 148.8mm of rainfall TMS 98/0505 had the highest amount of root dry matter yield and was significantly different from TMS 91/02324. At 10 and 12 MAP, TME 419 and TMS 98/0505 with additional increase in rainfall amount of 74.3 mm and 226 mm were significantly different from TMS 30572 and TMS 91/02324 respectively. While other varieties increase in root dry matter yield, Oko-iyawo and TMS 30572 had a reduction in the amount of root dry matter yield from 6 to 10 MAP

At Ikenne, there was significant difference ($p<0.05$) in dry matter yield of all cassava varieties with increasing amount of rainfall. At 6 to 10 MAP TMS 98/0505 had the highest dry matter yield at the accumulated rainfall amount of 1459.6 mm; TMS 91/02324 had the highest dry matter yield at

1789.1 mm rainfall while Oko-iyawo had the lowest dry matter yield at all harvesting time. TMS 98/0505 and TMS 91/02324 were significantly different from Oko-iyawo at all harvest time. At Ikenne, there was a progressive increase of DYLD from 6 to 12 MAP.

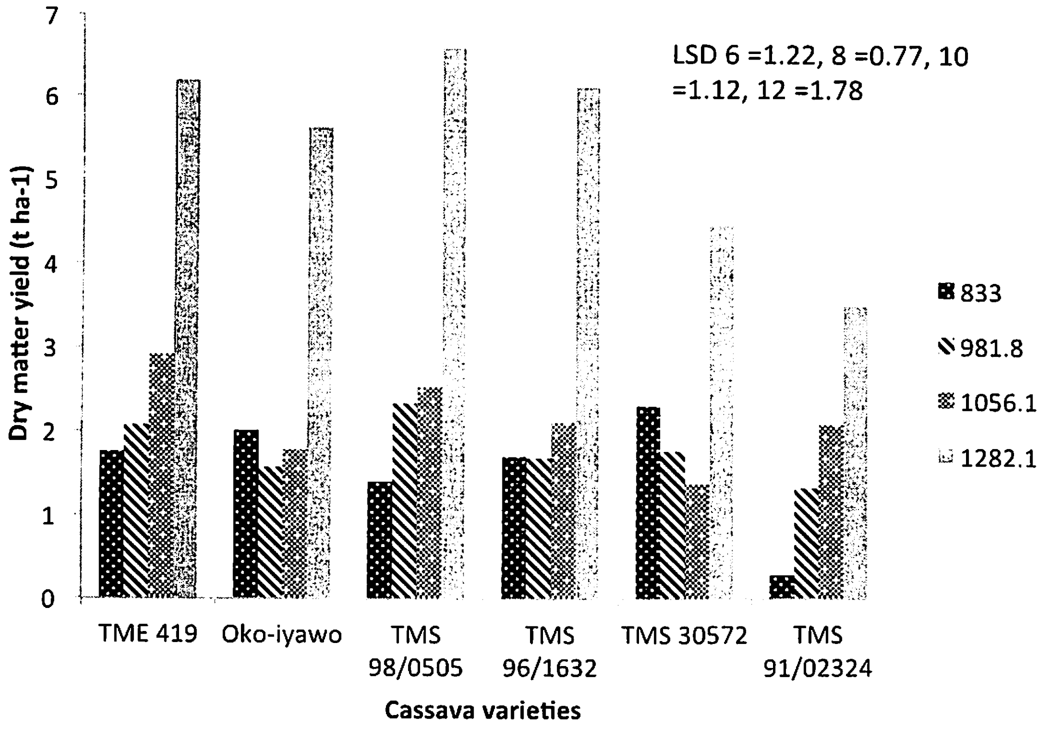


*Figure 24*: Accumulated amount of rainfall on root dry matter yield of cassava varieties at Oke-oyi

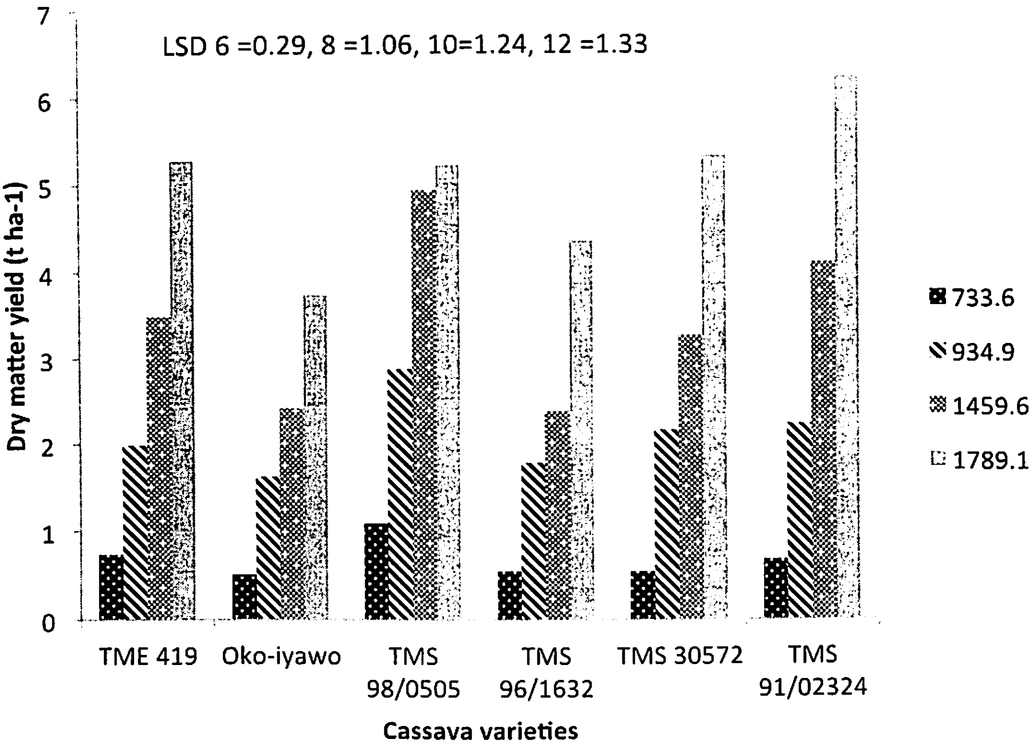


*Figure 25*: Accumulated amount of rainfall on root dry matter yield of cassava varieties at Ikenne

**Root Tuber Dry Matter Content**

Intra-seasonal rainfall effect on root tuber dry matter content showed that dry matter accumulation was highest at 833 mm and lowest at 981.3 mm and 1056.1 mm accumulated rainfall. Increase in the amount of rainfall from 833 mm to 981.3 mm accumulated rainfall resulted in reductions in dry matter content of cassava varieties. At Oke-oyi, there was significant difference ($p<0.05$) only at 981.3 mm and 1282.1 mm. At both times TMS 96/1632 was significantly different from TMS 91/02324.

At Ikenne, dry matter content of cassava varieties increased gradually at from 733.6 mm to 1789.1 mm accumulated rainfall amount. At Ikenne, accumulated increase in rainfall resulted in increase in dry matter content of cassava varieties. There was significant difference ($p<0.05$) at all harvest time among the cassava varieties. TMS 91/02324 was significantly different ($p<0.05$) from TMS 30572 at 733.6 mm while TME 419 differed significantly ($p<0.05$) from TMS 91/02324 at 934.9 mm and 1459.6 mm accumulated rainfall amount and from TMS 96/1632 at 1789.1 mm of rainfall.

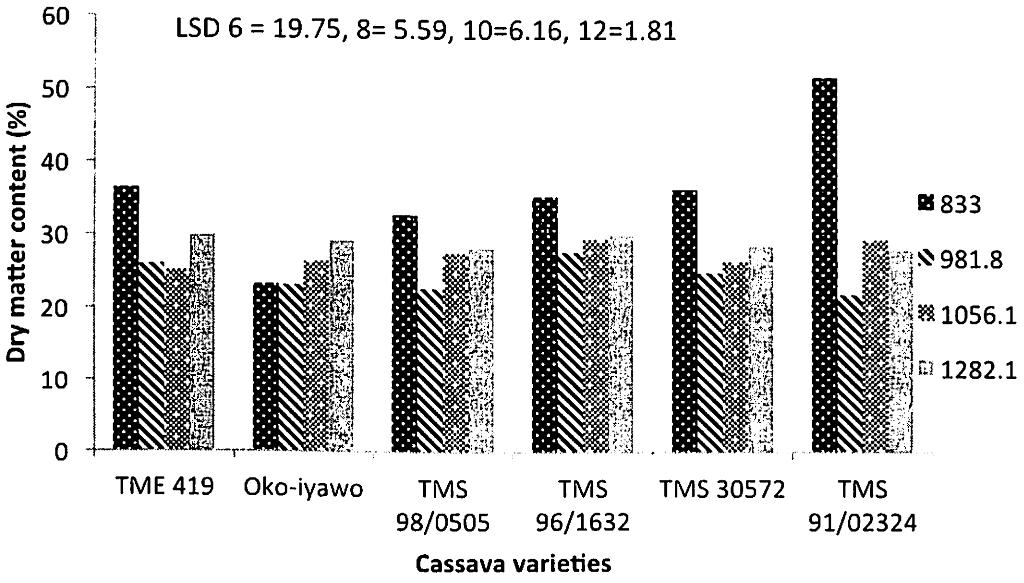


*Figure 26*: Accumulated amount of rainfall on root dry matter content of cassava varieties at Oke-oyi

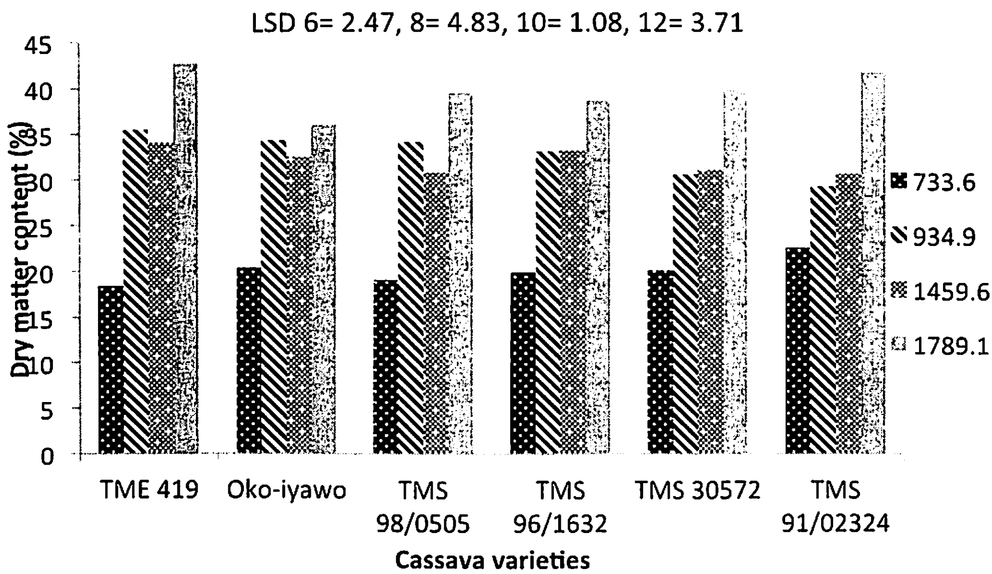


*Figure 27*: Accumulated amount of rainfall on root dry matter content of cassava varieties at Ikenne

## Cyanide Potential

Cyanide potential of cassava varieties at Oke-oyi with accumulated rainfall showed that there is significant difference at all harvesting times except at 10 MAP. TMS 96/1632 had the highest concentration of cyanide potential and was significantly different ($p<0.05$) from TME 419 at 833mm and 1282.1 mm accumulated rainfall amount, TMS 91/02324 was significantly different from TME 419 at 981.3 mm of accumulated rainfall. Cyanide potential was lowest at 10 MAP with 1056.1 mm accumulated amount of rainfall and highest at 12 MAP with 1282.1 mm accumulated amount of rainfall.

At Ikenne experimental site, there was significant difference in cyanide potential of cassava varieties at all harvesting times. TMS 96/1632 was significantly different ($p<0.05$) from TME 419 at 733.6 mm and 934.9 accumulated amount of rainfall, TMS 91/02324 $p<0.05$ from TME 419 at 1459.6 mm accumulated rainfall and TMS 30572 $p<0.05$ from TMS 91/02324 at 1789.1 mm accumulated rainfall.

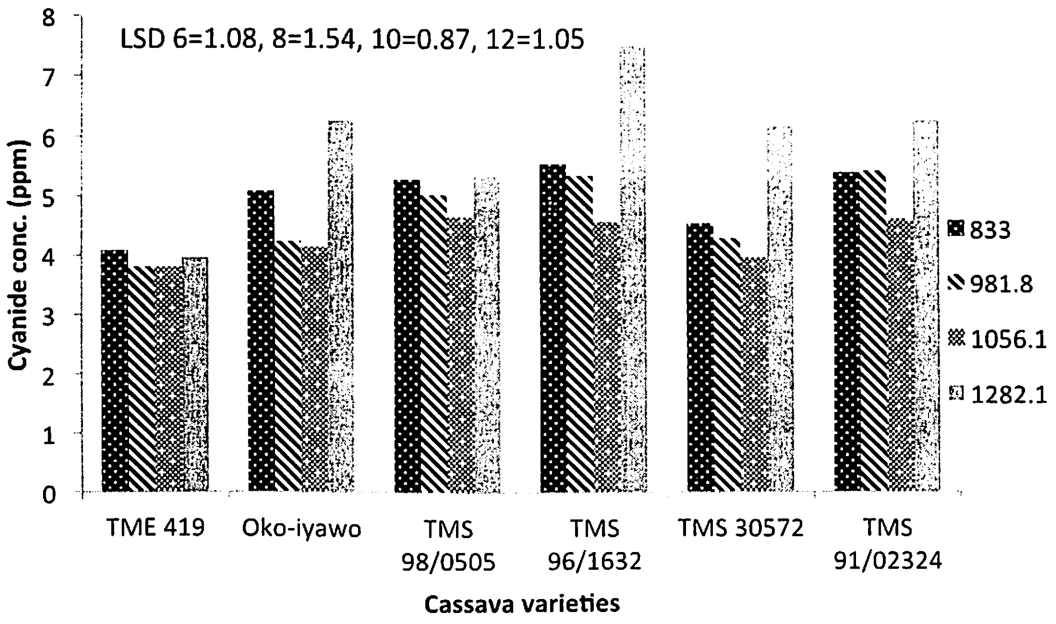


*Figure 28*: Accumulated amount of rainfall on cyanide potential of cassava varieties at Oke-oyi

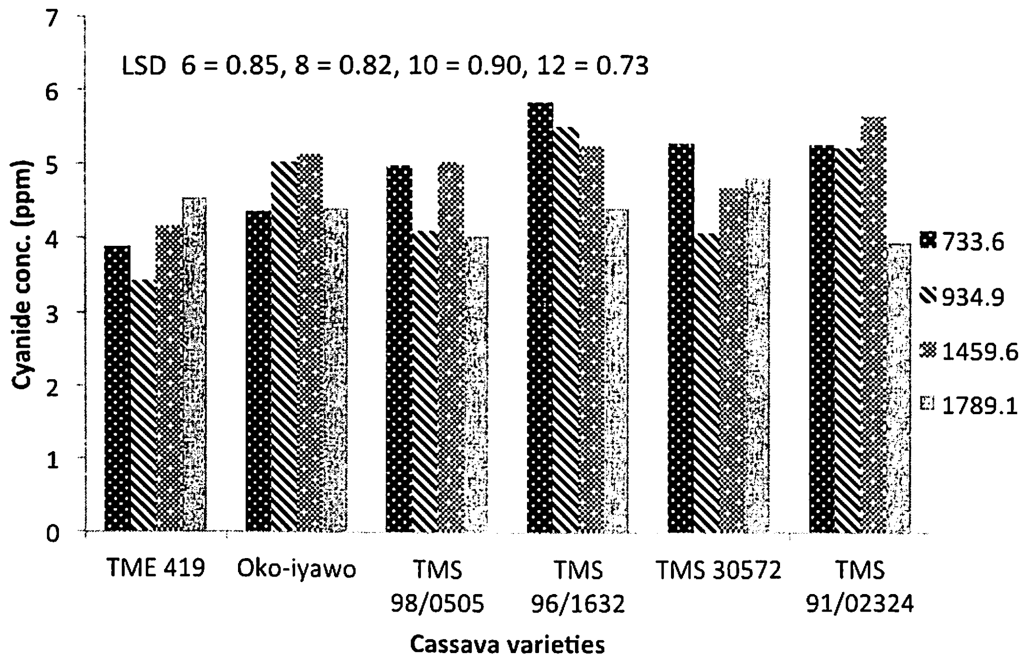


*Figure 29*: Accumulated amount of rainfall on cyanide potential of cassava varieties at Ikenne

**Starch Content of Cassava**

Starch content of cassava at the two locations showed distinct difference with cassava varieties producing more starch at Ikenne than at Oke-oyi.

At Oke-oyi, there was significant difference among the cassava varieties only at 981.3 mm and 1282.1 mm accumulated amount of rainfall. TMS 96/1632 had the highest starch content and was significantly different ($p<0.05$) from TMS 91/02324 at 981.3 mm and 1282.1 mm. TMS 96/1632 had the highest starch content at 1056.1 mm accumulated amount of rainfall though not significant.

However, at Ikenne, starch content of cassava varieties increased from 733.6 mm accumulated rainfall to 1789.1 mm accumulated rainfall amount.

TME 419 had the highest starch content from 934.9 mm to 1789.1 mm accumulated rainfall amount and was significantly different ($p<0.05$) from TMS 30572 at 934.9 mm and 1459.6 mm and TMS 96/1632 at 1789.1 mm accumulated rainfall amount.

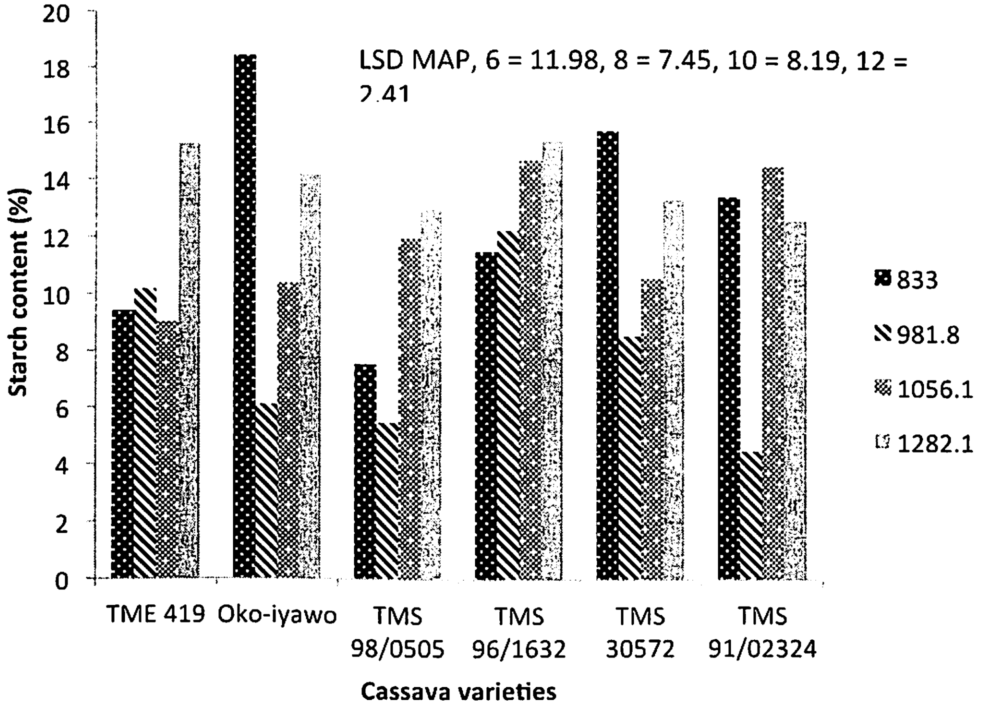


*Figure 30*: Accumulated amount of rainfall on starch content of cassava varieties at Oke-oyi

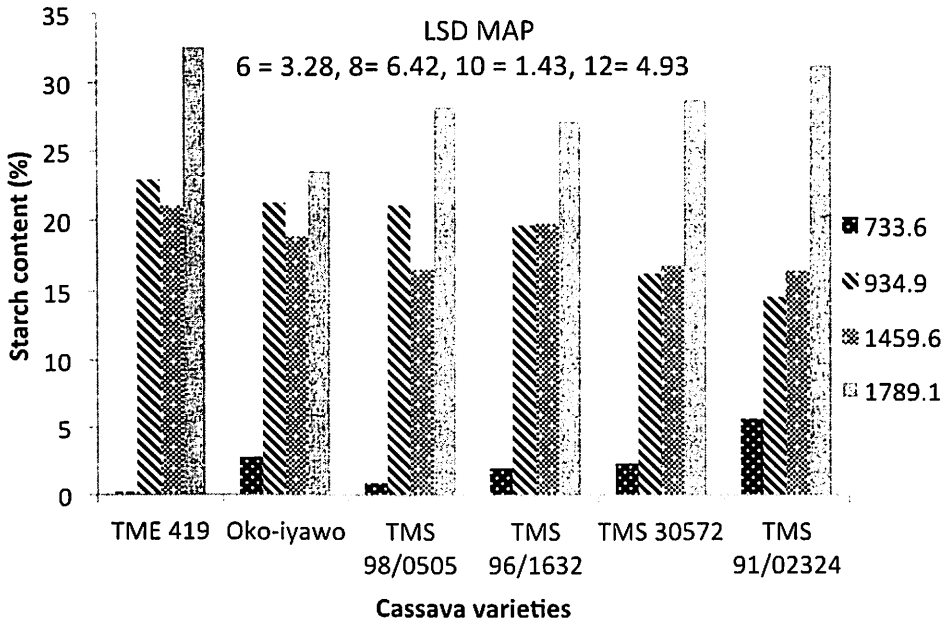


*Figure 31*: Accumulated amount of rainfall on starch content of cassava varieties at Ikenne

**Discussion**

The objectives of this chapter were to determine the effect of intra-annual rainfall variability on root dry matter content, root dry matter yield, cyanide concentration and starch content of cassava varieties at Oke-oyi and Ikenne experimental sites.

Cassava starch yield in Ikenne increased with increasing rainfall amount reaching its highest amount at 12 MAP. This result agrees with the work of Santisopasri et al. (2001), Ebah-Djedji et al. (2012). However, at 6 MAP at Ikenne, the starch content was very low. This could be due to the fact that cassava was not physiologically matured so the starch contents are poor as well as dry matter content. As the crop matures both the dry matter content and starch percentage increases. Another explanation is the time of starch evaluation. 6 MAP evaluations at Ikenne fell into the period of onset of rains and at this time cassava starch reading are known to be extremely poor (Moreno & Gourdji, 2015) which could be due to translocation.

The cyanogenic potential of cassava at Oke-oyi experimental site was in the order of 12 MAP > 6 MAP > 8 MAP > 10 MAP. Rainfall variability and total amount does not necessarily lead to lower cyanogenic potential in the cassava varieties at Oke-oyi. The increase in cyanogenic potential at 12 MAP with its attended rainfall increase of 271mm over 10 MAP shows the complexity of cassava cyanogenic potential characteristics as stated also by Bokanga et al. (1994).

At Ikenne, the cyanogenic potential of cassava varieties reduced with increasing rainfall amount. Cyanogenic potential of cassava varieties at 6 and 10 MAP were higher than at 8 and 12 MAP. At 6 MAP, cassava varieties had received 733 mm of rainfall, at 8 MAP cassava varieties had an additional 201.9 mm which resulted in a decrease in cyanogenic potential at 8 MAP. Between 8 and 10 MAP, cassava varieties had 524.7 mm of rainfall which resulted in an increased cyanogenic potential while additional rainfall amount of 329.5mm at 12 MAP caused a decrease in cyanogenic potential of cassava varieties at 12 MAP. The non-availability of rainfall two months before first harvest at 6 MAP could have resulted in the higher cyanogenic potential while the increase in rainfall amount before final harvest at 12 MAP could have caused the reduction in cyanogenic potential. This corroborates with the findings of Okechukwu et al. (2010) and Bokanga et al. (1994).

Dry matter content of cassava roots in Oke-oyi, did not increase with increasing amount of rainfall. 6 MAP evaluations of cassava varieties at Oke-oyi were in the dry season, when growth rates were reduced, whereas 8 and 10 MAP evaluations were at the onset of rainy season when dry matter and starch contents are known to decrease due to translocation. Thus, the variations in the storage root dry matter contents at the experimental sites over the harvest times followed a seasonal pattern (Hammer, Hobman, & Shepherd, 1987; Sagrilo et al. 2003).

Root dry matter yield of cassava varieties with accumulated amount of rainfall caused an increased for all varieties except for Oko-iyawo and TMS 30572 at Oke-oyi.

# CHAPTER EIGHT

# GENERAL DISCUSSION

## Revisiting the Original Objectives

The purpose of the research is to quantify yield (quantity and quality) response of six cassava varieties to different management options in rainforest and guinea savannah agro-ecological zones of Nigeria. The specific objectives are to:

1. Determine the effect of different harvest periods on biomass production, fresh root yield, root dry matter yield, hydrogen cyanide concentration and starch contents from the root of two cassava varieties
2. Determine the interactive effect of fertilizer application with harvesting time on the above variables
3. Determine yield and total dry matter response of six different cassava varieties to the application of different fertilizer NPK types (NPK 15-15-15, NPK 20-10-10 and NPK 12-12-17) and rates (150 $kgha^{-1}$ and 300 $kgha^{-1}$)
4. Determine quality response of different cassava varieties to the application of different fertilizer NPK types (NPK 15-15-15, NPK 20-10-10 and NPK 12-12-17) and rates (150 $kgha^{-1}$ and 300 $kgha^{-1}$)

5. Determine locational effects of intra-seasonal rainfall variability on quality and total dry matter cassava varieties at two different agro-ecological zones of Nigeria.

**Initial Soil Properties**

The low amount of total nitrogen in the experimental soils was as a result of the low organic carbon which is due to burning practices and lack of applied crop residues (Fosu-Mensah, 2012) to the fields. Low extractable P value at Ikenne indicates P deficiency (Landon, 1996). K values are low in both soils, at Ikenne, probably because cassava was previously planted on the soil and large K export occured in harvested roots (El-Sharkawy & Cadavid, 2000). At Oke-oyi, K may have been highly depleted before the land was left to fallow and not yet well replenished in the soil.

**Harvest Index**

The harvest index, defined as the ratio of economic yield to biological yield is used to describe the accumulation and distribution of assimilates to achieve final yield (Bange, Hammer, & Rickert, 1998; Fosu-Mensah (2012). HI is defined as the proportion of root weight to total plant weight at harvest (Kawano et al. 1978a). The result revealed that TMS 98/0505 and TMS 96/1632 had the HI regardless of the site. This shows the effect of variety on HI. All HI values were greater than 0.5 except for TMS 91/02324 at 12 MAP at Oke-oyi.

According to Ramanujam (1985), HI of cassava ranges between 0.30-0.65. In this study, the treatments that promote better growth of cassava had a positive influence on HI, presumably due to faster growth and portioning of more carbohydrates into the root.

## Total Dry Matter Content of Roots

The variations in the storage root dry matter contents over the harvest times followed a seasonal pattern (Hammer et al. 1987) and were higher in slow growing and plant rest periods and decreased sharply during the canopy regeneration and active growth periods (Sagrilo et al. 2003). The high dry matter content observed in the first harvest at Oke-oyi were as a result that the harvesting was done during the dry season while subsequent reduction in these values (during the raining season) was probably caused by the need to mobilize assimilates (starch and dry matter) from storage roots to meet the demand of new forming plant structures (Sagrilo et al. 2003). According to Keating et al. (1982), the end of the slow growth period represents the best harvest time, because of the high contents of dry matter and starch.

## Above Ground Biomass

The above ground biomass of cassava varieties in experiment one responded to fertilizer application. Response of above ground biomass production to fertilizer application of cassava varieties was higher at Ikenne than at Oke-oyi. This could be as a result of the fact that the Oke-oyi experimental site was under fallow before the establishment of the experiment, thus availability of nutrients in the soil without fertilizer application was higher than at Ikenne.

In experiment two, the above ground biomass at Oke-oyi showed that TMS 98/0505 responded best to NPK 12-12-17 at 300 kg ha$^{-1}$ while TME 419 responded more to NPK 20-10-10 at 150 kg ha$^{-1}$ at Ikenne.

**Harvest Times**

Biomass production of leaves of cassava varieties increased with length of growing cycle at Oke-oyi while in Ikenne it progressively decreased from 6 to 12 MAP. Stem dry matter content of cassava at both experimental sites decreased as the cassava plant matured. As shown in the results section greater amount of dry matter was partitioned to the root (Lahai & Ekanayake, 2009) as the cassava varieties matured. Fresh storage root yield of cassava varieties at both locations also increased from 6 to 12 MAP at both experimental sites (Mulualem & Ayenew, 2012), especially at Oke-oyi where root weight gain from 10 to 12 MAP was > 50% for all the varieties. As cassava root weight increases, starch content of all cassava varieties increased from 6 to 12 MAP at both experimental sites. Cassava varieties produced more starch at Ikenne than at Oke-oyi except at 6 MAP. Some striking differences in varietal characteristic were detected especially for Oko-iyawo which had high average starch content at the first harvest (6 MAP) but showed a significant decrease when compared to other varieties at subsequent harvest dates. This result corroborates with the findings of Sagrilo et al. (2003) in Brazil. The effect of harvesting time on HCN of cassava varieties show that the inherent varietal characteristic (IITA, 1990), played major role in the exhibition of HCN concentration of cassava varieties at both experimental sites.

**Yield of Cassava in Response to Fertilizer Type and Rate**

Low and moderate rate of the NPK fertilizers showed that there was no significant difference between the two rates of fertilizer application regarding fresh storage root yield at both experimental sites. Similar trend was observed for fertilizer types for fresh storage root weight. Root dry matter content and dry matter yield followed a similar trend with fertilizer rate at both experimental sites. Effect of fertilizer types on dry matter yield at Oke-oyi showed no significant difference but at Ikenne NPK 12-12-17 performed significantly better than the other fertilizer types. Quality (Starch and HCN) of cassava varieties also followed a similar trend with fertilizer rates and types whereby there was no significant difference in their response to fertilizer application.

# CHAPTER NINE

# SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

## Summary and Conclusions

Cassava is one of the most important food crops and a popular one in the farming system of most Nigerian farmers. The performance and productivity of the crop is influenced by the fertility status of the soil and the harvesting time. The study was carried out to evaluate quantity and quality response of six cassava varieties to different management options in the rainforest and guinea savannah agro-ecological zones of Nigeria.

Field experiments were conducted between 2014 and 2015 at Oke-oyi (Guinea savannah) and Ikenne (Rainforest) to determine the effects of fertilizer treatments (types and rates) and harvesting date on the yield and quality of cassava. Three types of NPK fertilizers (NPK 15-15-15; NPK 20-10-10 and NPK 12-12-17) at two rates (150 kg $ha^{-1}$ and 300 kg $ha^{-1}$) and non-fertilized plots as control were evaluated on the performance of six cassava varieties. Four periods of harvesting (6, 8, 10 and 12 MAP) were also investigated to determine the optimum period of harvest. The experiments were evaluated using the split split plot arrangement in a randomized complete block design (RCBD) and replicated three times.

The major findings of the study are summarized as follows:

1. Application of NPK 12-12-17 was an appropriate cassava fertilizer in producing optimum fresh cassava root yield at both experimental sites.

2. The effects of fertilizer rates on fresh roots yield was only significant at Ikenne, but not at Oke-oyi due to a previous fallow at Oke-oyi
3. Harvesting of cassava roots during the dry season at Oke-oyi gave the highest starch and dry matter content.
4. Application of NPK 20-10-10 fertilizer type was effective to produce optimum above ground dry matter yield at Ikenne at 10 and 12 MAP without being statistically significant.
5. Fertilizer application causes reduction of HCN in the roots of cassava varieties at Ikenne but this was statistically significant only at 12 MAP and with the rate of 300 kg $ha^{-1}$
6. Cassava varieties had higher fresh root weight at Oke-oyi than at Ikenne because of higher nutrient availability but dry matter content of cassava varieties at Ikenne was higher than that of Oke-oyi except at 6 MAP.
7. Root dry matter content at 12 MAP was highest with TME 419 compared to the other cassava varieties at both experimental sites. However, at Ikenne, root dry matter yield was highest with TMS 91/02324, TMS 30572 and TME 419 at 12 MAP. At Oke-oyi, highest root dry matter yields were obtained with TMS 98/0505, TME 419 and TMS 30572 at 12 MAP.

**Recommendations**

A. This study should be further replicated in other agro-ecological zones of Nigeria suitable for cassava cropping with the inclusion of organic fertilizer types.

B. Further study should be carried out in the dry season showing the impact of irrigation on cassava and quantifying the potential biomass production and yield

C. Future study should also concentrate on the development of crop models for cassava production under irrigated and non-irrigated conditions.

## REFERENCES

Adedeji, O. H., & Gbadegesin, A. S. (2012). Base Cation Leaching From the Canopy of a Rubber (*Hevea brasiliensis* Willd. Muell-Arg) Plantation at Ikenne, South West Nigeria. *Ethiopian Journal of Environmental Studies and Management, 5*(4), 384-390.

Adejuwon, J. O. (2005). Food Crop Production in Nigeria:1 Present effects of Climate Variability. *Inter Research Climate Research, 30*, 53-60.

Adejuwon, J. O., & Odekunle, T. O. (2006). Variability and the Severity of the "little Dry Season" in southwestern Nigeria. *Journal of Climate, 19*(3), 483-493.

Adejuwon, S. A. (2004). *Impacts of climate variability and climate change on crop yield in Nigeria. In stakeholders' workshop on assessment of impacts and adaptation to climate change.* Obafemi Awolowo University, Nigeria.

Adeoti, O. (2010). Water use impact of ethanol at a gasoline substitution ratio of 5% from cassava in Nigeria. *Biomass and Bioenergy, 34*(7), 985-992.

Aderi, O. S., Ndaeyo, N. U., & Edet, U. E. (2010). Growth and yield responses of four cassava morphotypes to low levels of NPK fertilization in a humid agro ecology of South-eastern Nigeria. *Nigerian Journal of Agriculture, Food and Environment, 16*, 34-43.

Adesina, A. (2008). *Achieving Africa's Green Revolution: Lessons for Transforming Nigeria's Agriculture.* Paper presented at the

International Conference on Food Security on "Global Food Crisis: Nigeria's Economic Opportunity", Abuja, Nigeria.

Adeyemi, A. A. (1991). *Cropping pattern and NPK (15-15-15) fertilization in cassava/maize/melon intercropping system.* PhD doctoral dissertation, University of Ibadan, Ibadan.

Agbaje, G. O., & Akinlosotu, T. A. (2004). Influence of NPK fertilizer on tuber yield of early and late-planted cassava in a forest Alfisol of south-western Nigeria. *African Journal of Biotechnology, 3*(10), 547-551.

Agwu, N. M., Nwachukwu, I. N., & Anyanwu, C. I. (2012). Climate Variability: Relative Effect on Nigeria's Cassava Productive Capacity. *Report and Opinion, 4*(12), 11-14.

Aina, O. O. (2006). *Influence of shoot and root charcteristics on tuber yield of cassava.* PhD doctoral dissertation, University of Ibadan, Ibadan.

Akoroda, M. O. (2005). Root Crops (pp. 537). Ngaounudere, Cameroon: Institute of Agricultural Research.

Akoroda, M. O., & Okechukwu, R. U. (Eds.). (2007). *Agrolyser for Cassava: Lessons Learned.* Ibadan, Nigeria: IITA.

Alexandratos, N., & Bruinsma, J. (2012). World agriculture towards 2030/2050: the 2012 revision In FAO (Ed.), *ESA Working paper* (Vol. 12-03, pp. 4). Rome.

Alimentarius, C. (2003). Codex principles and guidelines on foods derived from biotechnology. Codex Alimentarius Commission, Joint

FAO/WHO Food Standards Programme, Food and Agriculture Organisation. Rome: Food and Agriculture Organisation, Rome.

Alleman, J., & Dugmore, N. (2004). Potential for cassava production in the Bathurst region of the Eastern Cape Province of South Africa. *African Crop Science Journal, Vol.12*(3), 275-281.

Alves, A. A. C. (2002). Cassava botany and physiology. In Hillocks, R. J., Thresh, J. M., & Bellotti, A. (Eds.). *Cassava: Biology, production and utilization*. 67-89. CABI. Netherlands

Ande, O. T. (2011). Soil suitability evaluation and management for cassava production in the derived savanna area of Southwestern Nigeria. *International Journal of Soil Science, 6*(2), 142.

Apea-Bah, F. B., Oduro, I., Ellis, W. O., & Safo-Kantanka, O. (2009). Principal components analysis and age at harvest effect on quality of gari from four elite cassava varieties in Ghana. *African Journal of Biotechnology, 8*(9), 943-949.

Apea-Bah, F. B., Oduyo, I., Ellis, W. O., & Safo-Kantaka, O. (2011). Factor analysis and age at harvest effect on quality of flour from four cassava varieties. *World Journal of Dairy and Food Sciences, 6* (1), 43-54.

Ashoka, P. V., Nair, S. V., & Kurian, T. M. (1984). Influence of stages of harvest on the yield and quality of cassava (*Manihot esculenta* Crantz) Mandraos. *Agric. J, 71*, 447-449.

Assanvo, J. B. (2008). *Surveys of production and consumption of traditional Ivorian attieke and characteristic organoleptic attieke from four* *cassava varieties.* Doctoral dissertation, University of Cocody-Abidjan, Abidjan.

Ayanlade, A., Odekunle, T. O., & Orimoogunje, O. O. (2010). Impacts of climate variability on tuber crops in Guinea Savanna Part of Nigeria: A GIS Approach. *Journal of Geography and Geology, 2*(1), 27.

Ayling, S., Ferguson, M., Rounsley, S., & Kulakow, P. (2012). Information resources for cassava research and breeding. *Tropical Plant Biology, 5*(1), 140-151.

Ayoola, O. T. (2010). Yield performance of crops and soil chemical changes under fertilizer treatments in a mixed cropping system. *African Journal of Biotechnology, 9*(26), 4018- 4021.

Ayoola, O. T., & Makinde, E. A. (2011). Cassava/maize intercrop performance and soil nutrient changes with fertilizers. *Journal of Agricultural Science, 3*(4), 136.

Badiane, O., & Delgado, C. L. (2002). A 2020 vision for food, agriculture, and the environment in sub-Saharan Africa. Washington DC USA. *Intl Food Policy Res Inst.*

Bange, M. P., Hammer, G. L., & Rickert, K. G. (1998). Temperature and sowing date affect the linear increase of sunflower harvest index. *Agronomy Journal, 90*(3), 324-328.

Bassey, E. E., & Harry, G. I. (2013). Screening cassava (*Manihot esculenta* Crantz) genotypes for tuber bulking, early maturity and optimum harvesting time in Uyo, South Eastern Nigeria. *Peak Journal of Agricultural Sciences, 1*(5), 83-88.

Beeching, J. R., Marmey, P., Gavalda, M. C., Noirot, M., Haysom, H. R., Hughes, M. A., & Charrier, A. (1993). An assessment of genetic diversity within a collection of cassava (*Manihot esculenta* Crantz) germplasm using molecular markers. *Annals of Botany, 72*(6), 515-520.

Beeching, J. R., Niger, T., & Tohman, J. (2000). *Postharvest physiological deterioration of cassava. Proceedings of 12th Symposium of International Society of Tropical Root Crops*. Tsukuba, Japan.

Benesi, I. R. M., Labuschagne, M. T., Dixon, A. G. O., & Mahungu, N. M. (2004). Genotype x enviroment interaction effects on native cassava starch quality and potential for starch use in the commercial sector *African Crop Science Journal, 12*(3), 205-216.

Black, C. A., Evans, D. D., & Dinauer, R. C. (1965). *Methods of soil analysis* (Vol. 9, pp. 653-708). Madison USA.American Society of Agronomy.

Bokanga, M., Ekanayake, I. J., Dixon, A. G., & Porto, M. C. (1994). Genotype-environment interactions for cyanogenic potential in cassava. *Acta Hort.* 375, pp 131-139.

Braima, J., Neuenschwamder, H., Yaninek, F., Cudjoe, J. P., Exhendu, N., & Toko, M. (2000). *Pest Control in Cassava farms: IPM Field Guide for Extension Agents*. Lagos, Nigeria: Wordsmiths Printers.

Bremner, J. M., & Mulvaney, C. S. (1982). Nitrogen—total. *Methods of soil analysis. Part 2. Chemical and microbiological properties*, (methods of soil an2), 595-624. Madison, USA.

Bud, S. Q. (2008). Cassava Stalk (Java) black fungus cultivation key technologies. *Journal of fungi, 3*, 36-37.

Burns, A. E., Bradbury, J. H., Cavagnaro, T. R., & Gleadow, R. M. (2012). Total cyanide content of cassava food products in Australia. *Journal of Food Composition and Analysis, 25*(1), 79-82.

Cardoso, A. P., Mirione, E., Ernesto, M., Massaza, F., Cliff, J., Haque, M. R., & Bradbury, J. H. (2005). Processing of cassava roots to remove cyanogens. *Journal of Food Composition and Analysis, 18*(5), 451-460.

Carsky, R. J., & Toukourou, M. A. (2005). Identification of nutrients limiting cassava yield maintenance on a sedimentary soil in southern Benin, West Africa. *Nutrient Cycling in Agroecosystems, 71*(2), 151-162.

Ceballos, H., Iglesias, C. A., Pérez, J. C., & Dixon, A. G. (2004). Cassava breeding: opportunities and challenges. *Plant molecular biology, 56*(4), 503-516.

Chadha, K. L. (2007). *Hand book of horticulture Indian council of agricultural research*. New Delhi: Directorate of Information and Publications of Agriculture.

Chávez, A. L., Sánchez, T., Jaramillo, G., Bedoya, J., Echeverry, J., Bolaños, E. A., & Iglesias, C. A. (2005). Variation of quality traits in cassava roots evaluated in landraces and improved clones. *Euphytica, 143*(1-2), 125-133.

Cock, J. H. (1985). Cassava: physiological basis. In: J. H. Cock and J. A. Reyes (Eds.), *Cassava: Research, Production and Utilization* (pp. 33-62). Columbia CIAT.

Cock, J. H., & Howeler, R. H. (1978). The ability of cassava to grow on poor soils. In G.A. Jung, (Ed.): *Crop Tolerance to Suboptimal Land Conditions* (pp. 145-154). Madison, USA. American Society of Agronomy.

Colombo, C., Second, G., Valle, T. L., & Charrier, A. (1998). Genetic diversity characterization of cassava cultivars (*Manihot esculenta* Crantz). RAPD markers. *Genetics and Molecular Biology, 21*(1)..

Conn, E. E. (1969). Cyanogenic glycosides. *Journal of Agricultural and Food Chemistry, 17*(3), 519-526.

Connor, D. J., & Cock, J. H. (1981). Response of cassava to water shortage II.Canopy dynamics. *Field crops research, 4*, 285 - 296.

Daff, S. A. (2010). *Cassava production guideline*. Pretoria, South Africa: Department of Agriculture, Forestry and Fisheries.

De Tafur, S. M., El-Sharkawy, M. A., & Cadavid, L. F. (1998). Response of cassava (*Manihot esculenta* Crantz) to water stress and fertilization. *Photosynthetica, 34*(2), 233 - 239.

Dixon, A. G. O., Okechukwu, R. U., Akoroda, M. O., Ilona, P., Ogbe, F., Egesi, C. N., Kulakow, P., Ssemakula, G., Maziya-Dixon, B., Iluebbey, P., Yomeni, M. O., Geteloma, C., James, B., Eke-Okoro, O. N., Sanni, L., Ntawuruhunga, P., Tarawali, G., Mahunga, N., Lemchi, J., Ezedinma, C. I., Okoro, E., Kanju, E., Adeniji, A. A., & Nwosu, K.

Ekwe, K., Nwachukwu, C. I., & Ekwe, C. C. (2008). Determinants of improved garri processing technologies utilization and marketing profile among rural households in southeastern Nigeria. *Nig. J. Rural Socio, 8*(1), 1 - 8.

El-Sharkawy, M. A. (1993). Drought-tolerant cassava for Africa, Asia, and Latin America. *BioScience, 43*(7), 441 - 451.

El-Sharkawy, M. A. (2004). Cassava Biology and Physiology *Plant Molecular Biology, 56*, 481-501.

El-Sharkawy, M. A., & Cock, J. H. (1990). Photosynthesis of cassava (*Manihot esculenta*). *Experimental Agriculture, 26*(3), 325 - 340.

Ellis, R. H., & Roberts, E. H. (1979). Germination of stored cassava seed at constant and alternating temperatures. *Annals of Botany, 44*(6), 677 - 684.

Endris, S. (2006). *Cyanogenic potential of cassava cultivars grown under varying levels of potassium nutrition in Southwestern Ethopia.* Paper presented at the Cassava Improvement to Enhance Livelihoods in Sub-Saharan Africa and Northeastern Brazil. First International Meeting on Cassava Breeding, Biotechnology and Ecology, Brasilia, Brazil.

Environmental and Energy Study Institute (EESI). (2016a). Bioenrgy (Biofuels and Biomass) Retrieved 20/01, 2016, from http://www.eesi.org/topics/alternative-fuels/description.

Environmental and Energy Study Institute (EESI). (2016b). Aternative low/ no carbon fuels. Retrieved 20/01, 2016, from http://www.eesi.org/topics/alternative-fuels/description

Ezedinma, C., Udensi, U., Okechukwu, R., Ibana, S., Akoroda, M., Ilona, P., Ogbe, F. O., Sanni, P. L., Lemchi, J., Chikoye, D., & Dixon, A. G. O. (2007). Cassava Weeds and Management in Nigeria. Ibadan, Nigeria. IITA.

Ezedinma, F. O. C., Ibe, D. G., & Onwuchuruba, A. I. (1981). *Performance of cassava in relation to time of planting and harvesting. In Tropical root crops: research strategies for the 1980s.* Paper presented at the first triennial root crops symposium of the International Society for Tropical Root Crops, Africa Branch, International Development Research Centre. Ibadan, Nigeria.

FAO. (1984). *Food and Agriculture Organisation Processing technologies for cassava and other root and tuber crops.* Paper presented at the Proceedings of the workshop on root and tuber crops in Africa 28th November –2nd December,1983, Abijan, Cote D'Ivore.

FAO. (1997a) Human nutrition in the developing world. *Food and Nutrition.* Rome.

FAO. (2000). The places of Agriculture in Sustainable Development: the way forward., *SARD Committee on Agriculture, Sixteenth Session, Item 7 of the provisional Agenda* (pp. 26-30). Rome.

FAO. (2007). Food and Agriculture Organisation, Statistics Division, from http://faostat.org

FAO. (2008). *Cassava improvement to enhance livelihoods in sub-Saharan Africa and north eastern Brazil.* Paper presented at the First

International Meeting on Cassava Breeding, Biotechnology and Ecology, Brasilia.

FAO. (2011a). FAOSTAT from http://www.fao/org/

FAO. (2011b). Food and Agriculture Organization of the United Nations.Food Outlook, Global Market analysis. Trade and markets division information analysis and forecasts. (pp. 185-186).

FAO. (2013a). FAOSTAT statistical database http://faostat.fao.org

FAO. (2013b). Safe and Grow Cassava. A guide to sustainable production intensification. (pp. 141 -142).

FAO. (1997b). Feeding pigs in the tropics. FAO *Animal Production and Health Paper 132*. Rome.

FAOSTAT. (2016). FAO Statistics Division. http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor

Fermont, A. M., Obiero, H. M., Van Asten, P. J. A., Baguma, Y., & Okwuosa, E. (2007). *Improved cassava varieties increase the risk of soil nutrient mining: An ex-ante analysis for western Kenya and Uganda.* https://www.researchgate.net/publication/227067910. DOI: 10.1007/978-1-4020-5760-1_48.

Fermont, A. M., Tittonell, P. A., Baguma, Y., Ntawuruhunga, P., & Giller, K. E. (2010). Towards understanding factors that govern fertilizer response in cassava: lessons from East Africa. *Nutrient cycling in agroecosystems, 86*(1), 133-151.

Fermont, M. A. (2009). *Cassava and soil fertility in intensifying smallholder farming systems of East Africa.* . PhD Wageningen University, Wageningen, Netherlands.

Fosu-Mensah, B. Y. (2012). *Modelling maize (Zea mays L.) productivity and impact of climate change on yield and nutrient utilization in sub-humid Ghana.* PhD. Retrieved from http://www.zef.de/fileadmin/webfiles/downloads/zefc_ecology_development/eds_87_fosu-mensah_text.pdf (Series No. 87).

Fregene, M., Bernal, A., Duque, M., Dixon, A., & Tohme, J. (2000). AFLP analysis of African cassava (*Manihot esculenta* Crantz) germplasm resistant to the cassava mosaic disease (CMD). *Theoretical and Applied Genetics, 100*(5), 678 - 685.

Fregene, M. A., Suarez, M., Mkumbira, J., Kulembeka, H., Ndedya, E., Kulaya, A., & Dean, R. (2003). Simple sequence repeat marker diversity in cassava landraces: genetic diversity and differentiation in an asexually propagated crop *Theoretical and Applied Genetics, 107*(6), 1083-1093.

Fresco, L. (1993). *The dynamics of cassava in Africa: an outline of research issues. COSCA, Collaborative Study of Cassava in Africa.*

Ganiyu, M. O., Akinniran, T. N., & Adeyemo, S. A. (2013). Rainfall Pattern and Trend on Arable Crops Production in Oyo State. Nigeria (1990-2009) *World Rural Observations, 5*(2), 7-11.

Gerakis, A., & Baer, B. (1999). A computer program for soil textural classification. *Soil Science Society of America Journal, 63*(4), 807-808.

Gerland, P., Raftery, A. E., Ševčíková, H., Li, N., Gu, D., Spoorenberg, T., Alkema, L., Fosdick, B. K., Chunn, J., Lalic, N., Bay, G., Buettner, T., Heilig, G. K., & Wilmoth, J. (2014). World population stabilization unlikely this century *Science 346,* 234–237. doi: doi: 10.1126/science.1257469

Githunguri, C. M. (2004). *Effects of Growth Environment and Bulking Rate on Cyanogenic Potential of Cassava Tuberous Roots. Agricultural Research Institute.* Paper presented at the 8th KARI biennial Scientific Conference, Nairobi, Kenya.

Githunguri, C. M., Chweya, J. A., Ekanayake, I. J., & Dixon, A. G. O. (1998). *Climatic and growth stage influence on tuberous root yield and cyanogenic potential, leaf water potential and leaf area duration of divergent cassava (Manihot esculenta Crantz) clones. In Root Crops in the 21st Century.* Paper presented at the 7th Triennial Symposium of the ISTRC-AB, Cotonou, Benin.

Goldsworthy, P. R., & Fisher, N. M. (1984). The physiology of tropical field crops.

Gwalema, S. R. (2010). The Extent of Food Insecurity and its Linkage to Poverty in Kigoma Region, Tanzania: A Case Study of Kitahama, Mwali and Kalinzi Villages. *Huria Journal, 8*, 44-67.

Hahn, S. K., John, C., Isoba, G., & Ikohun, T. (1989). Resistance breeding in root crops at International Institute of Tropical Agriculture (IITA). In IITA (Ed.), *Crop Prot* (Vol. 8, pp. 147-168). Ibadan, Nigeria.

Hahn, S. K., Terry, E. R., Leushner, K., Akobundu, I. O., Okali, C., & Lal, R. (1979). Cassava improvement in Africa. *Field Crops Res.* Vol. 2, 193-226.

Hammer, G. L., Hobman, F. R., & Shepherd, R. K. (1987). Effects of planting time and harvest age on cassava (*Manihot esculenta*) in Northern Australia. I. Crop growth and yield in moist environments. *Experimental Agriculture, 23*, 401- 414.

Hay, R. K. M. (1995). Harvest index: a review of its use in plant breeding and crop physiology *Annals of applied biology, 126*(1), 197-216.

Heanes, D. L. (1984). Determination of total organic C in soils by an improved chromic acid digestion nd spectrophotometric procedure. *Communications in Soil Science and plant Analysis, 15*, 1191-1213.

Hidayat, A., Zuraida, N., & Hararida, I. (2002). The Cyanogenic Potential of Roots and Leaves of Ninety Nine Cassava cultivars. *Indonesian Journal of Agricultural Science, 3*(1), 25 – 32.

Hillocks, R. J., & Thresh, J. M. (Eds.). (2002). *Cassava in Africa.* Wallingford, UK: CABI publishing.

Howeler, R. H. (1991). Long-term effect of cassava cultivation on soil productivity. *Field crops research, 26*(1), 1-18.

Howeler, R. H. (1993). Integrated soil and crop management to prevent environmental degradation in cassava-based cropping systems in Asia.

In J. W. T. Bottema & D. R. Stoltz (Eds.), *Upland agriculture in Asia* (pp. 41-54). Bogor, Indonesia.

Howeler, R. H. (2008). *Results, achievements and impact of the Nippon foundation Cassava project. Integrated cassava based cropping systems in Asia.* Paper presented at the workshop of the Nippon Foundation cassava project in Thailand, Vietnam and China.

Howeler, R. H., & Cadavid, L. F. (1983). Accumulation and distribution of dry matter and nutrients during a 12 month cycle of cassava. *Field Crops Research, 7*, 123 -129.

Howeler, R. H., & Cadavid, L. F. (1990). Short- and long-term fertility trials in Colombia to determine the nutrient requirements of cassava. *Fertilizer Research 26*, 61 - 80.

Howeler, R. H., Hillocks, R. J., Thresh, M. J., & BellotI, A. C. ( 2002). *Cassava Mineral Nutrition and fertilization* Wallingford, Oxon UK: CABI publishing.

Iglesias, C. A., Calle, F., Hershey, C., Jaramillo, G., & Mesa, E. (1994). Sensitivity of cassava (*Manihot esculenta* Crantz) clones to environmental changes. *Field Crops Research, 36*(3), 213 - 220.

IITA. (1985). *Cassava in Tropical Africa.A Reference Manual.*

IITA. (1990). *Cassava in Tropical Africa Cassava Reference Manual.* United Kingdom: Chayce Publication Services.

IITA. (2005). International Institute of Tropical Agriculture. *Cassava Production Manual.* (pp. 2-3). Integrated Cassava Project (ICP). Ibadan, Nigeria.

Ikpi, A. E., Gebremeskel, T., Hahn, N. D., Ezumah, H. C., & Ekpere, J. A. (1986). Cassava: a crop for household food security *IITA-UNICEF Collaborative Program Report* (pp. 110-113.). Ibadan, Nigeria: IITA.

Ilesanmi, O. O. (1981). *Aspect of the precipitation climatology of the July–August rainfall minimum of Southern Nigeria. Preprints, N.G.A.* Paper presented at the Regional Planning Committee Seminar on Urban and Regional Problems in Nigeria, Ile-Ife, Nigeria, University of Ife.

Issa, U., Alagbe, S. A., & Garba, M. L. (2014). Hydrogeology and Physico-Chemical Quality Assessment of Groundwater in Oke-oyi Area and Environs, Kwara State, Nigeria. *Journal of Environment and Earth Science, 4*(18) pp 76-83.

Iwueke, C. O. (1991). *Fertilizer requirements in a cassava-based intercropping system in South Western Nigeria.* Ph.D disertation, University of Ibadan, Ibandan, Ibadan, Nigeria.

Iwuoha, G. N., Ubeng, G. G., & Onwuachu, U. I. (2013). Detoxification Effect of Fermentation on Cyanide Content of Cassava Tuber. *J. Appl. Sci. Environ. Manage, 17*(4), 567 - 570.

Jarvis, A., Ramirez-Villegas, J., Herrera Campo, B. V., & Navarro-Racines, C. ( 2012). Is Cassava the Answer to African Climate Change Adaptation? *Trop. Plant Biol., 5*(1), 9 - 29.

Jones, H. A., & Hockey, R. D. (1964). The geology of part of SW Nigeria. *Geol. Surv.Bull*, 31 - 101.

Jones, W. O. (1959). *Manioc in Africa.* Stanford, USA: Stanford University Press.

Kamara, A. Y., Menkir, A., Badu-Apraku, B., & Ibikunle, O. (2003). The influence of drought stress on growth, yield and yield components of some maize genotypes. *J. Agric. Sci., 141*, 43 - 50.

Kang, B. T., & Gutteridge, R. C. (2011). Forage Tree Legumes in Alley Cropping systems, from www.fao.org/ag/AGP/AGPC/doc/Publication.

Kang, B. T., & Okeke, J. E. (1983). *Nitrogen and Potassium Responses of Two Cassava Varieties Grown on an Alfisol in Southern Nigeria. International Society for tropical root crops.* Paper presented at the Sixth Triennial Symposium – International Potato Centre (CIP), Lima, Peru. .

Kasele, I. N. (1980). *Investigation on the effect of shading, potassium and nitrogen and drought on the development of cassava tuber at early stage of plant growth.* MSc Unpublished, University of Ibadan, Ibadan, Nigeria.

Kawano, K., Amaya, A., Daza, P., & Rios, M. (1978b). Factors affecting efficiency of hybridization and selection in cassava. *Crop Science, 18*(3), 373 - 376.

Kawano, K., Daza, P., Amaya, A., Rios, M., & Goncalves, W. M. (1978a). Evaluation of cassava germplasm for productivity. *Crop Science, 18*(3), 377 - 380.

Kawano, K., Fukuda, W. M. G., & Cenpukdec, U. (1987c). Genetic and environmental effects on dry matter content of cassava root. *Crop Sci.* , *27*, 69 - 74.

Lain, S. L. (1985). Selection for yield potential. In: Cock J. H. and J. A. Reyes (Eds.), *Cassava: Research, Production and Utilization.* Cali, Columbia: UNDP/CIAT.

Lancaster, P. A., Ingram, J. S., Lim, M. Y., & Coursey, D. G. (1982). Traditional cassava-based foods: survey of processing techniques. *Econ Bot 36*, 12 – 45.

Landon, J. R. (1991). *Booker Tropical Soil manual.* London, UK.: Longman.

Lefèvre, F., & Charrier, A. (1993). Heredity of seventeen isozyme loci in cassava (*Manihot esculenta* Crantz). *Euphytica, 66*, 171-178.

Lema, K. M., Tata-Hangy, K., & Bidiaka, M. (2004). Management of African root and tuber scale using improved cassava genotypes and mineral fertilisers. *African Crop Science Journal, 12*(3), 217- 221.

Liu, C.-W., Sung, Y., Chen, B.-C., & Lai, H.-Y. (2014). Effects of Nitrogen Fertilizers on the Growth and Nitrate Content of Lettuce (*Lactuca sativa* L.). *International Journal of Environmental Research and Public Health, 11*(4), 4427 – 4440.

Maini, S. B., Indira, P., & Mandal, R. G. (1977). Studies on maturity index in cassava. *J. Root Crops 3*(2), 33 - 35.

Makinde, E. A., Ayeni, L. S., Ojeniyi, S. O., & Odedina, J. N. ( 2010). Effect of organic, organomineral and NPK fertilizer on nutritional quality of Amaranthus in Lagos, Nigeria. *Researcher 2*(2), 91 - 96.

Makinde, E. A., Saka, J. O., & Makinde, J.O. (2007). Economic evaluation of soil fertility management options on cassava-based cropping systems in the rain forest ecological zone of south western Nigeria. *African Journal of Agricultural Research, 2*(1), 7 - 13.

Marmey, P., Beeching, J. R., Hamon, S., & Charrier, A. (1993). Evaluation of cassava (*Manihot esculenta* Crantz) germplasm collections using RAPD markers. *Euphytica, 74*(3), 203 - 209.

Mclean, E. O. (1965). Aluminium in Methods of Soil Analysis. In C. A. Black (Ed.). *Agronomy* (Vol. 9, pp. 978-998). Madison, Wisconsin: Amer. Sci. Agronomy.

Mignouna, H. D., & Dixon, A. G. O. (1997). Genetic relationships among cassava clones with varying levels of resistance to African mosaic disease using RAPD markers. *African J Roots Tuber Crops., 2*, 28 – 32.

Molongo, M., Ngbolua, K., Monde, G., Magbukudua, M., Ngemale, G., Malomalo, M., Shabani, W., Mwanza, F., & A, P. (2015). *Effect of Sample Cuttings Area on The Cassava (Manihot esculenta Crantz) Tuber Yields UnderAgroecological Conditions of Gbadolite City, Democratic Republic of Congo.* https://www.researchgate.net/publication/275022513.

Moreno, P., & Gourdji, S. (2015). Cassava starch content and its relationship with rainfall.CCAFS,CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS)

Multani, D. S., & Lyon, B. R. (1995). Genetic fingerprinting of Australian cotton cultivars with RAPD markers. *Genome, 38*(5), 1005 - 1008.

Mulualem, T., & Ayenew, B. (2012). Cassava (*Mannihot esculenta* Crantz) varieties and Harvesting Stages Influenced Yield and Yield Related Components. *J. Nat. Sci. Res, 2*(10), 122-128.

Ngendahayo, M., & Dixon, A. G. O. (2001). *Effect of varying stages of harvest on tuber yield, dry matter, starch and harvest index of cassava in two ecological zones in Nigeria. Root Crops in the 21st Century.* Paper presented at the 7th Triennial Symposium of the International Society for Tropical Root Crops–African Branch, Centre International des Conference, Cotonou, Benin.

Nguyen, H., Schoenau, J. J., Nguyen, D., Van Rees, K., & Boehm, M. (2002). Effects of long term Nitrogen, Phosphorus and Potassium fertilization on cassava yield and plant nutrient composition in North Vietnam. *Journal of Plant Nutrition, 25*(3), 425 - 442.

Njoku, D. N., Egesi, C. N., Asante, I., Offei, S. K., & Vernon, G. (2009). *Breeding for improved micronutrient cassava in Nigeria: Importance, constraints and prospects.* Paper presented at the 43rd Annual Conference of the Agricultural Society of Nigeria, National Universities Commission Auditorium and RMRDC, Abuja, Nigeria.

Nnodu, E. C., & Dixon, A. G. O. (2001). *Evaluation of newly improved low cyanide cassava varieties in different agroecozones of Nigeria,Root crops in the 2ist century.* Paper presented at the 7thTriennial symposium of the International Society for Tropical Root Crops-Africa Branch (ISTRC-AB) Centre International des conferences, Cotonou, Benin.

Nnodu, E. C., Ezulike, T. O., & Asumugha, G. N. (2006). Cassava. In N. U. A. Idem & F. A. Showemino (Eds.), *Tuber and Fibre Crops of Nigeria: Principles of Production and Utilization.* Zaria: Ade Commercial Press.

Nnodu, E. C., Okeke, J. E., & Ogbe, F. O. (1992). *Evaluation of new cassava varieties in different ecozones of Nigeria.* Annual Report. In National Root Crops Research Institute . Umudike, Nigeria.

Nuwamanya, E., Chiwona-Karltun, L., Kawuki, R. S., & Baguma, Y. (2012). Bio-ethanol production from non-food parts of cassava (*Manihot esculenta* Crantz). *AMBIO, 41*, 262 – 270.

Nwachokor, M. A., & Uzu, F. O. (2008). Updated Classification of Some Soil Series in Southwestern Nigeria. *Journal of Agronomy, 7*, 76 - 81.

Nwaobiala, C. U., & Nottidge, D. O. (2013). Effect of climatic variables on cassava farmers' production in Abia state, Nigeria. *Nigerian Journal of Agriculture, Food and Environment, 9*(4), 57 - 62.

Nweke, F. (2004). New challenges in the cassava transformation in Nigeria and Ghana *Environmental and production technology division discussion paper No. 118*. Washington, D.C.

Nweke, F. I. (1994a). Farm level practices relevant to cassava plant protection. *Afr. Crop Sci. J.*, *2*, 563 - 582.

Nweke, F. I. (1994b). Processing Potential for Cassava Production Growth in Saharan Africa *Collaborative Study of Cassava in Africa COSCA Working paper 11*. Ibadan, Nigeria: IITA.

Nwosu, K. L. (2005). *Agricultural rebirth for improved production in Nigeria.* . Paper presented at the 39th Annual Conference of the Agricultural Society of Nigeria, University of Benin, Nigeria.

Obigbesan, G. O. (1977). Investigations on Nigerian root and tuber crops: response of cassava cultivars to potassium fertilizer in western Nigeria. *The Journal of Agricultural Science, 89*(1), 23 - 27.

Obigbesan, G. O. (1999). *Fertilizer: Nigerian Farmers Dilemma* Inaugural Lecture. University of Ibadan. Ibadan, Nigeria.

Odurukwe, S. O., & Arene, O. B. (1980). Effect of N, P, K fertilizers on cassava bacterial blight and root yield of cassava. *International Journal of Pest Management, 26*(4), 391 - 395.

Ogbe, F. O. (2001). *Survey of cassava begomovirus in Nigeria and the response of resistant cassava genotypes to African cassava mosaic begomovirusinfection.* Ph.D Unpublished, University of Ibadan, Ibadan, Nigeria.

Ogwo, J. N., Dike, O. C., Mathew, S. O., & Akabuogu, E. U. (2012). Overview of biomass energy production in Nigeria: implications and challenges. *Asian J Nat Appl Sci, 1*(4), 46 - 51.

Ojeniyi, S. O., Adejoro, S. A., Ikotun, O., & Amusan, O. (2012). Soil and plant nutrient composition, growth and yield of cassava as influenced by integrated application of NPK fertilizer and poultry manure. *New York Sci. J, 5*(9), 62 - 68.

Ojeniyi, S. O., Ezekiel, P. O., Asawalam, D. O., Awo, A. O., Odedina, S. A., & Odedina, J. N. (2009). Root growth and NPK Status of cassava as influenced by oil palm bunch ash. *African Journal of Biotechnology, 8*(18), 4407 - 4412.

Okechukwu, R. U., Akoroda, M. O., Ogbe, F., & Dixon, A. G. O. (2010). Analytical steps to a multi-trait selection index for rapid participatory appraisal of cassava varieties for release to farmers. *African Journal of Root and Tuber Crops, 8*(1).

Okechukwu, R. U., & Dixon, A. G. O. (2009). Performance of Improved Cassava Genotypes for Early Bulking, Disease Resistance, and Culinary Qualities in an Inland Valley Ecosystem *Agronomy Journal 101*(5).

Okechukwu, R. U., Sanni, L., Ezedinma, C. E., Patino, M., Adetunji, M. O., & Dixon, A. G. O. (2005). Cassava, the multipurpose crop *IITA Integrated Cassava Project Monograph* (pp. 6pp).

Okpara, D. A., Agoha, U. S., & Iroegbu, M. (2010). Response of cassava variety TMS 98/0505 to Potassium fertilization and time of harvest in South Eastern Nigeria. *Nigeria Agricultural Journal, 41*(1), 84 - 92.

Okudoh, V., Schmidt, S., & Trois , C. (2015). *Biogas production in Africa: Benefit potentials of cassava biomass*: Lambert Academic Publishing.

Okudoh, V., Trois, C., Workneh, T., & Schmidt, S. (2014). The potential of cassava biomass and applicable technologies for sustainable biogas production in South Africa. *A review. Renewable and Sustainable Energy Reviews, 39*, 1035 - 1052.

Olsen, K. M., & Schaal, B. A. (2001). Microsatellite variation in cassava (*Manihot esculenta*, Euphorbiaceae) and its wild relatives: further evidence for a southern Amazonian origin of domestication. *American Journal of Botany, 88*(1), 131 - 142.

Olukosi, J. O., Elemo, K. A., Kuman, V., & Ogungbile, A. O. (1991). Farming systems research and development of improved crop mixtures technologies in the Nigerian Savanna. *Agricultural systems in Africa, 1*(1), 17 - 24.

Oluleye, A. K., & Akinrinde, E. A. (2009). Effects of phosphate fertilizers and maize plant density on productivity of cassava/maize/egusi-melon mixtures on Alfisols of Ekiti State, South-West Nigeria. *Journal of Food, Agriculture and Environment, 7*, 224 - 227.

Omoti, U., & Ataga, D. D. (1980). *Nutritional problems in root crop production*. Paper presented at the First National Seminar, Umudike.

Omotosho, J. B. (1988). Spatial variation of rainfall in Nigeria during the 'Little Dry Season'. *Atmospheric research, 22*(2), 137-147.

Onwueme, I. C., & Charles, W. B. (1994). *Tropical root and tuber crops: production, perspectives and future prospects* (No. 126). Food & Agriculture Org.

Oriola, E. O. (2004). Dynamics of Soil chemical properties I Oke-oyi irrigation projects sites of the Lower Niger River Basin Development Authority, Ilorin Nigeria *Geo-studies Forum, 2*(1), 96 - 105.

Osiru, D. S. O., & Hahn, S. K. (1998). Dry matter production and partitioning in cassava (*Manihot esculenta*) intercropped with maize or groundnuts. In M. O. Akoroda & I. J. Ekanayake (Eds.), *Sixth Symposium of*

*ISTRC-AB Root Crops and Poverty Alleviation* (pp. 76). Lilongwe, Malawi: International Society for Tropical Root Crops, Ibadan,.

Rahaman, M. A. (1976). A review of the Basement geology of Southwestern Nigeria. In C. A. Kogbe (Ed.), *Geology of Nigeria*. Lagos: Elizabethan publ.

Raji, A. (2003). *Assessment of genetic diversity and heterotic relationships in African improved and local cassava (Manihot esculenta* Crantz*) germplasm.* PhD disertation, University of Ibadan, Ibadan, Nigeria.

Raji, A. A., Ladeinde, T. A. O., & Dixon, A. G. O. (2007). Agronomic traits and tuber quality attributes of farmer grown cassava landraces in Nigeria. *Journal of Tropical Agriculture, 45*, 9 - 13.

Ramanujam, T. (1985). Leaf density profile and efficiency in partitioning dry matter among high and low yielding cultivars of cassava (*Manihot esculenta* Crantz). *Field Crops Research, 10*, 291 - 303.

Rattanachomsri, U., Tanapongpipat, S., Eurwilaichitr, L., & Champreda, V. (2009). Simultaneous non-thermal saccharification of cassava pulp by multi-enzyme activity and ethanol fermentation by Candida tropicalis. *J. Biosci. Bioeng, 108*(4), 357.

Rijks, J. Q. (2003). *Overview of Previous FAO Activities on Root Crop Statistics, Their Outcomes and Recommendations.* Paper presented at the Proceedings of the Expert Consultation on Root Crop Statistics. FAO, Rome.

Rockström, J., Folke, C., Gordon, L., Hatibu, N., Jewitt, G., Penning De Vries, F., Rwehumbiza, F., Sally, H., Savenije, H., & Schulze, R. (2004). A

Watershed Approach to Upgrade Rainfed Agriculture in Water Scarce Regions through Water System Innovations: An Integrated Research Initiative on Water for Food and Rural Livelihoods in Balance with Ecosystem Functions. *Physics and Chemistry of the Earth, 29*, 1109 - 1118.

Rolinda, L., Talatala, R.L., Ma, T.P. and Loreto I. (2008). Cyanide content of cassava cultivars at different fertility levels and stages of maturity. http://region 10.dost.gov.ph/index.php

Rosenthal, D. M., & Ort, D. R. (2012). Examining cassava's potential to enhance food security under climate change. *Tropical plant bio, 5*, 30 - 38.

Rosling, H. (1987) Cassava toxicity and food security. Uppsala, Sweden: International Child Health Care Unit,University Hospital,.

Sofa-Kantanka, O., & Osei-Minta, M. (1996). Effect of cultivar and age at harvest on the dry matter, starch gelatinization properties and the cooking quality of cassava. *Ghana J. Agric. Sci, 29*, 81-89.

Sagrilo, E., VidigalFilho, P. S., Pequeno, M. G., Scapim, C. A., Vidigal, M. C. G., Diniz, S. P. S. D. S., & Kvitschal, M. V. (2003). Effect of Harvest Period on the Quality of storage roots and protein content of the leaves in five cassava cultivars (*Manihot esculenta* Crantz). *Brazilian Archives of Biology and Technology, 46*(2), 295 - 305.

Salami, B. T., & Sangoyomi, T. E. (2013). Soil fertility status of cassava fields in south western Nigeria. *American Journal of Experimental Agriculture, 3*(1), 152-164.

Sambo, A. S. (2005). Renewable energy for rural development: the Nigerian perspective. *ISESCO Science and Technology Vision, 1*, 12 - 22.

Sanchez, P., Shepherd, K., Soule, M., Place, F. M., Buresh, R., Izac, A. M. N., & Buresh, R. J. (1997). Soil fetility repleshnishment in Africa: an investment in natural resource capital. In P. A. Sanchez (Ed.), *Repleshing Soil Fertility in Africa, ASA, CSSA, SSSA*. Madison, Wisconsin.

Sanchez, P. A., & Miller, D. (1986). Organic matter and soil fertility management in acid soils of the tropics. *Transactions of the X111 Congress of International Soil Science Society, 11*, 609 - 625.

Sánchez, T., Salcedo, E., Ceballos, H., Dufour, D., Mafla, G., Morante, N., & Moreno, I. X. (2009). Screening of starch quality traits in cassava (*Manihot esculenta* Crantz). *Starch-Stärke,* , *61*(1), 12 - 19.

Sangpenchan, R. (2009). *Climate change impacts on cassava production in Northeastern Thailand.* MSc The Pennsylvania State University Pennsylvania, USA.

Sanni, L., Ezedinma, F., Okechukwu, R., Lemchi, J., Ogbe, F., Akoroda, M., Okoro, E., Maziya-Dixon, B., Ilona, P., & Dixon, A. G. O. (2007). *Cassava postharvest needs assessment survey in Nigeria*: Synthesis Report. Ibadan, Nigeria. IITA.

Santisopasri, V., Kurotjanawong, K., Chotineeranat, S., Piyachomkwan, K., Sriroth, K., & Oates, C. G. (2001). Impact of water stress on yield and quality of cassava starch. *Industrial crops and products, 13*(2), 115 - 129.

Schulte, R. P., Bampa, F., Bardy, M., Coyle, C., Creamer, R. E., Fealy, R., & O'Donoghue, C. (2015). Making the most of our land: managing soil functions from local to continental scale. *Frontiers in Environmental Science, 3*, 81. doi: doi: 10.1016/j.envsci.2013.10.002

Schulte, R. P., Creamer, R. E., Donnellan, T., Farrelly, N., Fealy, R., O'Donoghue, C., & O'hUallachain, D. (2014). Functional land management: a framework for managing soil-based ecosystem services for the sustainable intensification of agriculture. *Environmental Science & Policy, 38*, 45-58.

Sharma, J. R. (1996). *Principles and practice of plant breeding*. New Delhi: Tata McGraw-Hill Publishing Co. Ltd.

Sirirote, P., Thnaboripat, N. K., & Tripak, S. (2010). The production of biogas from cassava tubers. *KMITL SciTechnol J, 10*(1), 30 - 36.

Sittibusaya, C. R. (1993). Annual Cassava Program Review.Progress report of soil research on fertilization of field crops, 1992 *Thailand: Annual Cassava Program Review*. Thailand: Department of Agriculture, Ministry of Agriculture and Cooperatives.

Soccol, C. R. (1996). Biotechnology products from cassava root by solid state fermentation. *J. Scientific and Industrial Research, 55*, 358 – 363.

Sofa-Kantanka, O., & Osei-Minta, M. (1996). Effect of cultivar and age at harvest on the dry matter, starch gelatinization properties and the cooking quality of cassava. *Ghana J. Agric. Sci, 29*, 81 - 89.

Sondur, S. N., Manshardt, R. M., & Stiles, J. I. (1996). A genetic linkage map of papaya based on randomly amplified polymorphic DNA markers. *Theoretical and Applied genetics, 93*(4), 547 - 553.

Sriroth, K., Piyachomkwan, K., Santisopasri, V., & Oates, C. G. (2001). Environmental conditions during root development: Drought constraint on cassava starch quality. *Euphytica, 120*(1), 95 - 102.

Tautz, D., & Renz, M. (1984). Simple sequences are ubiquitous components of the eukaryotic genomes. *Nucleic Acids Research, 12*, 4127 – 4138.

Technicon Instrument Corporation. (1971) Preliminary Total Nitrogen. *Industrial method* (pp. 146 - 171). Tarrytown, N.Y.

Teye, E., Asare, A. P., Amoah, R. S., & Tetteh, J. P. (2011). Determination of the dry matter content of cassava (*Manihot esculenta*, Crantz) tubers using specific gravity method. *ARPN Journal of Agricultural and Biological Science., 6*(11), 23-28.

Tittonell, P. (2008). *Targeting Resources within Diverse, Heterogeneous and Dynamic Farming Systems of East Africa.* Ph.D dissertation Wageningen University, Wageningen, Netherlands.

Thai Tapioca Development Institute (TTDI). (2013). What is Tapioca? Retrieved from http://www.tapiocathai.org/English/C_e.html

Turyagyenda, L. F., Kizito, E. B., Ferguson, M. E., Baguma, Y., Harvey, J. W., Gibson, P., Wanjala, B. W., & Osiru, D. S. O. (2012). Genetic diversity among farmer-preferred cassava landraces in Uganda. *African Crop Science Journal, 20*, 15 - 30.

USDA. (1961). United States Department of Agriculture system (Klingebiel and Montgomery, 1961).

Uyoh, E. A., Udensi, O., Natui, v., & Urua, I. (2007). Effect of different processing methods on cyanide content of garri from four cultivars of cassava. *J of Food, Agriculture and Environment.*, *5*(3 & 4), 105 - 107.

Vanlauwe, B., Six, J., Sanginga, N., & Adesina, A. A. (2015). Soil fertility decline at the base of rural poverty in sub-Saharan Africa. *Nature plants*. Correspondence to the Editor. Published 7 July, page 1. Article number: 15101 | DOI: 10.1038/NPLANTS.2015.101. Pp 1.

Vanlauwe, B., Titonell, P., & Mukalama, J. (2006). Within-farm soil fertility gradients affect response of maize to fertilizer application in Western Kenya. *Nutrient Cycle Agroecosystem.*, *76*, 171 - 182.

Virchow, D., Beuchelt, T. D., Kuhn, A., & Denich, M. (2016). *Biomass-Based Value Webs: A Novel Perspective for Emerging Bioeconomies in Sub-Saharan Africa* (pp 225-238). Paper presented at the Technological and Institutional Innovations for Marginalized Smallholders in Agricultural Development. Springer International Publishing.

Wang, W. (2002). Cassava production for industrial utilization in China.Present and future perspectives. In: Howeler R.H. (Ed) *Cassava Research and Development in Asia: New Opportunities for an Ancient Crop.* Proceedings of the Seventh Regional Workshop held in Bangkok, Thailand Oct. 28 – Nov1, pp33-38.

Welsh, J., & McClelland, M. (1990). Finger printing genomes using PCR with arbitrary primers. *Nucleic acids research, 18*(24), 7213 - 7218.

Wenham, J. E. (1995). *Post-harvest deterioration of cassava: a biotechnology perspective* (pp. 160 ). Plant Production and Protection Papers, Rome: FAO.

Wholey, D. W. (1974). *Rapid propagation of cassava.* Ph.D dissertation, University of the West Indies, St. Augustine, Trinidad.

Wilde, J., Waugh, R., & Powell, W. (1992). Genetic fingerprinting of Theobroma clones using randomly amplified polymorphic DNA markers. *TAG Theoretical and Applied Genetics, 83*(6), 871 - 877.

Zacarias, A. M., Botha, A. M., Labuschagne, M. T., & Benesi, I. R. M. (2004). Characterisation and genetic distance analysis of cassava (*Manihot eculenta* Crantz) germplasm from Mozambique using RAPD fingerprinting. *Euphytica, 138*, 49 – 53.

Zhaohui, W., & Shengxiu, L. (2004). Effects of Nitrogen and Phosphorus Fertilization on Plant Growth and Nitrate Accumulation in Vegetables. *Journal of Plant Nutrition, 27*(3), 539 - 556. doi: DOI: 10.1081/PLN-120028877.

Zingore, S. (2006). *Exploring diversity within smallholder farming systems in Zimbabwe; Nutrient Use Efficienciess and Resource Management Stratgies for Crop Production.* Ph.D dissertation, Wageningen University, Wageningen, Netherlands.

Zingore, S., Murwira, H. K., Delve, R. J., & Giller, K. E. (2007). Soil type, management history and current resource allocation: Three dimensions regulating variability in crop productivity on African smallholder farms. *Field Crops Research, 101*(3), 296 - 305.

## APPENDICES

APPENDIX A

**Effect of variety and fertilizer application on fresh biomass of cassava**

Table 1: *Effect of variety on fresh foliage and stem yield (t ha$^{-1}$) at Oke-oyi*

| | Months after planting | | | |
|---|---|---|---|---|
| | Foliage Yield (t ha$^{-1}$) | | Stem Yield (t ha$^{-1}$) | |
| Variety | 10 | 12 | 10 | 12 |
| TME 419 | 1.90$^{c}$ | 4.60$^{b}$ | 5.22$^{ab}$ | 9.36$^{a}$ |
| Oko-iyawo | 1.93$^{bc}$ | 6.26$^{ab}$ | 5.13$^{ab}$ | 9.76$^{a}$ |
| TMS 98/0505 | 2.01$^{bc}$ | 5.86$^{ab}$ | 5.58$^{a}$ | 8.81$^{a}$ |
| TMS 96/1632 | 1.92$^{bc}$ | 4.46$^{b}$ | 4.14$^{b}$ | 6.60$^{b}$ |
| TMS 30572 | 2.58$^{ab}$ | 6.62$^{a}$ | 6.09$^{a}$ | 10.60$^{a}$ |
| TMS 91/02324 | 3.20$^{a}$ | 5.21$^{ab}$ | 6.32$^{a}$ | 9.15$^{a}$ |
| Sig. | NS | NS | NS | NS |
| LSD | 0.66 | 1.87 | 1.25 | 2.04 |

Means followed by the same letter (s) in a column are not significantly different p> 0.05 level of probability using LSD. NS = not significant.

Table 2: *Effect of cassava varieties on fresh foliage yield (t ha$^{-1}$) at Ikenne*

| | Months after planting | | |
|---|---|---|---|
| Variety | 6 | 10 | 12 |
| TME 419 | 1.33$^{ab}$ | 1.96$^{c}$ | 1.57$^{a}$ |
| Oko-iyawo | 1.30$^{ab}$ | 2.43$^{bc}$ | 1.61$^{a}$ |
| TMS 98/0505 | 1.50$^{a}$ | 3.46$^{a}$ | 1.63$^{a}$ |
| TMS 96/1632 | 1.02$^{c}$ | 2.01$^{c}$ | 1.35$^{a}$ |
| TMS 30572 | 1.20$^{bc}$ | 2.80$^{ab}$ | 1.48$^{a}$ |
| TMS 91/02324 | 1.23$^{bc}$ | 2.15$^{bc}$ | 1.30$^{a}$ |
| Sig | S | S | S |
| LSD | 0.24 | 2.33 | 0.48 |

Means followed by the same letter (s) in a column are not significantly different p> 0.05 level of probability using LSD. S = significant.

Table 3: *Effect of fertilizer rate and type on foliage and stem yield at Oke-oyi*

| | Months after planting | | | |
|---|---|---|---|---|
| | Foliage Yield (t ha$^{-1}$) | | Stem Yield (t ha$^{-1}$) | |
| **Fertilizer rate** | **10** | **12** | **10** | **12** |
| Non-fertilized | 1.87$^{a}$ | 6.05$^{a}$ | 4.65$^{b}$ | 9.50$^{a}$ |
| NPK 150Kg ha$^{-1}$ | 2.27$^{a}$ | 4.97$^{a}$ | 5.16$^{ab}$ | 8.58$^{a}$ |
| NPK 300Kg ha$^{-1}$ | 2.19$^{a}$ | 5.83$^{a}$ | 5.79$^{a}$ | 9.30$^{a}$ |
| LSD | 0.52 | 1.50 | 0.98 | 1.64 |
| **Fertilizer Type** | **10** | **12** | **10** | **12** |
| Non-fertilized | 1.88$^{b}$ | 6.06$^{a}$ | 4.66$^{b}$ | 9.50$^{a}$ |
| NPK 15-15-15 | 2.20$^{ab}$ | 4.95$^{a}$ | 5.07$^{ab}$ | 9.03$^{a}$ |
| NPK 20-10-10 | 1.97$^{ab}$ | 5.24$^{a}$ | 5.57$^{ab}$ | 8.41$^{a}$ |
| NPK 12-12-17 | 2.51$^{a}$ | 6.01$^{a}$ | 5.80$^{a}$ | 9.41$^{a}$ |
| LSD | 0.55 | 1.59 | 1.04 | 1.74 |

Means followed by the same letter (s) in a column for the same factor are not significantly different p> 0.05 level of probability using LSD

Table 4: *Effect of fertilizer rate and fertilizer type on foliage yield (t ha$^{-1}$) at Ikenne*

| | Months after planting | | |
|---|---|---|---|
| **Fertilizer rate** | **6** | **10** | **12** |
| Non-fertilized | 1.17$^{a}$ | 2.11$^{a}$ | 1.22$^{b}$ |
| NPK 150Kg ha$^{-1}$ | 1.26$^{a}$ | 2.64$^{a}$ | 1.61$^{a}$ |
| NPK 300Kg ha$^{-1}$ | 1.28$^{a}$ | 2.41$^{a}$ | 1.44$^{ab}$ |
| LSD | 0.19 | 0.57 | 0.38 |
| **Fertilizer Type** | **6** | **10** | **12** |
| Non-fertilized | 1.18$^{a}$ | 2.12$^{a}$ | 1.23$^{a}$ |
| NPK 15-15-15 | 1.27$^{a}$ | 2.61$^{a}$ | 1.38$^{a}$ |
| NPK 20-10-10 | 1.22$^{a}$ | 2.53$^{a}$ | 1.59$^{a}$ |
| NPK 12-12-17 | 1.33$^{a}$ | 2.44$^{a}$ | 1.61$^{a}$ |
| LSD | 0.20 | 0.60 | 0.41 |

Means followed by the same letter (s) in a column for the same factor are not significantly different p> 0.05 level of probability using LSD

Table 5: *Effect of cassava varieties on stem yield (t ha$^{-1}$) at Ikenne*

| | Months after planting | | |
|---|---|---|---|
| **Variety** | **6** | **10** | **12** |
| TME 419 | 3.44$^{a}$ | 6.68$^{ab}$ | 6.33$^{a}$ |
| Oko-iyawo | 2.96$^{ab}$ | 8.15$^{a}$ | 4.79$^{b}$ |
| TMS 98/0505 | 3.33$^{ab}$ | 6.13$^{ab}$ | 5.3$^{ab}$ |
| TMS 96/1632 | 2.63$^{b}$ | 5.21$^{b}$ | 3.95$^{c}$ |
| TMS 30572 | 2.74$^{ab}$ | 5.33$^{b}$ | 5.18$^{ab}$ |
| TMS 91/02324 | 3.43$^{a}$ | 6.58$^{ab}$ | 5.06$^{ab}$ |
| LSD | 0.73 | 2.33 | 1.33 |

Means followed by the same letter (s) in a column are not significantly different p> 0.05 level of probability using LSD.

Table 6: *Effect of fertilizer rate and fertilizer type on cassava stem yield (t ha$^{-1}$) at Ikenne*

| | Months after planting | | |
|---|---|---|---|
| **Fertilizer rate** | **6** | **10** | **12** |
| Non-fertilized | 3.01$^{a}$ | 6.89$^{a}$ | 4.45$^{a}$ |
| NPK 150Kg ha$^{-1}$ | 3.12a | 6.56a | 5.52$^{a}$ |
| NPK 300Kg ha$^{-1}$ | 3.05a | 5.86$^{a}$ | 4.91$^{a}$ |
| LSD | 0.59 | 1.87 | 1.07 |
| **Fertilizer Type** | **6** | **10** | **12** |
| Non-fertilized | 3.06$^{ab}$ | 6.90$^{a}$ | 4.46$^{a}$ |
| NPK 15-15-15 | 3.28$^{ab}$ | 6.10$^{a}$ | 5.14$^{a}$ |
| NPK 20-10-10 | 2.67$^{b}$ | 6.24$^{a}$ | 5.43$^{a}$ |
| NPK 12-12-17 | 3.31$^{a}$ | 6.26$^{a}$ | 5.07$^{a}$ |
| LSD | 0.63 | 1.99 | 1.14 |

Means followed by the same letter (s) in a column for the same factor are not significantly different p> 0.05 level of probability using LSD

APPENDIX B

Determination of Starch and dry matter content on the field

aking Fresh Weight of the Different Plant Parts6