YIELD OF CASSAVA (*Manihot esculenta* Crantz) VARIETIES AS INFLUENCED BY NPK APPLICATION AND STEM PROPERTIES IN TWO AGRO-ECOLOGIES OF NIGERIA

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A Thesis in the Department of Agronomy,
Submitted to the Faculty of Agriculture
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

of the

UNIVERSITY OF IBADAN

APRIL, 2023

CERTIFICATION

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DEDICATION

To the ALMIGHTY God,

my rock and sufficiency,

and to all devoted mothers

ACKNOWLEDGMENTS

I thank the Omniscience God for His faithful love, protection, provision, and numerous grace recieved while attaining this academic height. God be praised for the tremendous and magnificent things He has done in my life, as well as His strenght and mercy, which have remained with me throughout this study. A man can receive nothing unless it is given to him from heaven.

My sincere gratitude goes to my supervisor, Professor Malachy O. Akoroda, who by divine providence has become a father to me. I pray your generation shall continue to increase for the better; he devoted his time and resources nurturing me till I reached this beautiful height in my career.

My appreciation goes to Dr Peter Kulakow who co-supervised my work in IITA. I immensely appreciate my supervisory committee members: Profs O. Fagbola, O. J. Oyetunji, and Amdalat B. Olaniyan, Dr O. O. Aina and Dr Stephan Hauser who all contributed greatly to the success of my doctoral programme. I cannot but mention our Mummy at IITA cassava breeding unit, Dr Elizabeth Y. Parkes who was very supportive and encouraging, Mummy, you are indeed a blessing to this generation. To the members of the committees of Professors and Readers, Prof. H. Tijani-Eniola and Dr B. Olasanmi, I say very big thank you sirs for taking out time to read through my work. Your comments and suggestions were highly appreciated. I greatly appreciate the constructive comments and suggestions of Dr O. W. Olaniyi on this work.

Many thanks to Dr Marie O. Yomeni, Mr Peter Iluebbey, Dr A. N. Adetoro, Dr G. S. Pelemo, Mr A. A. Bello, Mr U. O. Effiong, Mr Godstime Sabu, Mr Ibrahim, Mrs Tosin Adeyemo and the entire IITA cassava breeding unit family in Ibadan and Ikenne stations. I also appreciate harvest plus Nigeria for funding these research findings and Alhaji Humaru who assisted throughout the field work in Tsonga. I immensely appreciate our data analysts, Mr M. Bakare and Mr A. Agbonna. I am greatly indebted to Mrs Priscilla Komolafe who has been a wonderful friend since high school days and encouraged me to further in my academics.

To my father, Pastor Joel T. Oketade, who invested so much on my academics not minding the fact that I am the only female among his three children, Daddy, may God satisfy you with long-life to eat the fruits of your labour in sound health. I appreciate my indispensable mother of blessed memory, Late Evang (Mrs) Rachael F. Oketade who taught me to be diligent, dutiful and godly in everything I do. Many thanks to my wonderful siblings, Mr Ayokanmi E. Oketade and Mr Kayode E. Oketade; I say a very big thank you for your supports and encouragements. I acknowledge deeply with gratitude my dear husband, Mr Oluwalade E. Folorunso, for his prayers, love, encouragements and supports throughout this programme. I appreciate my daughter, Deborah I. Oluwalade for her understanding whenever I travelled during the course of this programme.

I cannot but mention my wonderful room-mate for five sessions in Balewa Hall, University of Ibadan who is more of a sister to me, Mrs Sifon Odeleye, thanks so much, those wonderful times spent together cannot be easily forgotten. I am grateful to the International Association of Research Scholars and Fellows (IARSAF) for the opportunity provided me to undergo series of trainings, workshops, geo-tours and to be an executive member during 2013/2014 tenure.

I greatly appreciate the prayers, counsels and encouragements received from my spiritual fathers, particularly, Pastor and Mrs T. O. Erinwusi, Pastor and Mrs J. S. Oloyede, Pastor M. O. Olowe and the Sunday School Department of Christ Apostolic Church, Okeife, Agbowo, Ibadan. Thank you all.

ABSTRACT

Cassava is a major staple and commercial crop in the tropics, its yield is constrained by factors such as decline in soil fertility and use of inappropriate planting materials. Fertiliser application and use of appropriate planting materials could improve yield of suitable cassava varieties. However, there is dearth in knowledge on appropriate fertiliser formulations, application rate and qualities of stem cuttings for improved cassava varieties. Therefore, effects of different fertiliser formulations, application rates and stem portions and lengths of stem cuttings on cassava yield were evaluated in two agro-ecologies of Nigeria.

Experiments were conducted at Ikenne (Rain-Forest), Ibadan and Tsonga (Derived-Savanna). Four cassava varieties: TMEB419-(V1), IBA010040-(V2), IBA011412-(V3) and IBA070593-(V4) were planted and four fertiliser formulations [NPK15:15:15-(F1), TSP+KCl-(F2), urea+KCl-(F3) and urea+TSP-(F4)] were applied, so as to supply 0, 45-(R45) or 75-(R75) kg N, P_2O_5 and K_2O/ha. The experiment was a 4 × 4 × 2 factorial in a Randomised Complete Block Design (RCBD) with three replicates. Controls were no fertiliser-(F0). In another experiment, the four cassava varieties with three stem portions: Basal-(S1), Middle-(S2) and Top-(S3) and two stem cutting lengths (cm): 15-(L15) and 30-(L30) were laid out as a 4 × 3 × 2 factorial in a RCBD replicated three times. Plants were spaced at 1.0 × 0.8 m and harvested at 12 months after planting. Data estimates on Fresh Storage Root Yield–FSRY (t/ha), Dry Storage Root Yield–DSRY (t/ha) and Plantable Stem Yield–PSY (t/ha) were analysed using descriptive statistics and ANOVA$\alpha_{0.05}$.

Cassava varieties, fertiliser formulations and rates and their interactions were significantly different for all variables. Combination involving V3+F1+R75 resulted in significantly higher FSRY than all others. The FSRY ranged from 9.5±0.6 (V4+F4+R45) to 22.5±0.6 (V3+F1+R75). The DSRY ranged from 2.2±0.1 (V4+F4+R45) to 5.3±0.2 (V2+F2+R75), while PSY ranged from 7.8±0.3 (V1+F4+R75) to 15.4±0.3 (V2+F0). The

FSRY for R75 (15.4±0.8) was higher than that of R45 and F0 by 1.1% and 11.9%, respectively. The FSRY was in the order 29.4±0.9-Ikenne >24.8±0.6-Ibadan >18.5±0.8-Tsonga. The order of FSRY was 22.5±0.6 (V3) >19.4±0.4 (V2) >12.7±0.3 (V1) >12.4±0.6 (V4). Overall, PSY for F0 was the best and increased from 12.5±0.5 (Tsonga) to 18.1±0.4 (Ibadan) to 21.9±0.6 (Ikenne). Across the sites, FSRY ranged from 10.3±2.1 (V4+S3+L15) to 26.4±0.8 (V3+S2+L30). The DSRY ranged from 0.9±0.6 (V4+S3+L15) to 4.7±0.6 (V2+S2+L30) and PSY ranged from 2.5±1.1 (V4+S3+L15) to 9.6±0.3 (V3+S1+L30). The DSRY of L30 was 25.2% higher than L15 (2.4±0.2) and declined from 3.7±0.8 (Ikenne) to 3.3±0.7 (Ibadan) to 1.4±0.3 (Tsonga). The FSRY increased from 9.8±0.6 (S3) to 11.7±0.6 (S2) to 12.1±1.2 (S1). The PSY declined from 16.5±0.6 (Ibadan) to 14.7±0.9 (Ikenne) to 9.5±1.1 (Tsonga).

Application of NPK 15:15:15 at 75 kg N, P_2O_5 and K_2O ha^{-1} to TMEB419 in derived savanna and Urea+KCl at the same rate to IBA011412 in rain forest enhanced yield of cassava. A 30 cm basal stem cutting portion should be adopted for increased storage root production.

Keywords: Fertiliser formulations, Cassava varieties, Fresh storage root yield, Stem portions, Plantable stem yield

Word Count: 471

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LIST OF ABBREVIATIONS

AEC	Average Environment Coordinate
ANOVA	Analysis of Vaiance
CAD	Cassava Anthracnose Disease
CBB	Cassava Bacteria Blight
CMD	Cassava Mosaic Disease
CV	Co-efficient of Variation
DAP	Days after Planting
DF	Degree of Freedom
DMC	Dry Matter Content
DRY	Dry Root Yield
DSRY	Dry Storage Root Yield
FAO	Food and Agricultural Organisation
FAOSTAT	Food and Agricultural Organistion Corporate Statistical Database
FRY	Fresh Root Yield
FSY	Fresh Stem Yield
GEI	Genotype Environment Interactions
GGE	Genotype, Genotype by Environment
GIS	Geographical Information Service
Ha	Hectare
HCN	Hydrogen Cyanide
HI	Harvest Index
IBN	Ibadan
IBPGR	International Board for Genetic Resources
IITA	International Institute of Tropical Agriculture

IKN	Ikenne
KCl	Potassium Chloride
LAI	Leaf Area Index
MAP	Months after Planting
MET	Multi-Environment Trial
MOP	Muriate of Potash
PCA	Principal Component Analysis
PSY	Plantable Stem Yield
RCBD	Randomised Complete Block Design
RDMC	Root Dry Matter Content
RW	Root Weight
SE	Standard Error
SOM	Soil Organic Matter
SSA	Sub-Sahara Africa
SSP	Single Superphosphate
TSG	Tsonga
TSP	Triple Superphosphate
WAP	Weeks after Planting

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

In Africa, Asia, and Latin America, Cassava (*Manihot esculenta* Crantz) is a key staple crop having significant economic and nutritional importance (Ravi *et al*., 1996). Almost 500 million people get their cheap source of energy from cassava (Montagnac, *et al*., 2009); as a result, it is the third world largest human source of carbohydrate.

Nigeria, Thailand, Indonesia, Brazil, Angola, Ghana and the Democratic Republic of Congo are the major cassava producers (FAOSTAT, 2017). Cassava is critical for farm households' food security, employment, and income generating (FAOSTAT, 2011). Africa produces more than half of the world's cassava, with over 60 million tonnes produced in Nigeria each year (FAOSTAT, 2019). After sugarcane, maize, rice, wheat, potatoes, and sugar beets, cassava is the seventh major food crop (FAOSTAT, 2014).

Cassava production is important to Nigeria's government due to population increase and local consumption (El-Sharkawy, 1993). In terms of carbohydrate yields and drought resistance, it is superior to maize or rice. However, its drought tolerance is second only to yams (IITA, 2010). According to Asante-Pok (2013), cassava offers calories to 37% of the daily energy requiements of 500 000 000 people in Africa and it is consumed by nearly one billion people worldwide (Prochnik *et al*., 2012). Cassava can also be called hunger, conflict and drought crop due to its multipurpose use and adaptability to harsh environments (Pearce, 2007).

1.2 Statement of the problem

Cassava is commonly planted during the rainy season because there is enough water for the plant to grow and the roots develop partially during the drought. In the first six months after planting, water-stressed cassava plants give low outputs, thus water is essential during the vegetative and root growth stages (Santisopasri *et al*. 2001). It doesn't thrive in temperate areas, and its products are relatively unknown outside of the tropics and subtropics where they're farmed and consumed. Different cassava varieties respond to different environmental conditions in different ways. (Bokanga *et al*., 1994).

The most important element restricting productivity of crops in the African agricultural system is the soil's naturally low fertility, which has made food production in Sub-Saharan Africa (SSA) not to keep up with population expansion (Bjornlund *et al*., 2020). Total fertiliser consumption in Nigeria was only 13% and 3% of the amount consumed in Thailand and Brazil respectively (Ezedinma *et al*., 2007). Cassava adjusts its rate of growth to the soil's ability to deliver nutrients, ensuring a level of productivity that can be sustained by it (Fulton *et al*., 1996).

Potassium is drawn in large amounts by cassava roots followed by N, Ca, Mg, and P, and will exhaust soil nutrients if not sufficiently fertilised during continuous cropping (Nguyen, *et al*., 2001). As a result, supplemental fertiliser applications are required for long-term cassava production on the same plot of land. The return on investment in cassava fertiliser is 2.7 times better than the return on investment in maize fertiliser (Adiele *et al*., 2021). According to Sanginga and Woomer, (2009), many cassava growers do not have access to fertiliser and so are hesitant to use it even when the soil's nutritional quality is inadequate.

Cassava is grown commercially through stem cuttings, and the determinant for its quality are plant's age, stem diameter, each cutting size and number of nodes (Lozano *et al*., 1977). Increase in cassava yield is limited by several factors; among them is scarcity of planting material. Therefore, it is essential to prevent wastage of cassava stems while planting. Variation in shoot and root traits among cassava varieties can be used as a valuable breeding tool for increasing storage root yield and other desirable traits (IITA, 2010).

1.3 Aim and objectives of the study

The goals of the cassava breeding program are determined by the needs of production, processing, and marketing, and are based on pest and disease resistance, as well as an increase in root yield (Okogbenin *et al*., 1998). Improved cassava production will be

required as agricultural land becomes scarce, and this can be done by the use of appropriate planting materials and adequate fertiliser application, among other inputs.
In order to address this, the study:

1. evaluated agronomic practices and farming systems among cassava farmers in Ibadan, Oyo state;
2. compared compound fertiliser (NPK 15:15:15) with same doses of single element fertilisers (Urea, Potassium Chloride (KCl) and Triple Superphosphate (TSP)) supplying 0, 45 and 75 N, P_2O_5 and K_2O kg ha^{-1}.
3. evaluated development and yield of four cassava varieties as affected by omissions of Nitrogen, Phosphorus and Potassium and
4. examined the influence of stem parts and lengths of stem cuttings on plant sprout, survival, yield and productivity of four cassava varieties.

1.4 Significance of the study

Cassava has evolved into a staple meal and a valuable commercial commodity with global economic significance (Aerni, 2006). Although all portions of the cassava plant are suitable for consumption, the leaves and roots, which make for 6 and 50% of a fully developed cassava plant, respectively, are the healthiest to eat (Montagnac *et al*., 2009). Around 11% of world cassava root production is wasted due to nematode infestation and post-harvest deterioration, whereas 57% is used for human food and 32% is fed to animals and the rest is used in industries (Chinaka and Okoye 2019). In some parts of the tropics, especially Africa, cassava production and use has become more common and increase in human population leads to decrease in available cultivable fertile soil (Shackelford *et al*., 2018).

Improved cassava varieties produced more roots per unit area than local varieties (Baiyeri *et al*., 2008) hence; farmers' cassava yields (7–15 t ha^{-1}) are significantly lower than research station yields (30–50 t ha^{-1}). Nigeria has more potential to enhance cassava production than Thailand and Indonesia if suitable measures such as government subsidies on farm inputs (fertilisers, seeds, stems, seedlings, and so on) are put in place (Edamisan *et al*., 2020). Although storage root yields vary greatly, in farms where there is quality labour, fertile soils, proper weed management, and timely harvest, the maximum yields are produced (Fermont *et al*., 2009).

1.5 Scope of the study

To guarantee that decisions made in the farmer's field operate reliably and predictably, multi-location evaluation trials are often done. Thus, this work was carried out in six environments. Identifying superior cultivars for a target region is usually the primary focus (Yan *et al*., 2001). Due to government's promotion of cassava growing, Nigerian farmers are migrating from small-scale to large-scale cassava farming. These farmers, however, confront a variety of obstacles, including inadequate soil fertility, the high cost and shortage of improved planting supplies, and a lack of training in sustainable agronomic practices (Yomeni, 2011). In other to address these obstacles, fertiliser trial on improved cassava varieties was set up.

The immediate benefits of increased food security and revenue, as well as the long-term benefits of better soil fertility, should encourage agricultural technologies such as intercropping with legume species, use of fertiliser and integration of pesticide and fungicide in production systems of cassava (Kaluba *et al*., 2021). These are viewed as significant paths out of poverty in most developing nations; nonetheless, adoption of these technologies has remained low (Margaret and Samuel, 2015). Furthermore, as farmed areas expand, planting materials become scarce. This necessitated the development of a low-input and economically viable agricultural system where different parts and lenghts of stem cuttings was used.

CHAPTER TWO

LITERATURE REVIEW

2.1 Cassava origins and distribution

Manihot esculenta Crantz is the sole cultivated species in the genus *Manihot*. It was first adapted in South America about 8500-7000 years back (Olsen and Schaal, 1999). Wild subspecies, *Manihot glaziovii* and *Manihot reptans* are more closely related to *Manihot esculenta* which is the widely cultivated species (Colombo *et al*., 2000). Cassava was brought from Brazil to West Africa and the Congo basin by a Portuguese sailor (Onwueme and Sinha, 1991). Cassava is a root crop that can live at 200 meters above sea level (Hann, 1989) and is grown solely for food in 39 African countries. The most cassava is found in Anambra, Benue, Cross River, Delta, Edo, Imo, Oyo and Rivers States in Nigeria (Adekanye *et al*., 2013).

2.2 Botanical description of cassava plant

Cassava (*Manihot esculenta* Crantz) is a planted crop that grows to a height of approximately 2–3 meters and it is commonly farmed in the tropics especially in Latin America, Africa, and Asia (Howeler, 2014). With a long petiole connecting them to a short stem, the leaves are deeply lobed and palmate with 3–7 leaflets. Cassava flowers are greenish-yellow and grouped in panicles. After forming in capsules, ripe seeds subsequently blast. When cassava stem cuttings are used to reproduce the plant, adventitious roots emerge from the stem, forming a fibrous root system (Hillocks *et al*., 2001).

The internal structure of cassava roots initially resembles that of a typical dicot plant, and each root actively absorbs water and nutrients. These roots reach a depth of 50–100 cm in the earth. During the second month after planting, some of the roots thicken (Lian and Cock, 1979). This is accomplished through the creation of secondary xylem tissue, which is then followed by the deposition of starch in the tissue. Up to ten roots are usually filled with starch in each plant, and several more roots in the fibrous state continue to collect nutrients and water (Chuzel and Wheatley, 1993). Depending on the type and stage of growth, cassava roots can grow up to 1 m long and weigh up to 2 kg. A brown corky periderm covers the outside of the periderm, which is fragmented in several places, and within the periderm, a 1–2 mm thick cortex is discovered (Pinho *et al*., 1995).

2.3 Environmental adaptation of cassava

Cassava root production peaks at temperatures between 25^o and 32^o C. It stops growing as the temperature drops below 10°C, and it is quickly killed by frost (Anikwe and Ikenganyia, 2018). Cassava thrives in locations with less than 800 mm of yearly rainfall and a 4–6 month dry spell, which is critical for growth and output and yield (Pipatsitee *et al*. 2018). Cassava can withstand a 3–4 month dry season by dropping most of its leaves; but, a steady source of moisture is required during the 1–2 MAP (Howeler, 1980). Cassava requires water between 1 and 5 MAP, during initiation of root and tuberisation stages. Reduction in storage root output can be 32–60% if water is insufficient for at least two months during this time.

According to El-Sharkawy (2007), cassava adapts to semi-arid environments; it requires enough soil water mostly at first; it can tolerate some months of severe dryness once sprouted; it is not irrigated in most locations, but does respond well to irrigation in other areas. Temperatures, photoperiods, sun radiation, and rainfall are all highly valuable for cassava. Day lengths above 10–12 hour’s delays root bulking while short day’s favours tuberous root growth of cassava. Long days throughout the cassava growing season might cause bulking to be delayed, lowering yields (Onwueme and Sinha, 1991). Table 2.1 shows the physiological impacts of various temperatures on growth of cassava plant.

2.4 Morphological characterisation of cassava varieties

The leaf, stem, and root features of cassava are highly variable. Cassava yield can be affected by colour and branching behavior of the stem; shape and colour of storage root (Ntawuruhunga and Dixon, 2010). Cassava cultivar ambiguities are resolved using morphological criteria (Rogers and Appan, 1973). Leaf colour and shape (elliptic or

Table 2.1 Influence of various air temperatures on physiological growth of cassava plant

Air temperature (°C)	Physiological effects
< 15	Slow plant growth
< 17 or > 37	Problem in sprouting
< 17	Leaf production rate, fresh and dry root weight reduce
16–38	Increase in height of cassava plant
16–30	Linear rise in rate of transpiration and then falls
20–24	Increased rate of production and leaf size and decreased in life of leaf
28	Number of branches reduced and leaves were shed quickly
25–29	growth of cassava is flawless
25–30	Greenhouse photosynthetic rate increase
28.5–30.0	Ideal for sprouting
30–40	Increase photosynthetic rate in the field

Source: Alves, 2002.

lanceolate); petiole colour and length; plant height and branching habit; stem length and colour; nodes number and internode length have all been identified as stable morphological features that can be used to classify cassava (IBPGR, 1983). According to Chisenga *et al*. (2019), variation in root properties include number, size and form of roots; peel and inner flesh colour; thickness of peel, maturity time, yield and taste of root, root dry matter and cyanogenic glycoside content.

2.5 Growth and development of cassava plant

Sprouts and adventitious roots occur on stem cuttings after 1–2 weeks, while adventitious roots form at the cuttings' base after 2–3 weeks (IITA, 1990). Adventitious roots grow fibrous roots that absorb water and minerals from the earth. Under ideal conditions, in 2 MAP, flowering and formation of roots begin. Depending on the growth conditions and cassava variety planted, harvesting can be done from 6–24 MAP (El-Sharkawy, 1993), after which it will mature into a perennial plant. During the dry season, cassava slows down its growth and sheds most of its leaves, but once the rainy season begins, it resumes rapid growth and leaf production (Onwueme and Sinha, 1991).

Depending on the type, atmospheric and edaphic conditions, the index of cassava leaf area varies from 4 to 8; it is the area of leaf per unit ground area covered. Cassava lowers water loss by transpiration in dry weather and there are significant variances in genotypic responses in cassava under various environmental conditions (Adetoro *et al*., 2021). Because of their interplay, the effects of genetics and environment on the phenotype of an individual plant are not necessarily inclusive. Because of the wide range of genotype by environment interaction (GEI), and phenotypic values, accuracy of estimated yield and interaction between genotype and phenotype values are frequently affected (Ssemakula and Dixon, 2007).

2.6 Cassava fresh root yield

Root yield functionally interplay with various physiological components that differ between varieties, producing direct yield improvement. Number and size of storage roots and HI had a strong correlated response with storage root production, according to Ntawuruhunga *et al*. (2001). There was strong relationship between fresh root output and quantity of storage roots (Didier and Mabrouk, 1994).

The quantity and size of roots, plant height, thickness of stem, width of canopy, number of branches and index of harvest were all found to be strongly associated to root yield (Mahungu, 1983). Cassava cultivars vary more in root size and form than other root crops and under ideal soil and climate conditions, FRY of 40–60 t ha^{-1} are attainable (IITA, 2010)

2.7 Fertiliser application and productivity of cassava

Cassava grows and yields better in low-fertility soils, when many crops would not grow (Gleadow, *et al*., 2016). However, for best development and yield, light textured, proper-drained soils with enough water and soil nutrients are necessary. Cassava is commonly farmed in the tropics on sandy soils, poor in organic matter and soil nutrients, and even when grown effectively without fertiliser input, yields often fall (Cadavid *et al*., 1998).

According to Islam *et al*. (1980), cassava can tolerate low pH levels (4.0–8.0) in the soil. The ideal pH range for cassava production is 5.5–5.6, which has an impact on soil nutrient availability and uptake. The plant thrives on soils rich in exchangeable Aluminum (Al) and Potassium (K), but lacking in available Phosphorus (P) (Howeler, 2014). Cassava frequently shows signs of zinc (Zn) deficiency during its early stages of development, as a result, cassava's nutritional requirements were pH 4.5, 0.2 percent N, 7.3 mg available P kg^{-1}, and 0.14–120 cmol exchangeable K kg^{-1} (Howeler, 1991).

Few cassava farmers in Africa apply fertilisers to soil due to transportation costs, logistic defects, delivery failures and other factors, and few fertiliser studies have been conducted with cassava (Idachaba, 2000). However, application of NPK fertiliser considerably enhanced DRY, total biomass, and LAI (Didier and Mabrouk, 1994). Adequate quantity of fertiliser can be administered based on soil analyses. According to Adiele *et al*. (2021), Cassava development and production will be aided by an initial abundant supply of N and P, as well as moderate K, with an additional K top-dresses applied during the second phase of growth. When 60-60-120 kg N, P, and K ha^{-1} are applied to cassava, yields can be greatly boosted (Cong, 2001).

Cassava responded frequently to nitrogen fertilisers in West Africa, (Okogun *et al*., 1999). Crop yields are boosted and biological, physical, and chemical aspects of the soil, either directly or indirectly are altered when inorganic fertilisers, particularly N, P and K were applied. Hence, harvesting all parts of the plant removes 2.9–3.6, 0.8–1.3 and 5.3–7.9 kg Nitrogen, Phosphorus and Potassium per tonne fresh root weight respectively depending on cassava variety (Polthanee and Wongpichet, 2017). Because the minerals are immediately available, inorganic fertilisers do not need to be broken down before being taken by plants, unlike organic fertilisers (Manoharan and Mallinga, 2014). Fertiliser treatments interacted significantly with location and there was an 8.1% rise from early to mid-planting date and a 9.5% increase from early to late planting date (Enesi *et al*., 2021).

For the tropics and rain forest zone of Nigeria, Ibia and Udo (2009) proposed 400 kg NPK 15-15-15 ha^{-1}. Another study by Makinde and Ayoola (2007) looked at influence of fertiliser type on cassava growth and yield. They discovered that inorganic fertilisers produced 11.8 t ha^{-1} FRY, equivalent to 11.0 t ha^{-1} produced from mixture of organic and inorganic fertilisers. According to Edet *et al*. (2013), applying 600 kg NPK 15:15:15 ha^{-1} and optimum management methods resulted in 33 t ha^{-1} FRY. Quantity of manure applied must be carefully considered, as it is determined by the manure quality, soil nutrient availability, crop need, and environmental circumstances (Eghball *et al*., 2002). The usage of mineral fertiliser is projected to increase productivity by 50% to 100%. (Chianu *et al*., 2012). Table 2.2 shows the effects of varied NPK 15:15:15 treatment rates.

2.8 Cassava productivity as influenced by some agronomic practices

2.8.1 Cassava stem planting methods: Cassava is commonly propagated by stem cuttings, which can be inclined, vertically, or horizontally planted on level or gently undulating soil, ridges, mounds, or heaps (IITA, 1990). At the base of the cassava stem cutting, auxiliary buds produce aerial shoots and adventitious roots, some of which grow into storage roots (Elias *et al*., 2007). Cassava stem cuttings sown vertically sprout quickly, which is preferable to horizontal planting because horizontal planting yields are low. For optimal and luxuriant growth, the plant's nodes should be planted upward (Imakumbili, 2019).

Table 2.2 Effects of varied NPK 15:15:15 treatments on FRY of cassava

Authors	Fert. Applied (kg ha^{-1})	FRY (t ha^{-1})
Aderi *et al*., 2010	100	18.50
Aderi *et al*., 2010	0	17.42
Baiyeri *et al*., 2008	400	19.00
Edet *et al*., 2013	600	33.00
Fondufe *et al*., 2001	400	13.00
Ikeh *et al*., 2012	400	24.69
Makinde Ayoola, 2007	400	10.34
Odedina *et al*., 2012	400	29.30
Odedina *et al*., 2011	300	22.50
Odedina *et al*., 2011	100	10.27
Odedina *et al*., 2011	200	20.67
Mean		20.06
SE (±)		5.68
CV (%)		32.14

Source: Varied as per authors above

Cassava grown on ridges produced higher root yields, and increased number of roots plant^{-1} is a main contributor (Ennin, *et al*., 2009). With the nodes facing upward, angular or horizontal planting position of cassava cuttings is effective. In regions with high water table, however, angular (slanted) planting on mounds or ridges (raised beds) is required (Polthanee and Wongpichet, 2017). Climate, soil type, topography, and cropping system all influence the employment of certain land preparation methods, such as mounds, ridges, flat-tilled or not-tilled (Lebot, 2009).

Ridge-based approaches increased root and leaf production, while flat and furrow systems increased the harvested plant number. However, planting horizontally and slantly proved to be most effective (Okogbenin *et al*., 1999). In comparison to the horizontal technique, Mbah *et al*. (2008) found that vertical and inclined orientations yielded larger root yields. Planting cuttings inclinely with polythene-covering increased storage root yield according to Ahmed *et al*. (2013) and Keating *et al*. (1988) stated that planting method had no influence on cassava development and output.

2.8.2 Plant population and spacing: Cropping systems, land preparation methods, plant variety, soil quality, and farmer traditions are some of the elements that influence optimal plant spacing (Wargiono, 1983). Non-branching cultivars are of particular interest to farmers, both for mono-cropping and intercropping, because they are easier to manage; 10,000 plants ha^{-1} is sufficient for the production of huge quantities of commercial-size roots that are consumed fresh (Leihner, 1984). Nereu *et al*. (2014) also found that plant spacing of 1.2 × 1.2 m and 1.5 × 1.5 m yielded more commercial root weight per plant.

Commercial roots are longer than 10 cm and have a diameter of more than 2 cm (Schons *et al*., 2009). For maximal root production in fertile soils, cassava stakes (15 to 30 cm long) planted at 1 m inters and intra row to give 10,000 plants ha^{-1} is utilized and up to 2 m inter-row spacing and about 0.5 m intra-row spacing are utilized when cassava is intercropped with other crops (Iijima, 2004). Plants planted closer together produced more roots and yielded more than those with a higher population (> 12,500 plants ha^{-1}) (Villamayor *et al*., 1992).

If farmers' basic interest is in producing leaf and stem, respective spacing treatments of 65 × 50 cm and 50 × 50 cm shoud be use so that sale of roots, stem cuttings, and leaf biomass will increase revenue generated compared to the sale of cassava roots alone (Moyin-Jesu and Akinola, 2012). 5,000 plants ha^{-1} produce a marketable FRY (15.8 t ha^{-1}) and the yield value was more than doubled at 13,594 plants ha^{-1}. On the other hand, average marketable roots length and HI are reduced by increasing planting densities (Tiago *et al*., 2013). The effect of plant spacing on cassava fresh root output in various environments is shown in Table 2.3.

2.8.3 Cassava harvesting age: Sweet cassava cultivars deteriorate quickly after maturity (6–9 MAP), while it takes bitter cassava cultivars 12–18 months to mature and delay in harvesting does not cause significant root deterioration (Bolhius, 1966). Root development stops in most cassava cultivars after 7 to 9 months (Beck, 1960). Due to the prolonged dry season, cassava growth is often slowed and yields are reduced. Screening for early bulking and maturity has become a critical method for enhancing cassava output due to the power of source and sink (Agbona *et al*, 2021). Maturity period in cassava happens when the canopy is entirely developed and the growth rate gradually declines to zero (Mahakosee *et al*., 2019).

Cassava should be harvested between 12 and 15 MAP; harvesting after this age may not contribute significantly to root yield and quality, resulting in bacterial rot in some cassava varieties (Edet *et al*., 2015). When the crop is harvested too early, root yield is reduced, and roots become woody, fibrous, and low in starch content, causing the crop to deteriorate (Ntawuruhunga *et al*., 1998). The harvest period has a significant impact on DMC and starch yield of improved cassava cultivars, according to Ebah-Djedji *et al*. (2012), therefore roots should be harvested at 13 MAP. There was 44.8% and 13.1% increase in RDM yield with an increase in crop age from 9–11 MAP and 11–13 MAP respectively, hence, delaying harvests boosts root DM output in all planting dates (Enesi *et al*., 2021). Also, Tewodros and Biruk (2012) showed an increase in yield between 12–15 MAP and 18 MAP, indicating that under ideal ecological conditions, cassava should be harvested at that period.

Table 2.3 FRY of cassava as influenced by plant spacing in various environments

Plant spacing (cm)	Area per stands (m^2)	Plant population ($no.ha^{-1}$)	Fresh root yield ($t\ ha^{-1}$)	Reference
100 × 100	1.00	10,000	54.40	Moyin Jesu and Akinola, 2012
100 × 100	1.00	10,000	27.10	Eke-Okoro *et al.*, 2001
100 × 100	1.00	10,000	18.10	Edet *et al*., 2013
100 × 100	1.00	10,000	16.18	Ladera and Evangelio, 1998
100 × 80	0.80	12,500	24.33	Odedina *et al.*, 2009
100 × 75	0.75	13,333	30.00	Villamayor, 1983
90 × 70	0.63	15,000	52.20	Moyin Jesu and Akinola, 2012
80 × 80	0.64	15,625	20.97	Ladera andEvangelio, 1998
75 × 75	0.56	17,777	28.00	Villamayor, 1983
100 × 50	0.50	20,000	57.70	Moyin Jesu and Akinola, 2012
80 × 50	0.40	25,000	50.00	Moyin Jesu and Akinola, 2012
50 × 75	0.38	26,666	28.00	Villamayor, 1983
60 × 60	0.36	27,778	21.85	Ladera and Evangelio, 1998
70 × 50	0.35	28,000	33.30	Moyin Jesu and Akinola, 2012
65 × 50	0.33	30,800	28.80	Moyin Jesu and Akinola, 2012
50 ×50	0.25	40,000	26.60	Moyin Jesu and Akinola, 2012
25 × 75	0.19	53,333	22.00	Villamayor, 1983
Mean			31.74	
SE(±)			8.27	
CV (%)			41.84	

Source: Varied as per references above

2.8.4 Weed control in cassava production: Weed competition can reduce root yield by 40% in early-branching and 68% in late-branching or non-branching cultivars (Akobundu, 1980). Weed problems grow severe when plant canopies do not provide enough cover. Weeds are the most frequent crop pests in cassava growing regions; as a result, until closure of cassava plant canopy, weedings should be done 2–3 times during the first 3 MAP (Akinyosoye, 1999).

Majority of farmers in the tropics employ hoe weeding; only a few uses a manual tractor or an animal-drawn cultivator (Aye and Howeler, 2017). Herbicides or a tractor-mounted cultivator can also be used. Lack of awareness was highlighted as one of the reasons for not using herbicide in cassava, among other considerations (Udensi *et al*., 2012). In West Africa, less than 3% of cassava farmers use herbicides, as they have been shown to have harmful impacts on development and yield of crop, so also the environment (Ogundola and Liasu, 2006). Reduction in weed competition is possible by planting at the begining of dry season and timely fertiliser application to enhance closure of plant canopy (Howeler, 2014).

Spear grass (*Imperata cylindrica* (L) Beauv) and running carpet *grass (Axonopus compressus*) have caused major issues in cassava farms in Nigeria, according to Okon & Amalu (2003). Cassava plots are commonly infested with grasses and broadleaf weeds, which reduce yields and raise labour costs. Weed competition causes approximately 50% decrease in growth few months after planting (Leihner, 2002). Weed control, either manually or mechanically, herbicide application, or management measures, is critical for optimum yields and may help to decrease erosion.

Tongglum *et al*. (2001) recommended the use of metholachlor (1.5 kg a.i. / ha) just after planting, and then specific application of glyphosate or paraquat or 1–2 hand weeding using hoe. Compared to hoe weeding, application of weed emergence herbicide (Dual) at 2.4 l ha^{-1} increased yields and net revenue of cassava in Vietnam (Nguyen Huu Hy *et al*., 2001). Increased plant population and introducing vigorous, early branching cultivars were identified as low-cost weed management alternatives (Fermont *et al*., 2010). Other options for promoting early ground cover include the use of fertilisers and pesticides. Table 2.4 shows the effects of weed management regimes on cassava FRY.

Table 2.4 Effects of weed management regimes on FRY of cassava

Weeding practice	FRY ($t\ ha^{-1}$)	Reference
Pre-emergence herbicide + one hand weeding	23.7	Leihner, 2002
4, 12 and 20 WAP weeding	17.4	Ambe *et al*., 1992
Premextra+ 2 hoe weeding	12.3	Olorunmaiye, 2010
Hoe weeding at 3,8 and 12 WAP	16.6	Melifonwu, 1994
Herbicide + hoe weeding at 2 – 4 WAP	15.8	Chikoye *et al*., 2007
No weeding	8.3	Bacusmmo and Talatala, 1980
Hoe weeding at 3 WAP	10.2	Melifonwu, 1994
Weed free during 2 MAP	18.1	Bacusmmo and Talatala, 1980
Mean	14.88	
SE (±)	7.35	
CV (%)	32.23	

Source: Varied as per references above

2.8.5 Intercropping of cassava: The primary aim for intercropping is to provide protection against the risk of monoculture. Small-scale farmers, in particular, are subject to a wide range of risks in their output since they rely significantly on the vagaries of nature (Muhammad *et al*., 2003). Cassava is frequently intercropped with maize, cowpea, melon, okra, and green vegetables due to their growth habits (Leihner, 2002). Higher FRY was reported when cassava is grown with groundnut compared to cassava-cowpea and cassava-soybean systems (Mansaray *et al*., 2012). Hence, productivity of an intercrop system will differ with component variety and environment.

Crops such as upland rice, maize, and legumes are intercopped with cassava in the humid climate and enhanced total revenue by 33%, according to Makinde and Ayoola (2007). This was attributable to the crops' efficient use of resources due to morphological variations in mixture components, despite the fact that cassava development was initially slowed. According to Olasantan *et al*. (1997), the big component of maize reduces early development of cassava when cassava is intercropped with maize. Maize is primarily responsible for the amount of assimilates delivered to cassava roots. However, a high mono-crop relative yield can be achieved after early season crop have been harvested (Amanullah *et al*., 2006).

2.9 Effects of fertiliser application on nutritional value of cassava

Cassava's nutritional value is mostly determined by fertiliser treatments and genotype. The antioxidant activity of cassava cultivated in the field can be boosted by using vermicompost and empty fruit bunch compost (Dumas *et al*., 2003). By applying organic fertiliser, total phenolic acid content in roots and leaves is generally enhanced. The amount of cyanogenic glycoside in both plant parts had increased after inorganic fertiliser was applied. Vermicompost is beneficial for increasing antioxidants in cassava (Nur Faezah *et al*., 2013) and fertigation of K combined with adjustments in supplied water may increase the nutirional quality of young cassava and thus increase nutrient bioavailability in drought-prone locations (Wasonga *et al*., 2020).

Despite its lack of protein, fresh cassava roots are high in carbohydrate and contain 50 mg calcium, 40 mg phosphorus and 25 mg vitamins per 100g according to Zhang *et al* (2006). The roots are largely made up of starch (80 to 90% by weight), with water accounting for the remaining 60.3 to 87.1% (Harris and Koomson, 2011). Cassava fresh root contains roughly 30% starch and produces the largest starch per unit area of any other crop (Tonukari, 2004). There is low protein content, ranging from 13% to 15%. (Salcedo *et al*., 2010). High N levels result in high cyanide in cassava leaves and roots, according to Gleadow *et al*. (2016), but thorough processing, as done traditionally, decreases the cyanide in the end product (gari, lafun, etc.) to negligibly low and bearable levels.

2.10 Time and methods of fertiliser application to cassava

Fertiliser application is crucial during the first 6-8 weeks after cassava planting and after the first weeding (IITA, 2010). Thin and thick roots that absorb nutrients from the earth are produced at this phase. When fertiliser is applied to dry soil, it may not mineralize, resulting in nutritional deficiency for plant uptake. Nitrogen (N) application is necessary to maintain yields, however surface application may expose N to volatilization losses (Kishan *et al*., 2021).

When N-fertilisers were applied at higher rates during planting, the leaf area index (LAI) increased. Sangakkara and Wijesinghe (2014) found that by appling 90 kg N during planting and 45 days after resulted in the highest cassava shoots and roots N-recovery efficiency. Inorganic fertilisers should be spread to cassava stake and plant in short band using hoe at 5–10 cm because they break down quickly in soil. To reduce N volatilization and nutrient losses owing to run-off and erosion, fertilisers should be covered with soil after application. Cassava roots grow towards the fertiliser band so as to absorb the nutrients melted in soil solution. This restricted application or precision placement (banding) promotes root growth while preventing fertiliser application to surrounding weeds (Howeler, 2014).

Most soluble fertilisers, e.g Urea, SSP, TSP, KCl, Di-Ammonium Phosphate (DAP), or Potassium Sulfate (K_2SO_4), as well as many compound fertilisers, should be applied when the cuttings are planted or after root emergence at 1 MAP after the roots comes out to take up the nutrients. Immediately after planting, Phosphorus fertilisers should be administered whilst Nitrogen and Potassium fertilisers should be in two stages, with half applied immediately at planting and other applied at 2–3 MAP during optimum rate of growth of cassava (Howeler, 2014). At 4–6, 10–12, and 16–20 WAP, one third of the total amount of required fertiliser (N-P-K) should be applied. 20 cm from the base of the cassava plant, in a furrow with the shape of a half-moon, fertiliser can be put and then covered with soil (Enesi *et al*., 2021).

2.11 Mobility of inorganic fertilisers in the soil

Depending on plant density, cassava roots reaches 0.5 m depth below the soil surface at the early growth phase (1–4 MAP) and in a horizontal direction, it expanded 1 to 2 m (Iijima *et al*., 2004). As a result, any fertiliser applied below the root zone of 50 cm will be unavailable to the cassava crop. In some cases, fertiliser can be leached from fertilised to unfertilised areas. In the tropics, urea is one of the most extensively utilized nitrogen fertiliser sources, and it works best when applied in bands or split. Urea can also be sprayed on the leaves as a foliar spray.

Within 2 days of its addition, urea can diffuse 2.5 cm in the soil using the banded technique of application, whereas considerable levels of NH_4+ can be seen at distances of 3.8 cm from the band (Macnack *et al*., 2013). N losses of up to 50% or more can be expected when urea is broadcast without quick assimilation. Potassium diffusion varies by soil type; however it was lowest in sandy soil with minimal organic matter concentration. After seven days, Neves *et al*. (2009) discovered lowest K diffusion in an Oxisol (6.4 cm) and highest in an Inceptisol (8.4 cm). Muriate of potash (MOP) also called Potassium chloride (KCl), contains 60% K_2O and accounts for nearly all K fertilisers used in agriculture. Phosphate fertilisers are initially water soluble and hence readily utilised by plants, but they quickly become less soluble when they react with clays and other minerals in the soil. Faria and Pereira (1993) discovered that P moved through the 46–68 and 14–16 cm in clayey and sandy soils respectively after applying 150 and 300 kg P_2O_5 ha^{-1} to the surface of five distinct soils.

2.12 Effects of nutrient omission on cassava yield

Large quantity of K is drawn by cassava roots from the soil but not much N or P, which made harvested roots to have high K: N ratio. For optimum shoot and root yields of cassava, N and K are the most important nutrients (Obigbesan and Fayemi, 1976).

Excessive amounts of both nutrients promote vegetative growth at the expense of root formation, although proper K levels in the soil promote N fertiliser response (Onwueme and Charles, 1994). Potassium (K) depletion is more rapid in tropical soils than other plant nutrients, hence, application of potassium fertiliser increased root yield of cassava according to Adekayode and Adeola (2009).

As a result of the presence of cyanogenic glucoside in the roots, Potasium deficiency caused much reduction in production, lower root starch content and reduces the value of the roots for consumption (Rojanaridpiched *et al*., 2011). Cassava cultivars that produce a lot of root dry matter export a lot of nutrients from the soil and when potassium is present in the soil, a given leaf area increase its photosynthetic activity, and thus transfer photosynthates to the storage roots (Adjei-Nsiah, 2010).

Due to positive response of cassava to fertiliser treatment, it requires adequate nutrients to produce a good yield (Cadavid and Howeler, 1983). Although cassava has historically been produced without the use of fertilisers, it has been proven that the cassava plant responds effectively to the application of K, which improved cassava root yields and starch content (Suyamto and Howeler, 2001).

According to Uwah *et al*. (2013), N and K greatly increase growth and output of cassava and application of N and K between 80 and 120 kg ha^{-1} is adequate. Asoro (2013) also confirmed that foliage production is more responsive to P fertiliser application than root production.

2.13 Cassava productivity as influenced by stem cuttings properties

2.13.1 Cassava stem portions and lengths: Cassava is often planted via stem cuttings, sometimes known as "cuttings," and the ideal cuttings for establishment are typically 25 cm long and derived from plants that are 10 to 12 months old (Uguru, 1996). According to Oka, *et al*. (1986) stakes from the upper part of the stem sprouted at a considerably lower rate than those from the basal and mid portions of the stem, and cassava cutings 15–20 cm long germinate better than 5–10 cm cuttings. However, based on cassava variety, the upper section of some stems showed strong establishment.

Factors that affects quality of cassava plant according to Akoroda *et al*. (2004) include age of the plant used, thickness and number of nodes on each stake, differences in sprouting of each variety and disease and pest resistance. Cassava stem cuttings should be between 15 and 30 cm long, with 20–25 cm (Nigeria), 25–30 cm (Philippines), and 15–25 cm (Sierra Leone) (Onwueme and Charles, 1994). They claim that cuttings longer than these waste planting material and are difficult to manage, while cuttings shorter than these risk not having enough nodes. According to Okpara *et al*. (2022), in the field, 13-nodes cassava stake from the upper stem portion had a low germination potential and are prone to dehydration and destruction by pathogens. The most common cutting length among farmers is 15–25 cm, which is adequate until a field trial with production costs reveals another practical lenght.

By planting 20 cm cuttings horizontally and 30 cm cuttings inclinedly, respective root yield of 21.292 and 20.236 kg ha^{-1} was obtainable because the roots had higher starch and dry matter content (Viana, 2008). As a result of formation and dissemination of assimilates, an increase in stem dry matter, which was achieved by extending nodes number and length by up to three times, had a significant effects on the crop's growth and development (Bridgemohan and Bridgemohan, 2014).

Carvahlo *et al*. (1993) discovered that cassava stem cuttings with a minimum stem length of 20 cm produced the best results, and that there is a better chance of surviving for cuttings with more than 10 nodes. According to Onwueme and Sinha (1991), plant establish and yield better when using stem cuttings from mature parts than those taken from younger parts, whereas cuttings taken from extremely immature portions do not root well in the field.

2.13.2 Stem cutting diameter and weight: Farmers normally utilize stem cuttings to replicate and grow cassava, but researchers often use both sexual seeds and stem cuttings. However, cassava roots cannot be used for reproduction (Beeching *et al*., 1998). Furthermore, cassava root systems grown from botanical seed and vegetative cuttings are vastly different. The taproots of cuttings store more starches than the taproots of seedlings (Rubatzky and Yamaguchi, 1997). When cuttings are cultivated under suitable conditions for one week, sprouting and adventitious rooting occur. To promote rapid and consistent root development and yield, sharp instruments such as secateurs or cutlass should be used to cut stems into cuttings for planting (Adekunle *et al*., 2008).

For field planting, cuttings with a length of 20–25 cm and 5–7 nodes are recommended (Ekanayake *et al*., 1997). The best cuttings are from the base section of the stem, around 25 cm and 2.25 to 2.50 cm in length and diameter. According to Didier and El-Sharkawy (1994), the number of storage roots had a substantial impact on root yield, and size of cutting and number of storage root were connected to root yield. Rafaillac (1992) also stated that stem diameter and length are vital in defining the amount of nutrients held in a stake, which is a major feature in stake survival, growth, and yield, because under water stress, thinner stems are more susceptible to dryness.

2.13.3 Storage of cassava stems: Cassava planting materials stored for more than 8 weeks under shade by farmers' lose viability due to dehydration, and insect and disease assault (Leihner, 1984). For storage duration, Sungthongw *et al*. (2016) revealed that percentage germination and survival rate was reduced by 45 days. They came to the conclusion that storing planting material for less than 30 days, covering it with hemp bags and setting it outside in the shade of a tree, resulted in faster and greater germination and survival rates. By soaking cuttings in water solution for four hours, sprouting can be aided (Osei *et al*., 2009). Planting fresh stem stakes from mature plants on healthy soil is critical to the production and profitability of any cassava farm (IITA, 1990). However, the main constraint for vegetative propagation of cassava is the quick loss of viability of stems under storage, due to difficulties in protecting the voluminous planting stems from bad atmospheric conditions, insect and non-insect pests and diseases, desiccation, bruising and peeling (Rajendran *et al*., 2005).

2.14 Ideal stems cuttings for planting

The following features are described as crucial in most of the literature on stem cuttings for planting to develop tuberous roots. According to Yomeni (2011), they are as follows:

1. It should be mature enough to be used (between 8 and 18 months old).
2. The length should be between 20–30 cm.
3. Each cutting should have 5–7 alive and unbroken nodes.

4. The pith diameter should be no greater than 50% of the stem cutting's total diameter.
5. The outside circumference should be 2–3 cm.
6. The cutting's initial fresh weight should be around 88 g/stake at planting time.
7. Stem cuttings should not be mechanically damaged.
8. Even and straight cut surface.
9. Cutting skin should be free of bruises.
10. Stem cuttings should not be taken from plants that show signs of pest or disease.
11. When keeping stems, retain them as long as possible and avoid cutting them into cuttings, as this will considerably speed up dehydration.
12. Do not keep stem cuttings for more than 30 days.
13. Before storing stem cuttings, fungicides and insecticides should be applied.
14. Before planting, rehydrates stored cuttings in water or a nutrient solutionfor 4 hours.
15. Stem cuttings should not be planted in insect-infested soil unless an insecticide has been applied to the cutting or the soil.
16. Improved cassava plant varieties should be used for stem cuttings.
17. For cutting preparation, use razor-sharp tools that have been cleansed with soap and water.
18. Number of days between cuttings preparation and planting should be limited.
19. Cuttings should have 60% moisture content as at the time of planting.
20. Avoid using green stem cuttings (young branching tips).
21. Cuttings from the main stem should be used for commercial production.
22. The stem for cuttings should be selected while the plant is still actively growing in the field.
23. Cutting preparation should be done by trained or qualified people.

2.15 Techniques for rapid propagation of cassava

Two basic quick propagation strategies can be use. The first technique uses two-node cuttings to produce many shoots, whereas the second technique uses green stem auxiliary buds. The latter is quicker, but it necessitates more infrastructure and plant material handling expertise (Reizaluamar *et al*., 2020). Due to a constant scacity of planting materials for better cassava varieties, they were developed. The traditional 1:10 multiplication ratio in cassava planting material is increased to 1:60 using these approaches. Farmers have various levels of understanding of the individual activities that make up the cassava stem multiplication technology (Ekwe and Njoku, 2011).

2.16 Dry Matter Content of Cassava Roots

Cassava roots are 67% water with the rest consisting largely of starch-based dry matter. Cassava is necessary because of the high glucose contained in the roots (Rickard *et al*., 1991). Cassava root dry matter content is a highly desired feature for culinary and industrial applications since it indicates the crop's genuine biological yield and chemical potential (Kawano *et al*., 1987). DMC of cassava root is determined by plant age, the cropping season, the location, and the performance of the plant canopy in capturing sunlight, according to Lian (1985). The majority of cassava accessions have a range of dry matter content (20-40%), however values above 30% are considered average (Barima *et al*., 2000). Teye *et al*. (2011) developed a prediction equation for predicting RDMC using the specific gravity approach. He stated that an unstable source of electricity, particularly in the tropics, is a major constraint to employing the oven dry method.

2.17 Cassava postharvest physiological deterioration (PPD)

Fresh cassava roots have a limited storage period due to postharvest physiological deterioration (PPD), an endogenous physiological process. Wounds on cassava roots create enzymatic stress, which leads to this complicated operation (Beeching *et al*., 2002). After harvest, PPD causes a decrease in root acceptance. It also reduces cassava root storage and commercialisation. Unreliability of cassava root reduced small-scale farmers' root quality and affects large-scale processors (Naziri *et al*., 2014).

Cassava root stores photosynthates and does not require wound repair because it is not a propagule with reproductive activity. During evolution, cassava roots lost their ability to heal wounds (Reilly *et al*., 2004). Cassava roots, which contain about 65%

water, have a very limited shelf life because of PPD, which reduces their palatability and marketability (Han *et al*., 2001).

2.18 Pests and diseases of cassava: symptoms and management

Pests and diseases significantly reduce cassava production and low average outputs are ascribed to biotic and abiotic constraints, and the most intense is mosaic disease (Kaitisha 2003). The most frequent cassava diseases are CMD, CBB, CAD and root rot; CGM, CM and the variegated grasshopper are the main pests (Zhou *et al*., 1998). Cassava yield is reduced as the leaves, stems, and roots are damaged. In Africa, base on the variety, output losses ranging from 12% to 82% is caused by CMD with viral pedigree, and environmental circumstances (Owor *et al*., 2004). ACMV (African cassava mosaic virus) and EACMV (East Africa cassava mosaic virus) caused the disease and whitefly *Bemisia tabaci* Genn disseminates it (Martins *et al*., 2018). It is easily spread through multiplication of contaminated cuttings with plants showing severe deformation of leaves and drastic loss in leaf size and area (IITA, 1990). Uganda, the Democratic Republic of Congo, and Kenya felt greater impact of CMD, but resistant varieties have been identified by IITA Ibadan. The emergence of novel disease variants has prompted increased research efforts aimed at producing varieties with high levels of resistance to several disease variations.

Xanthosomonas campestris Manihotis causes CBB. Wilting of young leaves resulted from planting infected plant materials, whereas secondary symptoms from secondary infection included water soaked patches followed by blight (Martins *et al*., 2018). In extremely vulnerable cultivars, total yield loss is observed. Before falling off of the affected leaves, the leaves dry up and stay attached to the stem for a while. López and Bernal (2012) reported a yield loss of 12 to 100% is recorded on highly susceptible varieties and in all cassava growing regions.

Colletroticum gloeosporioides sp *Manihotis* Henn and *Glomerella Manihotis* Chev are the bacteria that cause CAD. According to IITA (1990), deeper cankers and fragile stems causing stems to be damaged easily by wind are symptom of CAD infection. Deep cankers obstruct the transport of vital nutrients to active growth zones. Fokunang (1995) found that different cassava varieties had different levels of CAD resistance, and that some improved varieties had far higher levels of CAD resistance than others. According to Owolade *et al*. (2005), Screening for clones with small and low canker numbers is also beneficial. This is because fewer cankers on stems result in fewer delays in vital mineral transport and nutrient availability to the plant.

The most significant cassava pests in Africa's primary cassava producing areas are CGM, namely *Mononychellus progresivus* and *M. tanajoa*. During the dry season, there is more severe attack on the plant, which lead to reduction in leaf size and, as a result, a reduction in photosynthesis. Yield loss of up to 80% can be caused by cassava green mite infestations and some cassava varieties have been found to be more sensitive to the pest attack than others (Owor *et al*., 2004). High occurrence and severity scores of green mite and grasshopper were recorded in sole cassava compared to the intercropped (Mansaray *et al*. 2021).

According to Ogbe *et al*. (2003), cultivating pest- and disease-resistant cassava varieties is the most reliable and simple technique for minimizing these biotic stressors. The most cost-effective long-term strategy for agricultural sustainability is to provide farmers with high-yielding, disease/pest-resistant cultivars (Kueneman, 2002).

2.19 Cassava's Importance

Cassava, a staple crop for human use in Africa, is generally cultivated in the tropics due to its diverse commercial and industrial applications (Mtunguja *et al*., 2019). Fresh cassava leaves are food for human and animal feed throughout Africa and Asia, but the tuberous roots are given top priority (Benesi *et al*., 2010). Aside using tuberous roots for meals, edible green cassava leaves which contain protein, vitamins, and minerals are also used (Ravindran, 1993). Other crops, such as bananas (2.9), sugarcane (1.9), rice (0.4), and maize (0.8), have a far lower K: N ratio than cassava roots (3.9) (Howeler, 2014). It is the world's third great carbohydrate source, providing a low-cost energy source to around 500 million people globally (Montagnac *et al*., 2009).

About 800 million people feed on cassava in tropical nations. A range of processings such as soaking, grating, fermenting, boiling, and drying/roasting whole or fragmented roots, are employed to minimize the overall cyanide content of cassava products (Dziedzoave *et al*., 2010). Cassava provides 500 kcal per day to over 100 million people, and 30 million individuals in Central Africa get more than 1000 kcal per day from it (Montagnac et al., 2009). Both the storage roots and the leaves are important delicacies in many cassava-growing regions; 2.32 N, 0.39 P, 3.05 K, 0.47 Ca, and 0.27 Mg $kg^{-1}$are found in one tonne of fresh cassava roots (Howeler, 1991). Cassava is a root crop that is eaten in many underdeveloped countries and provides a large quantity of energy to the body. According to Eyinla *et al*. (2021), using simple traditional methods, fresh cassava roots are processed into gari, fufu, flour, and starch in SSA.

Before being consumed, cassava roots are processed in other to detoxify, cleanse, preserve, and change them (Oyewole, 1991). Bitter cassava contains deadly hydrogen cyanide and should be processed before eating, while sweet cassava should only be cooked and consumed, according to Ubwa *et al*. (2015). Gari is made by pounding peeled fresh roots into a pulp and fermenting it for three to five days before frying it over an open flame. Gari is presently the commonest form of cassava eaten across the different regions of Nigeria and it accounts for 70% of cassava (Ohimain *et al*., 2013). Cassava flour, which is prepared by grinding dried cassava chips, has been used to substitute or combine with wheat flour for baking bread or cake (Widowati and Hartojo, 1992).

According to Montagnac *et al*., 2009, fresh roots of cassava contain around 30% starch content which is widely used in the laundry, culinary, and textile industries, and also in producing adhesives, cosmetics, and paper. It's made by crushing peeled fresh roots and squeezing out the starch in a series of water changes. Cassava flour is one of the most store-stable food products and a good approximation of the edible component of fresh cassava root (Udoro *et al*., 2021). The world's attention has shifted to ethanol derived from fermented cassava starch as fossil fuel prices have increased and global oil stocks have dwindled. According to Sorapipatana and Yoosin (2011), cassava starch can be utilized to make ethanol on a big scale in tropical areas, but further research is needed to make more efficient industrial processes.

2.20 Linear correlations among traits in cassava

When there is polygenic inheritance of a certain character that is linked with another, correlations quantify the degree of association between two variables and allow selection of a trait of interest (Cruz, 2005). Breeders can foresee the outcome of simultaneous change, which encourages direct selection of agronomic and morphological qualities, resulting in improved breeding program gains (Odjugo, 2008). Understanding the degree of link between traits that lead to yield and calculating their correlation coefficient are critical (Ceballos *et al*., 2004). Correlation coefficients, unlike covariance, are best used to examine the association and comparisons between distinct pairs of attributes (Rubaihayo *et al*., 2001).

2.21 Use of GGE biplot for multiple environment trials

Plant breeders frequently carried out trials in a variety of conditions in order to choose consistently good producing cultivars for a given environment. The analysis of these data frequently yields genotype-by-environment interactions, which are difficult to explain and reduce selection efficiency. GGE stands for Genotypic Responses in a Variety of Environments (Genotype + Genotype by Environment interaction). According to Kroonenberg (1995), the GGE interaction uses the statistical model of principal component analysis (PCA) and is used to comprehensively explore multi-environment trials (MET). Each PC is made up of a combination of genotypic and environmental scores. GGE biplot gives precise information on environmental and genotype performance. As a result, the GGE biplot is one of the most recent analyses frequently employed to overcome challenges in MET (Agyeman *et al*., 2015).

Genotype × environment interactions (GEI) are common in plant breeding programs (Kang, 1998), and they are induced by variation in cassava varieties' reactions to different environmental conditions (Adetoro *et al*., 2021). Plant breeders and farmers, according to Linnemann *et al*. (1995), prefer cassava varieties with low G × E interaction and high yield, with little or no effect of environment on genotypic performances. The GGE bipots were used to graphically display genotype evaluation (mean Vs stability), test environment evaluation (discriminating Vs representativeness), mega environment differentiation and specific adaptation (which-won-where) (Uchendu *et al*., 2022).

2.22 Cassava crop improvement and breeding programme

Cassava breeding at various research institutions organizations has aimed to create varieties with a wide range of desired attribute like high root yield, resistance to disease and pest, improved root quality and production stability across many circumstances (Fukuda *et al*., 2002). Because root quantity and size, particularly larger roots, are important drivers in cassava production increase, while increasing number of root, breeding work should focus on increasing size of root (Aina *et al*., 2007). A combination of various cassava varieties fortified with micronutrients was discovered in a recent research breakthrough (Okwulehie *et al*., 2014).

Cassava improvement projects in SSA are intended towards expanding and improving cassava's genetic basis while preserving its adaptability through population development, based on unique agro-ecologies (Dahniya, 1994). IITA Ibadan's cassava breeding program employs population enhancement strategies that entail the creation of superior source populations on the basis of qualitative and quantitative criteria. A new selection cycle begins when these superior individuals are recombined to produce a new population (Dixon *et al*., 1994). Improved variety development begins with the sowing of breeder's seeds in the seedling nursery and continues to discover cultivars with stable and high yields through clonal evaluation, preliminary yield trial, advanced yield trial, uniform yield trial and eventually multi-location yield trials.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Experimental Sites

3.1.1 Field Survey on cassava farmers practices

Ninety structured questionnaires were administered to farmers in Elekokan, Pontela and Elere-Adeogun villages which are respectively in Iwajowa, OgoOluwa and Ido local government areas of Oyo state, Nigeria (Figure, 3.1).

3.1.2 Description of field experimental sites

Two years field work was done at IITA experimental sites at Ibadan, Ikenne and Tsonga in Nigeria (Figure 3.2) during 2014/2015 and 2015/2016 planting seasons. Weather data for the period were collected from Geographic Information Systems (GIS) unit at IITA, Ibadan.

Ibadan: Derived savanna, Latitude 7°26'N, and Longitude 3°54'E, 243 metres above sea level, located in Oyo State, Southwestern part of Nigeria. It has annual rainfall of about 125.02 mm, 15.43 MJ/m^2/day of solar radiation; 31.60 and 22.38°C maximum and minimum temperature respectively and 69.15% relative humidity. It has two rainy seasons, one dry season and has potential for high crop yield. In 2014, experimental site in Ibadan was formally cultivated to yam while in 2015, it was cassava. Mineral fertiliser (NPK 15:15:15) was previously used in the experimental sites.

Ikenne: Rainforest savanna, Latitude 6°87'N and Longitude 3°43'E, 44 metres above sea level, located in Ogun State, Southwestern part of Nigeria. It has annual rainfall of about 116.60 mm, 14.94 MJ/m^2/day of solar radiation; 28.28 and 25.68°C maximum and minimum temperature respectively and 82.56% relative humidity. It has two rainy seasons, one dry season and has potential for high crop yield. In 2014 and 2015, experimental sites in Ikenne were formally cultivated to maize and mineral fertiliser (Urea) was used.

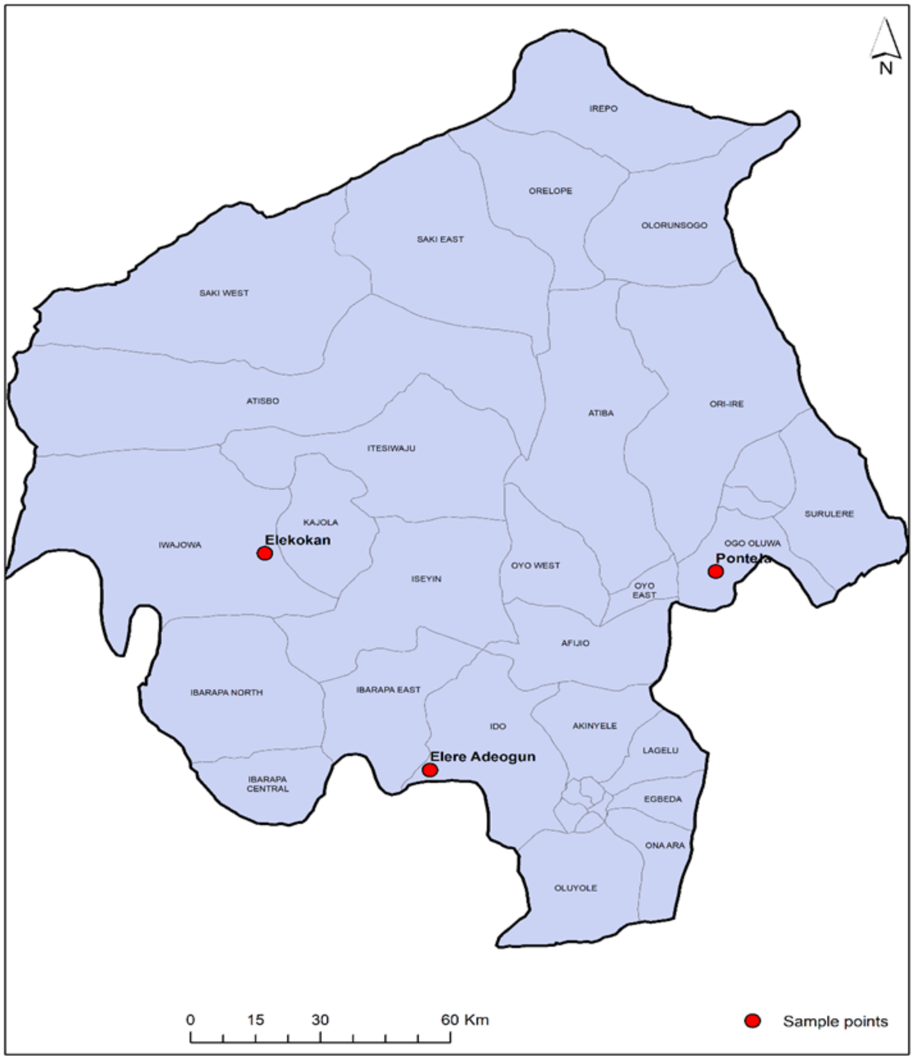

Figure 3.1 Map of Oyo state showing the three communities where survey was carried out in 2015

Source: IITA, GIS unit, Ibadan.

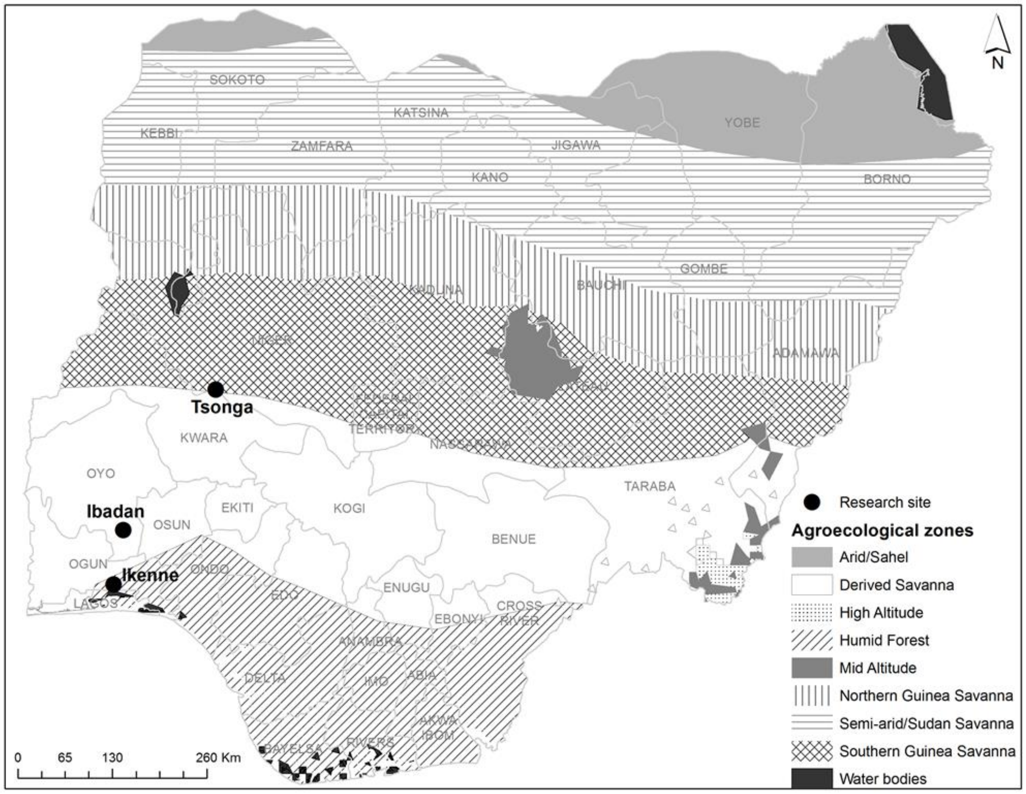

Figure 3.2 Map of Nigeria where locations of the field trials conducted in 2014/2015 and 2015/2016 planting seasons are shown

Source: IITA, GIS unit, Ibadan.

Tsonga: Derived savanna, Latitude 8°94'N and Longitude 5°25'E, 219 metres above sea level, located in Kwara State, North central zone of Nigeria. Annual rainfall is about 97.27 mm, 18.17 MJ/m^2/day of solar radiation; 33.72 and 22.44°C maximum and minimum temperature respectively and 60.08% relative humidity. It has about 4–5 months of consistent rains and 3–4 months of drought. Experimental sites were formally cultivated to cassava and mineral fertilisers were not previously used.

3.2 Source and description of four varieties of cassava used in this study

IITA, Ibadan developed the four cassava varieties used in the field experiments and their characteristic traits are as follows;

IITA-TMS-IBA070593: Released in 2014, vitamin A bio-fortified yellow fleshed, multiple pest tolerance, high yielding (>25 t ha^{-1}), early bulking and stay green.

IITA-TMS-IBA011412: Released in 2011, vitamin A bio-fortified yellow fleshed, multiple pest tolerance, early bulking and high yielding (>25 t ha^{-1}).

IITA-TMS-IBA010040: Released in 2010, high dry matter (25%), multiple pest tolerance, early bulking, high yielding (>25 t ha^{-1}), pink skin and high starch.

TMEB419: Released in 2005, high dry matter (25%), multiple pest tolerance, high yielding (>25 t ha^{-1}), poundable and high starch.

3.3 Cultural practices

In all locations, field experimental sites were slashed, ploughed, harrowed and ridged mechanically by tractors. Stem cuttings were made from 12 months old plants using secateurs. Stem cuttings were planted under rain-fed conditions, with 1.0 m and 0.8 m between and within row planting distance for a total of 12,500 plants ha^{-1} with three replicates. Just after planting, before weed appearance herbicide (ParaeForce (200 ml) + Primextra Gold (50 ml) + water (20 l) was administered. Sprout count was done at 1 MAP and dead cuttings were supplied. At 5 and 10 WAP, manual hoe weeding was done before each split fertiliser application. 300 ml of herbicide (ParaeForce) into 20 litres of water was sprayed at 6 and 9 MAP and harvesting at 12 MAP.

3.4 Response of four improved cassava varieties to nitrogen, phosphorus and potassium fertiliser application

3.4.1 Soil collection and analyses: In each experimental field, soil auger was used to collect 30 soil samples randomly at 0-30 cm depth at planting and after harvest. These were thoroughly combined and bulked up. Two composite samples per location were collected, spread under shade so as to allow air pass through and sieved through a 2 mm and 0.5 mm sieve before being analysed at the IITA soil analytical laboratory for pre-planting and post-harvest soil analysis to establish the soil's nutrient status. Sodium hexametaphosphate (calgon) was used as the dispersant and the hydrometer method (Juo, 1979) was used to determine the particle size.

Soil pH in H_2O and KCl was determined in 1:1 soil/water and soil/KCl ratios using a glass electrode pH meter; 10 g of air dried 2 mm sieved soil was weighed into a 50 ml beaker, and 10 ml of distilled water/KCl was added. Using a glass rod, each mixture was stirred for 10 minutes. After standardising the electrometer, a pH meter electrode was placed into the suspension and a reading was taken. In the field, pH in water is frequently utilized due to water availability, whereas pH in KCl solution checks for inherent exchangeable aluminum in the soil.

The Walkley and Black (1934) method was used to determine organic carbon. In a 500 ml conical flask, 0.5 g of air dried 0.5 mm sieved soil was weighed, and then 10 ml of 1N $K_2Cr_2O_7$ from a burette was included and stirred together. Concentrated H_2SO_4 (20 ml) was added, stirred for 1 minute, and put aside for 30 minutes to settle. The solution was diluted in 200 ml distilled water, and orthophennothroline indicator (3 drops) was added. The same technique was followed to make a blank solution, but without the sample. With 0.5 N Ferrous Ammonium Sulphate solutions, the two solutions were titrated to a fine-red end point. Percentage of organic carbon (OC) was computed thus:

$$\% \ OC = \frac{\text{me } K_2Cr_2O_7 - \text{me } FeSO_4 \times 0.003 \times 100 \times f}{\text{Weight of sample}}$$

Where:

f = Correction factor (1.33) and me = Normality of solution X ml of solution

Organic matter of the soils was obtained from organic carbon by multiplying with the conventional ‘Van Bemmelar factor’ of 1.724.

Jackson (1958) developed the Kjeldahl digestion method to determine total nitrogen. In a dry macro Kjeldahl flask, 0.5 g of air dried 0.5 mm sieved soil; 10 ml of conc. H_2SO_4 and selenium tablet were added. The mixture was cooked for 5 hours on the digestion stand until it was completely digested. When the previously dark-colored medium turned clear and colourless, the chemical disintegration of the sample was complete.The mixture was taken off the digestion stand and set aside to cool. The digest was prepared to a volume of 50 mL and then transferred to sample cups. A 5 g sample of Boric acid was distributed into the distillation apparatus's condenser's end (Erlenmeyer flasks).

By opening the funnel stopcock, 5 ml of the digest solution was distilled with 5 ml of Sodium Hydroxide in the distillation flask. The condenser was kept cool by passing cold water through it, and the heat was controlled to avoid frothing and suck-back. The ammonium salt was converted to ammonia, resulting in a green solution (distillate). 0.01M HC1 was used to titrate the 50 ml of distillate collected. The ammonia changed color from green to pink as it came into contact with the acid. A blank sample was taken using the same process as before, but without the soil sample. The following formula was used to compute the percent total nitrogen:

$$\% \text{ Nitrogen} = \frac{(T - B) \times 14.01 \times 0.01N \times 100}{\text{Weight of soil sample}}$$

Where:

T = Titre value and B = Blank

The Bray P-1 method was used to determine the amount of phosphorus available (Bray and Kurtz, 1945). 12 g of Ammonium Molybdate was dissolved in 250 ml of distilled water, and 0.2908 g of Antimony Potassium titrates was dissolved in 100 ml of distilled water to make Reagent 'A.' The two dissolved reagents were added to 1000 ml of 2.5 M H_2SO_4, mixed thoroughly and made up to 2 litres. Reagent ‘B’ was prepared by dissolving 1.056 g of ascorbic acid in 200 ml from Reagent ‘A’. Exactly 2 g of air dried 0.5 mm sieved soil was weighed into each of the cups, 20 ml of Bray P-1 solution (extractant) was added and the suspension shaken for 10 minutes. The soil was filtered through 9 cm diameter Whatman No. 42 filter paper. To develop blue colouration, 5 ml of the clear supernatant was pipetted into a 50 ml volumetric flask and 30 ml Reagent 'B' added. The available P was read with NV 201 Camspec spectrophotometer set at wavelength of 882 nm.

Exchangeable (bases) cations were extracted with IN Ammonium Acetate (NH_4OAC) with pH 7 which was prepared by adding 58 ml of acetic acid and 70 ml of concentrated NH_4OH to 600 ml distilled water in a 2 litre beaker. The solution was allowed to cool and adjusted to pH 7 with pH meter by adding acetic acid or NH_4OH. The solution was made up to mark in a litre flask with distilled water. A dispersion cup was filled with exactly 2 g of air dried 2 mm sieved soil and 20 ml of ammonium acetate (NH_4OAC). On a mechanical shaker, the mixture was shaken for 10 minutes and later filtered using Whatman No 42 filter paper. Calcium (Ca) and Magnesium (Mg) were determined by with atomic absorption spectrophotometer while Potassium (K) and Sodium (Na) were determined with flame photometer (Black *et al.*, 1965). The percentage base saturation was calculated following Adeoye (1986) method as presented below:

$$\% \text{ Base Saturation} = \frac{TEB}{CEC} \times 100$$

Where:

TEB = Total Exchangeable Bases = cmol/kg of (Ca + Mg + Na + K)

CEC = Cation Exchange Capacity

Exchangeable acidity (H^+ and Al^{3+}) were determined by leaching the soils with IN KCl and titrating aliquots with 0.01 NaOH (McLean, 1965). 20 ml of 1N KCI was added to 2 g of the 2 mm sieved soil weighed into a dispersion cup. The solution was then stirred for 10 minutes using mechanical shaker and then filtered using Whatman No 42 (9 cm diameter) filter paper. Using phenolphthalein as indicator, 10 ml of the filtrate was titrated with 0.01N NaOH until the solution turned pinkish. The volume of base used was equal to the total amount of acidity in the aliquot shaken.

The effective cation exchange capacity (ECEC) was taken as the addition of exchangeable bases (Ca, Mg, K and Na) and exchangeable acidity (Al^{3+} and H^+).

$$ECEC = TEB + EA$$

Where:

TEB = Total exchangeable bases

EA = Exchangeable acidity

ECEC is expressed in cmol/kg.

Inorganic fertilisers used in this study were analysed to determine the actual percent N, P and K content.

3.4.2 Experimental design: Four cassava varieties: TMEB419 (V1), IBA010040 (V2), IBA011412 (V3) and IBA070593 (V4) were planted and four fertiliser formulations [NPK 15:15:15 (F1), TSP+KCl (F2), urea+KCl (F3) and urea+TSP (F4)] were applied, so as to supply 45 (R1) and 75 (R2) kg N, P_2O_5 and K_2O ha^{-1}. Treatments without fertiliser application (F0) serve as control. Nine treatment combinations (8 formulations + 1 control) planted with four cassava varieties were laid as a 4 × 9 (=36) factorial in a RCBD with three replicates. Fertiliser treatments used are NPK 15:15:15 (300 and 500 kg ha^{-1}) with same doses of N, P and K was applied as urea and triple superphosphate (98 and 163 kg ha^{-1}), and muriate of potash (78 and 130 kg ha^{-1}) as shown in Table 3.1. The nine fertiliser treatment combinations (fertiliser types and rates) were as follows;

1) Control
2) NPK 15:15:15 – R1
3) NPK 15:15:15 – R2
4) Urea+TSP (-K) – R1
5) Urea+TSP (-K) – R2
6) Urea+KCl (-P) – R1
7) Urea+KCl (-P) – R2
8) TSP+KCl (-N) – R1
9) TSP+KCl (-N) – R2

Basal application of TSP fertiliser was done at planting due to slow mineralization; split application of NPK 15:15:15, urea and KCl were equally done at 6 and 12 WAP using side placement method. Each plot consisted of 5 rows 5.6 m long with 1.0 m inter and 0.8 m intra row spacing. Plot size was 28 m^2 (5.6 m × 5 m) comprising of 35 plants (7 plants per ridge), while each net plot size was 12 m^2 (4 m × 3 m) comprising of 15

Table 3.1 Fertiliser types and their rates of application at Ibadan, Ikenne and Tsonga during 2014/2015 and 2015/2016 planting seasons (Plant population: 12,500 plants ha^{-1})

s/n	Fertiliser formulation	Fertiliser treatment	Fertiliser rate (kg ha^{-1})	kgN ha^{-1}	kgP_2O_5 ha^{-1}	kgK_2O ha^{-1}	Fertiliser rates (kg plot^{-1})	2 split applications (kg plot^{-1})	
1	NPK 15-15-15		300	45	45	45	0.84	0.42	0.42
			500	75	75	75	1.40	0.70	0.70
2	Urea+TSP	Urea (46% N)	97.8	45	-	-	0.27	0.14	0.14
			163	75	-	-	0.46	0.23	0.23
		TSP (46% P_2O_5)	97.8	-	45	-	0.27	-	-
			163	-	75	-	0.46	-	-
3	Urea+KCl	Urea (46% N)	97.8	45	-	-	0.27	0.14	0.14
			163	75	-	-	0.46	0.23	0.23
		KCl (60% K_2O)	75	-	-	45	0.21	0.11	0.11
			125	-	-	75	0.35	0.18	0.18
4	TSP+KCl	TSP (46% P_2O_5)	97.8	-	45	-	0.27	-	-
			163	-	75	-	0.46	-	-
		KCl (60% K_2O)	75	-	-	45	0.21	0.11	0.11
			125	-	-	75	0.35	0.18	0.18

plants (5 plants per ridge) where growth and yield data were collected. Three leaf samples were collected on three middle plants at 3 and 6 MAP and measured using leaf area metre (ADC Bioscience). Leaf area index (LAI) was calculated thus:

$$LAI = LA/a$$

Where:

LA = Product of leaf area and the number of leaves per plant

a = Land area (m^2) covered per plant

3.5 Growth and yield of cassava as affected by stem portions and lengths of stem cuttings

3.5.1 Experimental design: Four cassava varieties: TMEB419 (V1), IBA010040 (V2), IBA011412 (V3) and IBA070593 (V4), three stem cutting portions: Basal (S1), Middle (S2) and Top (S3) and two stem cutting lengths (cm): 15 (L1) and 30 (L2) were laid out as a 4 × 3 × 2 (=24) factorial in a RCBD replicated three times. Each plot size was 5.6 m × 4 m (22.4 m^2) comprising of 7 plants per ridge (28 plants), while each net plot size was 8 m^2 (4 m × 2 m) comprising of 10 plants (5 plants per ridge) where growth and yield data were collected. The six stem cutting portions and lengths are;

1) Basal stem – 30 cm
2) Basal stem – 15 cm
3) Mid stem – 30 cm
4) Mid stem – 15 cm
5) Top stem – 30 cm
6) Top stem – 15 cm

Plate 3.1 shows the portions and length of stem cuttings of TMEB419 used in this study.

3.6 Data collected

Level of resistance and susceptibility to major pests and diseases of cassava varieties were evaluated. At 1, 3 and 6 MAP, evaluation of ACMD was done as described by Terry (1975) as shown on plate 3.2, cassava bacteria blight at 3 and 6 MAP, cassava anthracnose disease at 6 and 9 MAP and cassava Green mite disease was evaluated twice during the dry season. Plant sprout and vigour was evaluated at 1 MAP. Growth data were collected at 3, 6, 9, and 12 MAP while yield and yield components data were

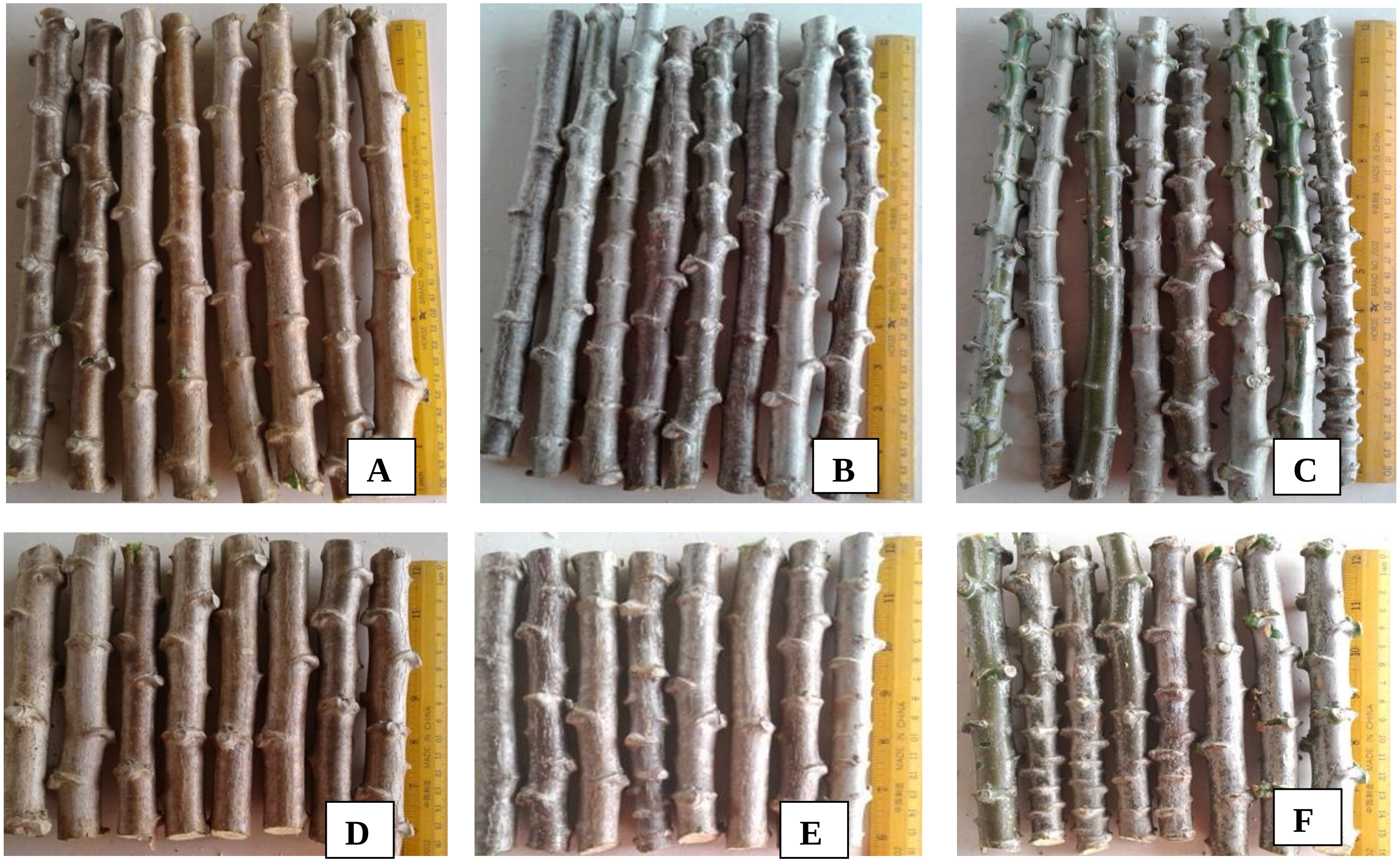

Plate 3.1: Stem properties of TMEB419 used in this study.
A: Basal stem, 30 cm B: Mid stem, 30 cm C: Top stem, 30 cm
D: Basal stem, 15 cm E: Mid stem, 15cm F: Top stem: 15 cm

 1 = No visible symptoms (highly resistant).

 2 = mild chlorotic patterns (moderately resistant).

 3 = mosaic patterns on all leaves and leaf distortion (tolerant)

 4 = mosaic pattern on all leaves, leaf distortion and general reduction in leaf size (susceptible).

 5 = misshapen twisted leaves and stunting of the whole plant (highly susceptible)

Plate 3.2 Description and evaluation of CMD severity on cassava leaf

collected at harvest. Yield (t ha^{-1}) of leaf and stem were expressed on fresh weight basis while fresh and dry weight of root yield was recorded. Using a general scoring scale of 1–5 for symptoms of cassava disease plant, CBB, CAD, and CGM were scored (IITA, 1990). Cassava varieties were described using the descriptor list for cassava published in 1983 by International Board for Genetic Resources (IBPGR).

Data on various plant parts were collected:

Leaf

- Plant vigour
- (CMD, CBB, & CGM)
- Leaf area index

Stem

- Total plant height
- Plant stem girth
- Disease evaluation (CAD)
- Height of plant canopy (Total plant height – Plant height without leaf)
- Number of plant stands

Root

- Visual scoring of root size and shape, outer and inner skin colour,root ease of peel, Total Carotene (TC) in root.
- Number and weight per plot of roots
- Number of rotten roots.
- Shoot weight (∑leaf, stem and stump weight)
- Average stem length
- Harvest index was estimated thus: (fresh root yield/total biomass)

- % root dry matter content was calculated thus:

  DM (percent) = (DW/FW) X 100.

- Root yield in tonnes/hectare was calculated thus;

$$\frac{\text{Weight of harvested root (kg)}}{\text{Plot area harvested}} \times \frac{10{,}000}{1{,}000}$$

Descriptions of some measured variables are shown in Table 3.2.

Table 3.2 Description of measured variable stating time of measurement, instrument used and the unit of measurement

S/N	Variable	Description	Time Measured (MAP)	Instrument used	Unit
1	Plant height	Vertical height of main stem from soil level to top of canopy	3, 6, 9 and 12	Calibrated metre rule	Centimetre (cm)
2	Number of leaves	Counting the number of widely opened leaves on each plant	3 and 6	-	-
3	Leaf area	Length and breadth of the leaf lobes	3 and 6	ADC Area metre 300	Square metre (m^2)
4	Stem girth	The main stem was measured around 50 cm from soil level	3, 6, 9 and 12	Rubber tape rule	Centimetre (cm)
5	Plant canopy height	Height of stems covered with leaves	3, 6, 9 and 12	Calibrated metre rule	Centimetre (cm)
6	Stay green	% reduction of the leaf number as a result of stress (drought)	6 – 9	Scoring	1. full canopy 3. 30% leaf reduction 5. 50% leaf reduction 7. 80% leaf reduction 9. total removal of leaves from the stems.
7	Disease evaluation: (CMD, CBB, CAD and CGM)	% infection and malformation on the leaf and/or stem	1, 3, 6, and 9	Scoring	1. 0 – 20% 2. 20 – 40% 3. 40 – 60% 4. 60 – 80% 5. 80 – 100% infection

3.7 Statistical analyses

For factorial in a RCBD, data were subjected to Analysis of Variance (ANOVA at $\alpha_{0.05}$) using the GLM (Generalized Linear Model) procedure of Statistical Analysis System (SAS) version 9.4. Duncan Multiple Range Test (DMRT) was used to separate means at 5% propability level. Principal Component Analysis (PCA) was done to obtain Genotype+Genotype-by-Environment (GGE) biplot. Phenotypic correlation co-efficient was also generated for some yield and yield related variables of the combined data.

Linear correlation coefficient is calculated thus:

$$r = \frac{\sum (X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum (X_i - \bar{X})^2 \sum (Y_i - \bar{Y})^2}}$$

Where

r = correlation coefficient

Xi = values of the x-variable in a sample

$\bar{X}$ = mean of the values of the x-variable

Yi = values of the y-variable in a sample

$\bar{Y}$ = mean of the values of the y-variable

The models for a GGE biplot: The model for a GGE biplot (Yan, 2002) based on Singular Value Decomposition (SVD) of first two principal components is:

$$Y_{ij} - \mu - \beta_j = \lambda_1 \xi_{i1} \eta_{j1} + \lambda_2 \xi_{i2} \eta_{j2} + \varepsilon_{ij}$$

Where

Yij is the measured mean (DBH) of genotype i in environment j,

μ is the grand mean,

β_j is the main effect of environment j,

$\mu + \beta_j$ being the mean yield across all varieties in environment j,

λ_1 and λ_2 are the singular values (SV) for the first and second principal component (PC1 and PC2), respectively,

ξ_{i1} and ξ_{i2} are eigenvectors of genotype i for PC1 and PC2, respectively,

η_{1j} and η_{2j} are eigenvectors of environment j for PCl and PC2, respectively and ε_{ij} is the residual associated with genotype i in environment j.

CHAPTER FOUR

RESULTS

4.1 Oyo State cassava growers' agricultural practices

The distribution of cassava farmers in Ibadan, Oyo State Nigeria based on the agronomic practices and farming systems they usually undertake is shown in Figure 4.1. Planting of middle stem portion and 20 cm stem cutting length among farmers accounted for 46.7% and 54.4% respectively. It was noted that 60% of the farmers planted on ridges and 90% used slanting orientation. Maize, melon, yam, vegetables with other crops were intercropped with cassava by 88.9% of the farmers. The use of inorganic fertiliser among farmers was 23.2% and 25.5% of the sampled farmers used only manual (hoe) weeding method while others used both chemical and hoe weeding. It was observed that 86.7% of the farmers grew cassava solely for the roots while other farmers included sale of stem cuttings.

4.2 Soil Characteristics of the Field Experimental Sites

After the cassava crop was harvested, pH of soil in H_2O and KCl of the trial sites were moderately acidic and slightly reduced (Table 4.1). Total Nitrogen in soils after harvest increased by 40%, 80% and 25% in Ibadan, Ikenne and Tsonga, respectively. Potassium in soils after harvest reduced by 45%, 39% and 50% in Ibadan, Ikenne and Tsonga, respectively. Available P also increased by 46% in Ikenne, but reduced by 29% in Ibadan and 12% in Tsonga. Ca, Mg, K, and Na were reduced after harvest of cassava roots, while Zn and Fe concentration increased after harvest at the three locations. Concentration of Cu in soils in Tsonga reduced by 54% after harvest and there was 31% increase in Ibadan and 63% increase in Ikenne. Also, concentration of Na in the soil after harvesting reduced at Ibadan, Ikenne and Tsonga by 27%, 11% and 13%, respectively. Soils at experimental sites were sandy loam.

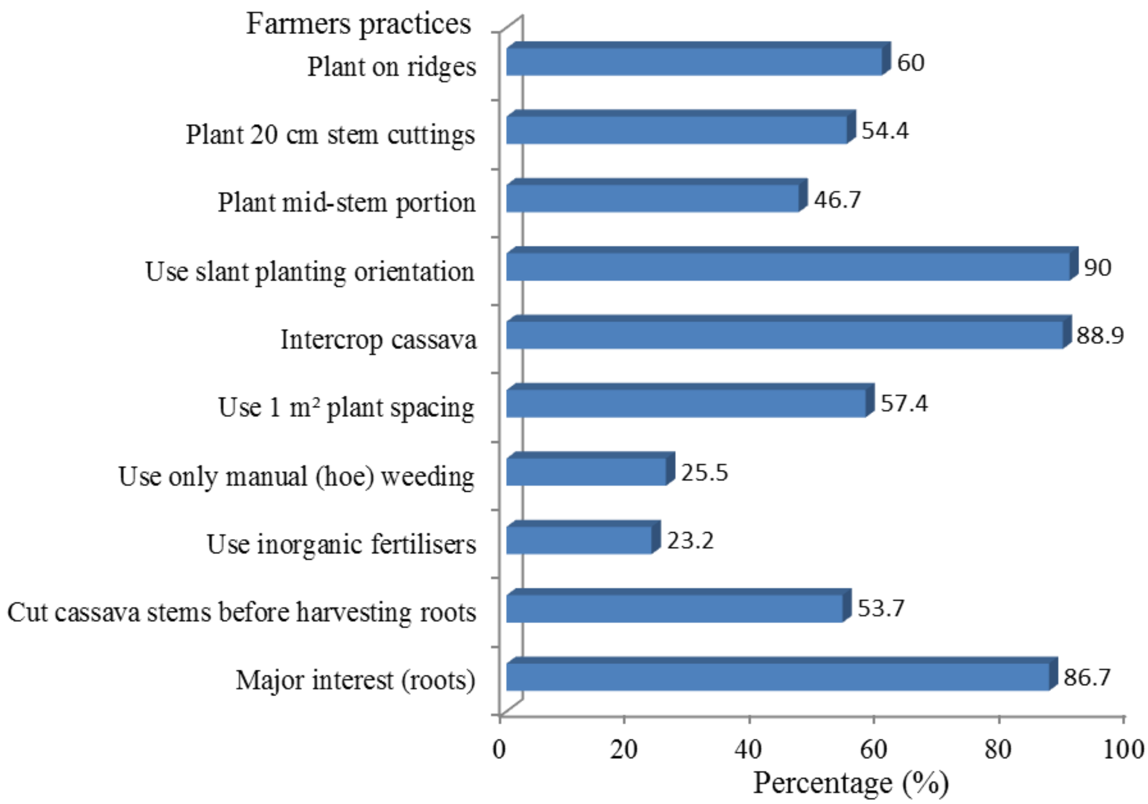

Figure 4.1 Percentage of some agronomic practices and farming systems among 90 cassava farmers in Iwajowa, OgoOluwa and Ido Local Government Areas of Oyo State, Nigeria.

Table 4.1 Soil properties at planting and after harvest of cassava varieties at Ibadan, Ikenne and Tsonga during 2014/2015 and 2015/2016 planting seasons

	Ibadan			Ikenne			Tsonga		
Soil properties	at planting	after harvest	% reduction	at planting	after harvest	% reduction	at planting	after harvest	% reduction
pH (H_2O)	6.7	6.1	9.0	5.5	5.2	5.5	6.0	5.9	1.7
pH (KCl)	5.2	4.9	5.8	4.3	4.0	7.0	4.1	4.2	-2.4
Organic Carbon (g/kg)	1.07	1.12	-4.7	1.05	1.30	-23.8	0.59	0.56	5.1
Total Nitrogen (g/kg)	0.10	0.14	-40.0	0.10	0.18	-80.0	0.04	0.05	-25.0
Available P (mg/kg)	11.02	7.78	29.4	4.97	7.27	-46.3	17.07	15.02	12.0
Exchangeable bases (cmol/kg)									
Ca	3.81	2.38	37.5	2.16	1.64	24.1	2.22	1.94	12.7
Mg	0.79	0.54	31.6	1.05	0.85	19.1	0.48	0.45	6.3
K	0.20	0.11	45.0	0.18	0.11	38.9	0.16	0.08	50.0
Na	0.11	0.08	27.3	0.09	0.08	11.1	0.08	0.07	12.5
Exc. Acidity	0.05	0.00	100.0	0.13	0.26	-100.0	0.00	0.00	0.0
ECEC	4.96	3.11	37.3	3.59	2.94	18.1	2.93	2.55	13.0
Micronutrients (mg/kg)									
Zn	48.84	70.24	-43.8	10.23	21.77	-112.8	9.84	14.41	-46.4
Cu	2.07	2.71	-30.9	1.69	2.74	-62.1	3.57	1.65	53.8
Mn	92.08	94.25	-2.4	23.87	18.96	20.6	49.54	78.40	-58.3
Fe	95.78	98.23	-2.6	68.55	98.47	-43.7	59.35	83.41	-40.5
Particle size distribution (%)									
Sand	72.00	73.80	-2.5	76.50	72.90	4.7	81.00	81.90	-1.1
Silt	11.50	11.00	4.3	7.00	6.50	7.1	9.00	8.00	11.1
Clay	16.50	15.50	6.1	16.50	21.00	-27.3	10.00	10.50	-5.0
Textural classification	Sandy-loam			Sandy-loam			Sandy-loam		

4.3 Effects of fertiliser application on four cassava varieties at three locations during 2014/2015 and 2015/2016 planting seasons

4.3.1 Variations in shoots and root characteristics at three locations during two planting seasons

Mean square from the combined ANOVA for shoots and root characteristics at three locations during two planting seasons is shown in Table 4.2. Highly significant ($P \leq 0.001$) mean squares (MS) for some of the sources of variation are seen. The MS for location, environment, rep (env), genotype and genotype by environment interactions were highly significant for all the traits. Year does not affect fresh root, dry root and plantable stem yield although it significantly affects sprout, vigour, CMD severity and number of roots ha^{-1}. MS for fertiliser was significant for number of roots ha^{-1} and highly significant for fresh root, dry root and plantable stem yield. Fertiliser rate significantly ($P \leq 0.01$) affects plant sprout, plantable stem yield and harvest index. However, fertiliser and genotype × fertiliser interactions were not significant for sprout, vigour and CMD severity. MS for the interaction effects of fertiliser × rate and genotype × fertiliser × rate were not significant for sprout, number of roots ha^{-1}, HI, FRY, DRY and PSY (Table 4.2).

4.3.2 Pooled mean FRY (t ha^{-1}), RDMC (%) and DRY (t ha^{-1}) of each cassava genotype as influenced by fertiliser application

Cassava fresh root yield was significantly affected by fertiliser application. FRY obtained from applying NPK 15:15:15 at 75 kg ha^{-1} (17.43 t ha^{-1}) was significantly higher than 13.77 t ha^{-1} got from urea+TSP at 45 kg ha^{-1} (Table 4.3). At harvest, omission of Nitrogen (TSP+KCl) at 75 kg ha^{-1} to IBA010040 had 20.6% increases over the control in fresh root yield and the same application rate to IBA011412 had 17.2% increases. Applying 75 kg NPK 15:15:15 ha^{-1} to IBA011412 produced 28.0% and TMEB419 produced 12.7% increase in FRY compared with the control. Omission of Nitrogen, Phosphorus and Potassium at 45 and 75 kg ha^{-1} had 4.0% and 4.1%, 3.5% and 2.3%, 15.3% and 17.2% reductions in FRY respectively.

Among the fertiliser treatments, omission of phosphorus (KCl+urea) at 75 kg ha^{-1} to TMEB 419 had the highest RDMC (30.9%). This had 4.9% increases compared with the unfertilized plots (control). However, omission of N, P and K fertilisers at 45 kg ha^{-1} to TMEB419 had 12.1%, 11.4% and 16.3% respective decline in RDMC. The highest

Table 4.2 In 2014/2015 and 2015/2016 planting seasons, mean squares from combined analysis of variance (ANOVA) of some shoot and root characteristics of four cassava varieties at three Nigerian locations

Source of variation	DF	Sprout	Vigour	CMD severity	No of roots ha^{-1}	Fresh root yield ($t\ ha^{-1}$)	Dry root yield ($t\ ha^{-1}$)	PSY ($t\ ha^{-1}$)	Harvest Index
Location	2	1.37***	10.98***	35.16***	25038.57***	5397.70***	586.34***	4937.90***	0.10***
Year	1	0.28***	122.41***	15.37***	3323.75***	51.65ns	0.07ns	45.64ns	0.01ns
Rep(env)	12	0.04***	5.35***	0.51***	1535.85***	111.79***	13.62***	136.47***	0.02***
Genotype	3	1.07***	46.75***	7.91***	8636.55***	2239.06***	72.68***	342.08***	0.45***
Rep*gen(env)	36	0.01*	1.59***	0.26***	641.45***	63.29***	4.51*	32.16***	0.02***
Env*gen	15	0.17***	15.46***	6.40***	8842.15***	587.49***	27.95***	223.32***	0.11***
Fertiliser	4	0.01ns	0.65ns	0.05ns	670.08*	184.62***	14.74***	204.84***	0.01ns
Gen*fertiliser	12	0.01ns	0.83ns	0.05ns	96.78ns	14.92ns	1.99ns	19.09ns	0.01***
Rep*gen*fert(env)	340	0.01ns	0.73ns	0.12ns	206.67ns	35.54**	4.01***	18.34***	0.01***
Rate	1	0.10**	0.54ns	0.42*	298.80ns	7.79ns	2.04ns	80.93**	0.03**
Gen*rate	3	0.00ns	1.37ns	0.03ns	454.25ns	40.63ns	6.55ns	42.65**	0.00ns
Fertiliser*rate	4	0.01ns	2.88**	0.27*	267.15ns	7.41ns	1.15ns	19.87ns	0.00ns
Gen*fertiliser*rate	12	0.01ns	1.41*	0.14ns	125.36ns	18.24ns	2.17ns	19.79ns	0.00ns
Standard Error		0.00	0.71	0.11	223.11	26.12	4.51	11.94	0.00
R^2		0.81	0.83	0.89	0.82	0.85	0.84	0.84	0.85
CV (%)		11.06	15.43	23.51	32.69	32.62	37.64	27.71	14.56

R^2: Coefficient of determination

Table 4.3 In 2014/2015 and 2015/2016 planting seasons, mean FRY (t ha^{-1}) of each cassava variety as influenced by fertiliser application

Fertiliser type	Fertiliser rate (kg ha^{-1})	TMS-IBA010040	TMS-IBA011412	TMS-IBA070593	TMEB419	Mean	SE(±)	CV (%)
Control	0	15.16	16.17	11.47	12.76	13.89^{c}	0.93	13.44
NPK 15:15:15	45	18.13	20.89	11.92	12.82	15.94^{bc}	1.86	23.30
NPK 15:15:15	75	17.94	22.47	14.69	14.61	17.43^{a}	1.60	18.40
TSP+ Urea (-K)	45	16.35	18.06	9.52	11.14	13.77^{c}	1.77	25.68
TSP +Urea (-K)	75	16.02	17.30	10.69	11.25	13.81^{c}	1.44	20.91
KCl +Urea (-P)	45	19.08	19.85	12.32	11.50	15.69^{bc}	1.90	24.22
KCl+Urea (-P)	75	17.36	19.52	14.80	13.45	16.28^{b}	1.17	14.37
KCl+TSP (-N)	45	18.46	19.13	11.84	12.99	15.60^{bc}	1.61	20.66
KCl+TSP (-N)	75	19.09	19.52	13.31	12.06	15.99^{bc}	1.67	20.89
Minimum		15.16	16.17	9.52	11.14			
Maximum		19.09	22.47	14.80	14.61			
Mean		17.51^{b}	19.21^{a}	12.28^{c}	12.51^{c}			
SE(±)		0.42	0.56	0.59	0.34			
CV (%)		7.78	9.52	15.68	8.84			
Fertiliser type ***; Fertiliser rate *; Cassava genotype ***								

***: significant at P≤0.001, ns: not significant. Means with the same alphabet are not significantly different.

RDMC was found on white cassava roots, TMEB419 (29.6%) and IBA010040 (26.0%) while IBA011412 had the least (21.1%) (Table 4.4).

Omission of Nitrogen (TSP+KCl) at 75 kg ha^{-1} to genotype IBA010040 produced the highest DRY (5.34 t ha^{-1}) which had 20.0% increases in yield when compared with the unfertilized (control) plot of the same genotype. IBA010040 produced the highest DRY (4.69 t ha^{-1}) then IBA011412 (4.20 t ha^{-1}) and IBA070593 had the least (3.04 t ha^{-1}). Also, omission of Nitrogen (TSP+KCl) at 75 kg ha^{-1} had the highest DRY (4.22 t ha^{-1}) while omission of Potassium (urea+TSP) at the same rate had the least (3.34 t ha^{-1}) which produced 20.9% reduction in DRY when compared with the control (Table 4.5).

Treatment mean across locations showed that omission of Nitrogen (KCl+TSP) at 45 kg ha^{-1} to IBA010040 produced the highest DRY (5.43 t ha^{-1}) while the least was omission of Potassium at 75 kg ha^{-1} to IBA070593 (2.21 t ha^{-1}). Across treatments, DRY obtained at Ikenne was highest (5.55 t ha^{-1}) which was 30.6% and 53.9% higher than Ibadan and Tsonga respectively (Table 4.6).

4.3.3 Periodic mean plant height and stem girth as influenced by fertiliser application and cassava varieties evaluated at three locations during 2014/2015 and 2015/2016 planting seasons

At 6 MAP, omission of Phosphorus (urea+KCl) at 75 kg ha^{-1} had 8.8%, 16.1% and 6.9% increase in total plant height while at 12 MAP; there was 10.0%, 17.0% and 0.6% increase in total plant height at Ibadan, Ikenne and Tsonga, respectively when compared with the unfertilized control. At 9 MAP at Ibadan, appling 45 kg NPK 15:15:15 ha^{-1} had 9.0% increases over the unfertilized control while at Ikenne, omission of Nitrogen (TSP+KCl) at 75 kg ha^{-1} had 12.3% increases. Mean plant height at 12 MAP ranged from 223.66 to 248.45 cm at Ibadan, 213.15 to 256.91 cm at Ikenne and 155.18 to 172.53 cm at Tsonga (Table 4.7). Also at 12 MAP, plants in unfertilized plots (control) had least plant height at Ibadan and Ikenne.

Between 6 and 12 MAP, increase in total plant height showed that genotype IBA010040 > TMEB419 > IBA070593 > IBA011412 across locations. At 3 and 6 MAP, Ibadan had the highest mean plant height (98.18 and 175.01 cm) which was

Table 4.4 Mean Influence of fertiliser application during 2014/2015 and 2015/2016 planting seasons on RDMC (%) of each variety of cassava

Fertiliser type	Fertiliser Rate (kg ha^{-1})	TMS-IBA010040	TMS-IBA011412	TMS-IBA070593	TMEB419	Trt Mean	SE(±)	CV (%)
Control	0	26.35	20.21	23.09	29.36	24.75^{ab}	1.98	6.24
NPK 15:15:15	45	26.07	22.85	24.35	29.15	25.61^{a}	1.35	9.47
NPK 15:15:15	75	26.94	21.15	24.24	29.36	25.42^{a}	1.77	7.19
TSP+Urea (-K)	45	25.44	21.94	23.91	27.40	24.67^{ab}	1.16	10.66
TSP+Urea (-K)	75	24.70	20.06	23.31	29.30	24.34^{ab}	1.92	6.35
KCl+Urea (-P)	45	26.24	21.65	24.35	29.01	25.31^{a}	1.55	8.16
KCl+Urea (-P)	75	25.62	20.44	22.60	30.86	24.88^{ab}	2.26	5.51
KCl+TSP (-N)	45	26.76	20.53	24.75	28.78	25.21^{a}	1.76	7.15
KCl+TSP (-N)	75	26.63	21.16	24.39	30.15	25.58^{a}	1.89	6.76
Minimum		24.70	20.06	22.60	27.4			
Maximum		26.94	22.85	24.75	32.73			
Var Mean		26.02^{b}	21.05^{d}	23.93^{c}	29.61^{a}			
SE(±)		0.23	0.25	0.21	0.40			
CV (%)		2.89	3.99	2.90	4.52			

Fertiliser type *; Fertiliser rate *; Cassava genotype ***

Table 4.5 Influence of fertiliser application on DRY (t ha^{-1}) of each cassava variety during 2014/2015 and 2015/2016 planting seasons

Fertiliser type	Fertiliser rate (kg ha^{-1})	TMS-IBA010040	TMS-IBA011412	TMS-IBA070593	TMEB419	Mean	SE(±)	CV (%)
Control	0	4.27	3.51	2.70	3.87	3.59^{b}	0.33	5.37
NPK 15:15:15	45	4.93	4.80	2.96	3.73	4.11^{a}	0.47	4.40
NPK 15:15:15	75	3.48	4.79	3.36	4.24	3.97^{ab}	0.34	5.90
TSP+Urea (-K)	45	4.47	4.00	2.46	3.12	3.51^{b}	0.45	3.91
TSP+Urea (-K)	75	4.12	3.52	2.24	3.47	3.34^{b}	0.39	4.23
KCl+Urea (-P)	45	5.31	4.39	3.28	3.48	4.12^{a}	0.47	4.42
KCl+Urea (-P)	75	4.43	4.15	3.44	4.21	4.06^{a}	0.21	9.46
KCl+TSP (-N)	45	5.06	4.02	3.03	3.83	3.99^{ab}	0.42	4.77
KCl+TSP (-N)	75	5.34	4.35	3.46	3.73	4.22^{a}	0.42	5.06
Minimum		3.48	3.51	2.24	3.12			
Maximum		5.34	4.80	3.79	4.24			
Mean		4.69^{a}	4.20^{a}	3.04^{b}	3.82^{ab}			
SE(±)		0.18	0.13	0.14	0.11			
CV (%)		12.61	10.58	15.64	9.50			
Fertiliser type ***; Fertiliser rate *; Cassava genotype ***								

Table 4.6 Mean effects of fertiliser application and cassava varieties on DRY ($t\ ha^{-1}$) at Ibadan, Ikenne and Tsonga in 2014/2015 and 2015/2016 planting seasons

S/N	Cassava variety	Fertiliser Formulations	Fert rate	Ibadan	Ikenne	Tsonga	Trt mean
1	I010040	TSP+KCl (-N)	45	4.47	*8.66*	3.17	5.43
2	I010040	TSP+KCl (-N)	75	5.35	7.90	2.78	5.34
3	I010040	Urea+KCl (-P)	45	4.95	8.12	2.87	5.31
4	I010040	NPK 15:15:15	75	5.38	7.77	2.27	5.14
5	I010040	NPK 15:15:15	45	5.21	5.11	4.48	4.93
6	I011412	NPK 15:15:15	75	3.77	7.01	3.86	4.88
7	I011412	NPK 15:15:15	45	4.90	6.77	2.73	4.80
8	I011412	TSP+KCl (-N)	75	3.40	6.57	4.16	4.71
9	I010040	Urea+TSP (-K)	45	5.59	5.21	2.61	4.47
10	I010040	Urea+KCl (-P)	75	*5.69*	4.66	2.95	4.43
11	I011412	Urea+KCl (-P)	45	3.75	6.83	2.60	4.39
12	I010040	Control	0	3.85	5.75	3.23	4.27
13	TMEB419	NPK 15:15:15	75	3.17	4.50	*5.04*	4.24
14	TMEB419	Urea+KCl (-P)	75	2.76	5.69	4.18	4.21
15	I010040	Urea+TSP (-K)	75	4.73	5.19	2.45	4.12
16	I011412	TSP+KCl (-N)	45	3.45	6.25	2.34	4.02
17	I011412	Urea+TSP (-K)	45	3.84	5.48	2.67	4.00
18	I011412	Urea+KCl (-P)	75	3.97	6.60	1.25	3.94
19	TMEB419	Control	0	3.25	4.64	3.72	3.87
20	TMEB419	TSP+KCl (-N)	45	2.58	5.24	3.66	3.83
21	TMEB419	NPK 15:15:15	45	2.75	3.89	4.56	3.73
22	TMEB419	TSP+KCl (-N)	75	2.37	4.05	4.75	3.73
23	I011412	Urea+TSP (-K)	75	3.75	4.80	2.01	3.52
24	I011412	Control	0	3.17	4.93	2.44	3.51
25	TMEB419	Urea+KCl (-P)	45	1.89	4.54	4.01	3.48
26	TMEB419	Urea+TSP (-K)	75	3.24	3.86	3.30	3.47
27	I070593	TSP+KCl (-N)	75	4.10	6.06	0.22	3.46
28	I070593	Urea+KCl (-P)	75	3.83	5.84	0.39	3.36
29	I070593	NPK 15:15:15	75	4.68	5.08	0.14	3.30
30	I070593	Urea+KCl (-P)	45	3.78	5.83	0.25	3.29
31	TMEB419	Urea+TSP (-K)	45	2.30	3.18	3.88	3.12
32	I070593	TSP+KCl (-N)	45	3.92	5.01	0.16	3.03
33	I070593	NPK 15:15:15	45	4.30	4.15	0.44	2.96
34	I070593	Control	0	4.87	2.83	0.54	2.75
35	I070593	Urea+TSP (-K)	45	3.76	3.30	0.37	2.48
36	I070593	Urea+TSP (-K)	75	2.74	3.75	0.14	2.21
			Minimum	1.89	2.83	0.14	2.21
			Maximum	5.69	8.66	5.04	5.43
			Loc mean	3.85	5.55	2.56	3.99
			SE(±)	0.15	0.21	0.23	0.12
			CV (%)	25.61	24.76	59.94	20.19

Table 4.7 Periodic mean plant height as influenced by fertiliser application evaluated across three locations in 2014/2015 and 2015/2016 planting seasons

Location		IBN	IKN	TSG	IBN	IKN	TSG	IBN	IKN	TSG	IBN	IKN	TSG
Fertiliser types	Fertiliser rate (kg ha^{-1})		3 MAP			6 MAP			9 MAP			12 MAP	
Control	0	90.95	76.98	62.77	168.69	138.72	96.41	188.92	191.05	126.56	223.66	213.15	161.06
NPK 15:15:15	45	103.98	95.64	75.10	181.04	162.48	108.30	207.50	211.38	134.52	243.39	233.33	169.02
NPK 15:15:15	75	100.43	94.45	76.84	182.46	156.84	114.95	205.95	200.96	138.03	243.53	230.08	172.53
Urea+TSP (-K)	45	98.85	84.84	69.13	166.20	147.76	97.55	195.63	194.68	122.84	228.18	213.59	157.34
Urea+TSP (-K)	75	100.92	87.27	69.96	177.97	149.73	101.81	201.02	198.44	125.99	235.81	214.52	160.49
Urea+KCl (-P)	45	98.33	93.03	72.60	173.96	161.76	103.76	193.15	217.28	128.82	231.50	253.23	163.32
Urea+KCl (-P)	75	97.52	97.91	70.91	184.99	165.31	103.50	207.39	212.47	127.59	248.45	256.91	162.09
TSP+KCl (-N)	45	93.80	87.98	60.03	168.59	155.97	94.12	191.62	212.01	120.68	230.08	243.33	155.18
TSP+KCl (-N)	75	96.72	92.26	65.52	166.50	162.03	102.20	191.00	217.73	121.62	229.17	254.07	156.12
Minimum		90.95	76.98	60.03	166.20	138.72	94.12	188.92	191.05	120.68	223.66	213.15	155.18
Maximum		103.98	97.91	76.84	184.99	165.31	114.95	207.50	217.73	138.03	248.45	256.91	172.53
Mean		98.18	90.98	69.69	175.01	156.70	103.07	198.44	208.92	128.03	235.83	238.36	162.53
SE(±)		1.07	1.86	1.55	2.05	2.45	1.76	2.12	3.26	1.64	2.54	5.48	1.64
CV (%)		3.62	6.78	7.38	3.89	5.19	5.68	3.55	5.17	4.25	3.58	7.63	3.35

7.4% and 10.4% higher than Ikenne location and 29.0% and 41.1% higher than the mean plant height at Tsonga. At 9 and 12 MAP, Ikenne had the highest mean plant height, followed by Ibadan, and Tsonga had the lowest (Table 4.8).

Compare with the control, at 6 MAP, applying 45 kg NPK 15:15:15 ha^{-1} had 10.1% increase in stem girth at Ibadan and the same application had 12.0% increases at Tsonga while at Ikenne, omission of phosphorus (urea+KCl) at 75 kg ha^{-1} had 9.4% increases. Across treatments at all locations at 3, 6 and 9 MAP, Ibadan showed the highest stem girth followed by Ikenne. At 12 MAP however, Ikenne had the highest mean stem girth of 10.06 cm which was 7.8% and 11.6% higher than Ibadan and Tsonga respectively (Table 4.9).

At 6, 9 and 12 MAP, IBA070593 gave the highest mean stem girth at Ibadan, while it was IBA010040 at Ikenne and Tsonga. Across varieties in the three locations at 3 and 6 MAP, Ikenne showed the highest coefficient of variation (7.0% and 7.8%) while at 9 and 12 MAP, the highest CV was seen at Ibadan (8.2% and 4.3%) (Table 4.10).

4.3.4 Mean, standard error and coefficient of variation for mean leaf number $plant^{-1}$, mean leaf area index $plant^{-1}$ and leaf yield (t ha^{-1}) as influenced by fertiliser treatments at three locations in Nigeria during two planting seasons (2014/2015 and 2015/2016)

Across locations, application of compound fertilisers (NPK 15:15:15) at 75 kg ha^{-1} had the highest mean number of leaves $plant^{-1}$ (71.26) and leaf area index $plant^{-1}$ (2.34) which were 19.7% and 18.4% higher than the control. However, mean fresh leaf yield across locations showed that omission of phosphorus (urea+KCl) at 75 kg ha^{-1} was 34.1% higher than the control. Ikenne had the highest mean number of leaves, LAI and fresh leaf yield followed by Ibadan (Table 4.11).

Across locations, IBA011412 produced the highest mean number of leaves $plant^{-1}$ and fresh leaf yield (77.25 and 7.21 t ha^{-1}) which were about 2 times higher than TMEB419 that produced the least (44.10 and 4.78 t ha^{-1}). However, IBA010040 had the highest leaf area index $plant^{-1}$ (2.56) and it was 20.7% greater than that of IBA070593 which had the least (2.03). The genotype by environment (G × E) interaction of these traits was highly significant ($p \leq 0.001$) (Table 4.12).

Table 4.8 Periodic mean height of plant of four cassava varieties evaluated at three locations during 2014/2015 and 2015/2016 planting seasons

Location	IBN	IKN	TSG	IBN	IKN	TSG	IBN	IKN	TSG	IBN	IKN	TSG
Genotype	3 MAP			6 MAP			9 MAP			12 MAP		
IBA010040	91.74	89.46	65.27	190.56	158.55	107.35	213.40	209.87	135.46	246.55	241.67	169.96
IBA011412	103.28	97.63	71.88	175.04	151.34	103.17	192.93	192.69	117.51	228.03	221.62	152.01
IBA070593	95.02	76.15	66.36	174.65	140.61	103.93	190.35	190.99	124.29	229.23	216.94	158.79
TMEB419	102.69	100.47	75.27	159.76	168.49	97.82	197.06	242.01	135.01	239.52	273.09	169.51
Mean	98.18	90.93	69.69	175.01	156.75	103.07	198.44	208.89	128.07	235.83	238.33	162.57
SE(±)	2.86	5.45	3.88	6.29	4.44	1.97	5.18	11.83	4.37	4.41	12.77	4.37
CV (%)	5.82	11.99	8.20	7.19	5.67	3.83	5.22	11.33	6.82	3.74	10.71	5.37

Table 4.9 Periodic mean stem girth of four cassava varieties as influenced by fertiliser application across three locations in 2014/2015 and 2015/2016 planting seasons

Location		IBN	IKN	TSG	IBN	IKN	TSG	IBN	IKN	TSG	IBN	IKN	TSG
Fertiliser type	Fertiliser rate (kg/ha)		3 MAP			6 MAP			9 MAP			12 MAP	
Control	0	5.94	5.25	3.73	6.79	6.49	5.42	7.16	6.99	6.61	8.86	9.52	8.76
NPK 15:15:15	45	6.13	5.99	3.99	7.55	6.98	6.16	8.01	7.51	6.85	9.51	10.02	9.00
NPK 15:15:15	75	6.12	5.91	4.16	7.42	6.95	6.14	8.00	7.34	7.13	9.75	10.14	9.28
TSP+Urea (-K)	45	6.09	5.63	3.88	7.21	6.67	5.73	7.69	7.09	6.51	8.96	9.36	8.66
TSP+Urea (-K)	75	6.11	5.60	3.91	7.37	6.65	5.82	7.85	6.91	6.64	9.38	9.30	8.79
KCl+Urea (-P)	45	6.03	5.90	3.99	7.27	7.08	5.82	7.53	7.76	7.05	9.17	10.66	9.20
KCl+Urea (-P)	75	6.05	5.99	4.03	7.49	7.16	5.89	7.65	7.63	6.64	9.30	10.44	8.79
KCl+TSP (-N)	45	6.13	5.80	3.68	7.17	7.02	5.47	7.46	7.66	6.30	9.06	10.03	8.45
KCl+TSP (-N)	75	6.12	5.80	3.75	7.28	7.00	5.51	7.24	7.53	6.55	8.92	10.27	8.70
Minimum		5.94	5.25	3.68	6.79	6.49	5.42	7.16	6.91	6.30	8.86	9.30	8.45
Maximum		6.13	5.99	4.16	7.55	7.16	6.16	8.01	7.94	7.13	9.75	10.66	9.28
Mean		6.10	5.82	3.92	7.34	6.93	5.82	7.67	7.48	6.73	9.28	10.06	8.88
SE(±)		1.84	1.76	1.18	2.21	2.09	1.76	2.31	2.25	2.03	2.80	3.03	2.68
CV (%)		1.24	4.35	3.76	3.27	3.21	4.53	3.88	4.75	3.75	3.31	4.71	2.84

Table 4.10 Periodic mean stem girth of four cassava varieties evaluated at three locations in 2014/2015 and 2015/2016 planting seasons

Location	IBN	IKN	TSG	IBN	IKN	TSG	IBN	IKN	TSG	IBN	IKN	TSG
Genotype	3 MAP			6 MAP			9 MAP			12 MAP		
IBA010040	5.98	6.41	4.23	7.34	7.63	6.11	8.10	7.82	7.15	9.55	10.27	9.30
IBA011412	6.06	5.76	3.62	7.21	6.32	5.66	7.01	7.55	6.48	8.75	10.06	8.63
IBA070593	6.14	5.48	3.92	7.88	7.00	5.93	8.31	7.13	6.82	9.61	10.07	8.97
TMEB419	6.21	5.64	3.90	6.91	6.78	5.59	7.28	7.39	6.50	9.20	9.83	8.65
Mean	6.10	5.83	3.92	7.34	6.93	5.82	7.67	7.47	6.74	9.28	10.06	8.89
SE (±)	3.05	2.91	1.96	3.67	3.47	2.91	3.84	3.74	3.37	4.64	5.03	4.44
CV (%)	1.65	7.02	6.35	5.53	7.81	4.10	8.18	3.82	4.69	4.26	1.79	3.55

Table 4.11 Mean effects of applying fertiliser on number of leaves plant^{-1}, leaf area index and fresh leaf yield (t ha^{-1}) at Ibadan, Ikenne and Tsonga in 2014/2015 and 2015/2016 planting seasons

		Number of leaves/plant				Leaf area index				Fresh leaf yield (t ha^{-1})			
Fertiliser types	Fertiliser rate(kg/ha)	Ibadan	Ikenne	Tsonga	Mean across sites	Ibadan	Ikenne	Tsonga	Mean across sites	Ibadan	Ikenne	Tsonga	Mean across sites
Control	0	51.82	65.12	54.67	57.20^{e}	1.61	2.34	1.79	1.91^{bc}	10.22	11.42	5.89	9.18^{c}
NPK 15:15:15	45	61.10	78.03	59.12	66.08^{bc}	2.29	2.27	2.00	2.19^{ab}	12.50	14.19	9.24	11.98^{b}
NPK 15:15:15	75	72.10	86.31	65.37	71.26^{a}	2.22	2.67	2.12	2.34^{a}	12.17	16.30	5.89	11.46^{b}
Urea+TSP (-K)	45	56.94	71.68	60.80	63.14^{c}	1.81	2.22	1.96	2.00^{b}	12.31	12.04	5.53	9.96^{c}
Urea+TSP (-K)	75	59.16	73.57	58.23	63.65^{c}	1.99	2.39	2.18	2.19^{ab}	13.31	15.63	8.29	12.41^{ab}
Urea+KCl (-P)	45	59.29	76.94	56.42	64.22^{c}	2.27	2.45	2.01	2.24^{a}	11.53	16.02	6.04	11.20^{b}
Urea+KCl (-P)	75	61.23	78.82	63.22	67.76^{b}	2.23	2.46	2.07	2.25^{a}	13.69	19.17	8.89	13.92^{a}
TSP+KCl (-N)	45	58.01	74.02	56.52	62.85^{d}	2.24	2.37	1.71	2.11^{b}	13.95	18.99	7.40	13.45^{a}
TSP+KCl (-N)	75	56.33	76.22	58.22	63.59^{c}	2.05	2.53	1.78	2.12^{b}	12.80	11.99	5.26	10.02^{bc}
Minimum		51.82	65.12	54.67	57.20	1.61	2.22	1.71	1.91	10.22	11.42	5.26	9.18
Maximum		72.02	86.31	65.68	71.26	2.32	2.67	2.18	2.34	13.95	19.17	9.24	13.92
Mean		69.61	76.31	60.20	65.37	2.11	2.43	1.97	2.17	12.43	15.41	6.96	11.60
SE(±)		1.23	1.63	1.16	1.22	0.07	0.04	0.05	0.04	3.75	4.65	2.10	3.50
CV (%)		6.87	7.07	6.38	6.21	10.70	5.40	7.59	5.82	8.48	17.52	20.16	15.39

Table 4.12 Mean effects of four cassava varieties on number of leaves plant^{-1}, leaf area index and fresh leaf yield (t ha^{-1}) at Ibadan, Ikenne and Tsonga in 2014/2015 and 2015/2016 planting seasons

	Number of leaves plant^{-1}				Leaf area index				Fresh leaf yield (t ha^{-1})			
Genotype	Ibadan	Ikenne	Tsonga	Mean across Sites	Ibadan	Ikenne	Tsonga	Mean across sites	Ibadan	Ikenne	Tsonga	Mean across sites
IBA010040	68.20	82.76	66.51	72.49	2.59	3.06	2.02	2.56	6.75	4.68	5.93	5.79
IBA011412	68.36	91.96	71.42	77.25	2.10	2.25	1.97	2.11	6.97	7.38	7.29	7.21
IBA070593	64.90	84.55	47.82	65.76	1.98	2.22	1.90	2.03	7.56	5.75	1.33	4.88
TMEB419	31.70	46.05	54.56	44.10	2.31	2.35	1.99	2.22	4.89	3.35	6.11	4.78
Minimum	31.70	46.05	47.82	44.10	1.98	2.22	1.90	2.03	4.89	3.35	1.33	4.78
Maximum	68.36	91.96	71.42	77.25	2.59	3.06	2.02	2.56	7.56	7.38	7.29	7.21
Mean	58.29	76.33	60.08	64.90	2.24	2.47	1.97	2.23	6.54	5.29	5.16	5.67
SE(±)	8.90	10.29	5.41	7.32	0.13	0.20	0.03	0.12	0.58	0.85	1.31	0.56
CV (%)	30.54	26.96	18.00	22.56	11.91	16.01	2.66	10.38	17.63	32.23	50.86	19.89
Genotype × environment				***				***				***

4.3.5 Fresh stem yield (t ha^{-1}) as influenced by cassava varieties and fertiliser application at three Nigerian locations in the 2014/2015 and 2015 /2016 planting seasons

Not applying fertiiser to IBA010040 produced the highest fresh stem yield (15.36 t ha^{-1}) because stems in fertilised plots matured earlier and lodged before harvest especially white root varieties (IBA010040 and TMEB419) in the three locations. Ikenne contributed 43.5% to the increase in stem yield while Ibadan and Tsonga contributed 30.4% and 26.1% respectively. Omission of Potassium (urea+TSP) at 75 kg ha^{-1} to TMEB419 produced the lowest fresh stem yield (7.81 t ha^{-1}) which reduced by 49.2% when compared with zero application of feriliser to IBA010040 (Table 4.13).

In the three locations, IBA010040 produced the highest stem yield. Omission of Phosphorus (urea+KCl) at 45 kg ha^{-1} produced the highest fresh stem yield at Ibadan (18.06 t ha^{-1}) while it was unfertilized plots (control) at Ikenne (21.88 t ha^{-1}) and application of 75 kg NPK 15:15:15 ha^{-1} at Tsonga (12.40 t ha^{-1}). However, at Ibadan, omission of Nitrogen (TSP+KCl) at 75 kg ha^{-1} to IBA070593 produced the lowest fresh stem yield (7.67 t ha^{-1}) while at Ikenne and Tsonga omission of Potassium (TSP+urea) at 75 and 45 kg ha^{-1} to TMEB419 produced the lowest fresh stem yield (7.96 and 1.13 t ha^{-1}) (Table 4.13).

All the cassava varieties performed better at Ikenne than Ibadan and Tsonga for the number of 25 cm plantable cuttings (PC) (Figure 4.2). TMEB419 produced the highest number of 25 cm PC at Ikenne (10 cuttings) while it was 8 cuttings at Ibadan and 6.5 cuttings at Tsonga. However, all varieties except TMEB419 produced more at Ibadan than Ikenne and Tsonga for number of roots ha^{-1}. IBA010040 produced the highest number of roots at Ibadan (55,846 ha^{-1}) and Ikenne (46,786 ha^{-1}) and TMEB419 was highest at Tsonga (46,174 ha^{-1}). Across varieties, average number of 25 cm plantable cuttings obtained at Ikenne was higher than at Ibadan by 12.4% and at Tsonga by 28.0% while the mean number of roots ha^{-1} at Ibadan was higher than at Ikenne by 19.3% and 35.6% at Tsonga.

Table 4.14 shows that in environment 3, 75 kg NPK 15:15:15 ha^{-1} had 20.5% increases in FRY compared with the control. Omission of Nitrogen, Phosphorus and Potassium at 75 kg ha^{-1} had 7.6%, 6.7% and 20.0% respective reduction in FRY compared with application of 75 kg NPK 15:15:15 ha^{-1}. FRY across environments

Table 4.13 Mean effects of fertiliser application and cassava varieties on plantable stem yield (t ha^{-1}) at Ibadan, Ikenne and Tsonga in 2014/2015 and 2015/2016 planting seasons

S/N	Variety	Fertiliser formulation	Fertiliser rate	Ibadan	Ikenne	Tsonga	Treatment mean
1	IBA010040	Control	0	11.92	*21.88*	12.28	*15.36*
2	IBA010040	NPK 15:15:15	45	12.85	21.31	11.83	15.33
3	IBA010040	NPK 15:15:15	75	13.58	18.78	12.40	14.92
4	IBA010040	TSP+KCl (-N)	45	15.83	18.92	8.78	14.51
5	IBA010040	TSP+KCl (-N)	75	10.90	19.83	11.33	14.02
6	IBA010040	Urea+KCl (-P)	45	*18.06*	12.69	9.71	13.49
7	IBA010040	Urea+KCl (-P)	75	16.81	20.86	1.89	13.19
8	IBA010040	Urea+TSP (-K)	45	10.42	19.72	8.86	13.00
9	IBA010040	Urea+TSP (-K)	75	14.72	18.06	5.86	12.88
10	IBA011412	Control	0	15.08	17.11	6.26	12.82
11	IBA011412	NPK 15:15:15	45	12.90	19.67	5.89	12.82
12	IBA011412	NPK 15:15:15	75	14.93	15.42	7.93	12.76
13	IBA011412	TSP+KCl (-N)	45	10.90	14.86	*12.50*	12.75
14	IBA011412	TSP+KCl (-N)	75	9.79	19.58	8.69	12.69
15	IBA011412	Urea+KCl (-P)	45	12.63	17.39	6.04	12.02
16	IBA011412	Urea+KCl (-P)	75	14.44	18.53	3.06	12.01
17	IBA011412	Urea+TSP (-K)	45	13.68	11.00	11.18	11.95
18	IBA011412	Urea+TSP (-K)	75	13.68	15.69	6.07	11.81
19	IBA070593	Control	0	8.19	14.69	12.01	11.63
20	IBA070593	NPK 15:15:15	45	14.10	14.11	6.08	11.43
21	IBA070593	NPK 15:15:15	75	13.06	13.47	6.97	11.17
22	IBA070593	TSP+KCl (-N)	45	12.29	13.99	6.71	11.00
23	IBA070593	TSP+KCl (-N)	75	7.67	15.46	8.25	10.46
24	IBA070593	Urea+KCl (-P)	45	11.29	13.92	5.44	10.22
25	IBA070593	Urea+KCl (-P)	75	15.06	13.19	2.19	10.15
26	IBA070593	Urea+TSP (-K)	45	11.11	17.01	2.17	10.10
27	IBA070593	Urea+TSP (-K)	75	9.43	12.50	7.44	9.79
28	TMEB419	Control	0	12.60	15.00	1.75	9.78
29	TMEB419	NPK 15:15:15	45	11.18	15.28	2.32	9.59
30	TMEB419	NPK 15:15:15	75	13.40	10.39	4.81	9.53
31	TMEB419	TSP+KCl (-N)	45	12.29	12.17	3.63	9.36
32	TMEB419	TSP+KCl (-N)	75	12.29	10.03	5.75	9.36
33	TMEB419	Urea+KCl (-P)	45	13.13	11.97	1.69	8.93
34	TMEB419	Urea+KCl (-P)	75	9.31	9.94	4.42	7.89
35	TMEB419	Urea+TSP (-K)	45	12.50	9.83	1.13	7.82
36	TMEB419	Urea+TSP (-K)	75	12.92	7.96	2.56	7.81
	Minimum			7.67	7.96	1.13	7.81
	Maximum			18.06	21.88	12.50	15.36
	Location mean			11.43	15.26	6.73	11.48
	Standard error (±)			0.37	0.56	0.49	0.31
	Coefficient of variation (%)			19.68	24.16	48.08	17.73

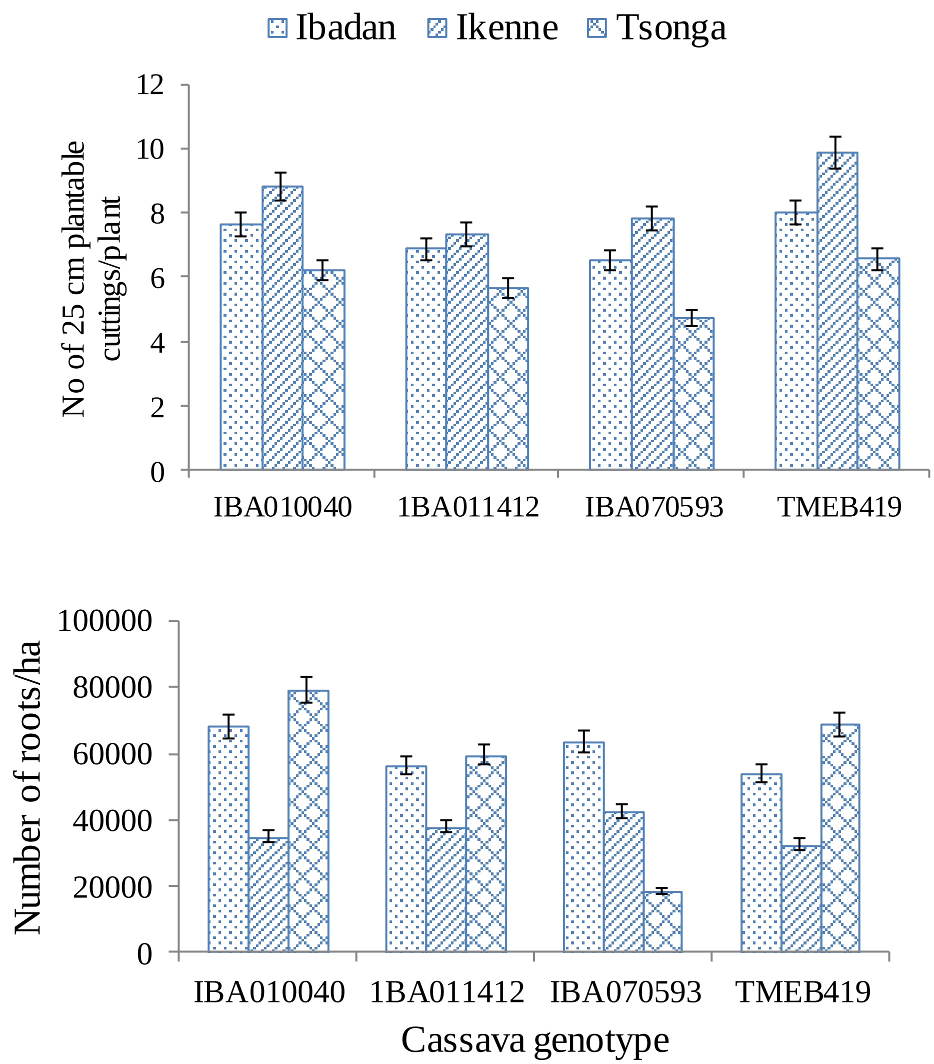

Figure 4.2 Average numbers of 25 cm plantable cuttings/plant and number of roots/ha for each genotype at 12 MAP at Ibadan, Ikenne and Tsonga in 2014/2015 and 2015/2016 planting seasons.

I signifies error bars at $P \leq 0.05$.

showed that ENV3 > ENV 4 > ENV 1 > ENV 2 > ENV 6 > ENV 5 (Table 4.14). Across environments, IBA011412 produced the highest FRY while IBA070593 produced the least (Table 4.15).

Phenotypic correlations and respective level of significance among qualitative and quantitative morphological characteristics of four cassava varieties was presented in Table 4.16. Results indicated that most of the plant traits evaluated were interrelated. Sprouting percent was positive and significantly correlated with CMD and CAD severity (r = 0.90*** and 0.89***) and CBB severity was negative and significantly correlated with FRY (r = -0.79***). CMD was significantly positively correlated ($P \leq 0.01$) with fresh shoot and root yield. There was significantly positive correlation between fresh root and shoot yield (r = 0.97***), number of roots ha^{-1} (r = 0.47**) and number of harvest (r = 0.89***). However, plant height and stem girth were significantly negatively correlated with leaf area index.

4.4 Effects of stem portions and lengths of stem cuttings on four cassava varieties at three locations during 2014/2015 and 2015/2016 planting seasons

4.4.1 Variations in shoots and root characteristics at three locations during two seasons

Mean square from the combined ANOVA for shoot and root characteristics at three locations during two planting seasons is shown in Table 4.17. Result showed that MS for location, environment, genotype and genotype by environment interactions were highly significant ($P \leq 0.001$) for most of the measured variables while stem portion × length interaction were not significant except for HI. MS of stem portion was highly significant ($P \leq 0.001$) for sprout and number of harvests and significant ($P \leq 0.05$) for shoot yield (t ha^{-1}) and HI. Highly significant ($P \leq 0.001$) was stem length for sprout, number of plants harvest and number of roots/plot. MS for interaction effects of stem portion × length and genotype × stem length were significant ($P \leq 0.01$) for HI and RDMC. MS for effects of interaction of stem portion × length was significant for HI and genotype × stem length was significant for RDMC. Genotype × Environment was highly significant ($P \leq 0.001$) for all the measured variables except for fresh shoot yield ($P \leq 0.05$) (Table 4.17).

Table 4.14 Mean fresh root yield (t ha^{-1}) in six environments as affected by fertiliser in 2014/2015 and 2015/2016 planting seasons

		Environment										
Fertiliser type	Fert rate (kg ha^{-1})	Env 1	Env 2	Env 3	Env 4	Env 5	Env 6	Min	Max	Mean^{a}	SE (±)	CV (%)
Control	0	15.15	15.91	19.85	10.15	6.96	15.64	6.96	19.85	13.94^{c}	5.69	33.06
NPK 15:15:15	45	16.17	18.33	20.67	14.67	11.79	14.00	11.79	20.67	15.94^{bc}	6.51	19.98
NPK 15:15:15	75	19.54	15.11	24.97	18.22	13.03	12.29	12.29	24.97	17.19^{a}	7.02	27.62
TSP+Urea (-K)	45	16.96	15.06	21.68	9.74	8.32	10.65	8.32	21.68	13.73^{c}	5.61	37.14
TSP+Urea (-K)	75	17.81	12.06	22.32	10.42	9.22	10.69	9.22	22.32	13.75^{c}	5.61	37.60
KCl+Urea (-P)	45	16.06	15.63	20.83	20.98	7.68	13.24	7.68	20.98	15.74^{bc}	6.42	31.73
KCl+Urea (-P)	75	19.51	14.19	22.42	19.45	9.03	11.66	9.03	22.42	16.04^{b}	6.55	32.52
KCl+TSP (-N)	45	13.99	17.70	20.74	20.68	7.35	13.63	7.35	20.74	15.68^{bc}	6.40	32.66
KCl+TSP (-N)	75	14.67	17.40	18.65	21.54	9.68	13.42	9.68	21.54	15.89^{bc}	6.49	26.39
Minimum		13.99	12.06	18.65	9.74	6.96	10.65					
Maximum		19.54	18.33	24.97	22.28	13.03	15.64					
Mean^{b}		16.65^{b}	15.71^{bc}	21.35^{a}	16.20^{b}	9.23^{d}	12.80^{c}					
SE (±)		0.54	0.55	0.50	1.51	0.62	0.47					
CV (%)		10.694	11.722	7.813	29.13	21.50	11.91					

Mean^{a}: mean across environments, mean^{b}: mean across fertiliser treatments, SE: Standard error; CV: Coefficient of variation, Env 1: Ibadan 2015, Env 2: Ibadan 2016, Env 3: Ikenne 2015, Env 4: Ikenne 2016, Env 5: Tsonga 2015, Env 6: Tsonga 2016

Table 4.15 Mean fresh root yield (t ha^{-1}) of four cassava varieties in six environments in 2014/2015 and 2015/2016 planting seasons

	Environment										
Genotype	Env 1	Env 2	Env 3	Env 4	Env 5	Env 6	Min	Max	Mean[a]	SE (±)	CV (%)
IBA010040	19.20	19.07	24.30	21.78	6.12	16.19	6.12	24.30	17.78[b]	2.59	35.63
IBA011412	21.24	18.90	27.57	22.22	11.17	14.70	11.17	27.57	19.30[a]	2.37	30.04
IBA070593	13.03	17.67	18.67	12.58	0.88	2.07	0.88	18.67	10.82[d]	3.12	70.62
TMEB419	13.18	6.25	14.44	12.32	14.22	15.90	6.25	15.90	12.72[c]	1.39	26.67
Minimum	13.03	6.25	14.44	12.32	0.88	2.07					
Maximum	21.24	19.07	27.57	22.22	14.22	16.19					
Mean[b]	16.66[b]	15.47[bc]	21.24[a]	17.22[b]	8.10[d]	12.22[c]					
SE (±)	2.10	3.09	2.92	2.76	2.93	3.40					
CV (%)	25.17	39.93	27.48	32.03	72.32	55.61					
Genotype x environment ***											

Mean[a]: mean across varieties, Mean[b]: mean across environments, Env 1: Ibadan 2015, Env 2: Ibadan 2016, Env 3: Ikenne 2015, Env 4: Ikenne 2016, Env 5: Tsonga 2015 and Env 6: Tsonga 2016

Table 4.16 Correlation coefficients among qualitative and quantitative morphological characteristics of four cassava varieties evaluated at Ibadan, Ikenne and Tsonga in 2014/2015 and 2015/2016 planting seasons

Variables	Sprouting percent	CMD Severity	CBB severity	CAD Severity	Plant height	Stem girth	No of leaves/ plant	Leaf area index	No of harvests	No of roots/ha	Fresh shoot yield	Fresh root yield
SP	1.00	0.90***	-0.18ns	0.89***	0.19ns	0.17ns	0.14ns	0.07ns	0.67***	0.83***	0.48**	0.51***
CMDS		1.00	-0.12ns	0.92***	0.05ns	0.03ns	0.05ns	0.03ns	0.58***	0.84***	0.44**	0.43**
CBBS			1.00	0.12ns	0.09ns	0.11ns	0.11ns	-0.11ns	-0.79***	0.03ns	-0.82***	-0.79***
CADS				1.00	0.10ns	0.08ns	0.05ns	0.04ns	0.41**	0.89***	0.27ns	0.29ns
Plant height					1.00	0.98***	0.39*	-0.60***	0.13ns	0.20ns	-0.10ns	0.00ns
Stem girth						1.00	0.45**	-0.53***	0.10ns	0.19ns	-0.11ns	-0.02ns
No of leaves/plt							1.00	-0.47**	0.10ns	0.19ns	0.00ns	0.06ns
Leaf area index								1.00	-0.01ns	-0.10ns	0.08ns	0.03ns
No of harvests									1.00	0.51***	0.87***	0.89***
No of roots/ha										1.00	0.42**	0.47**
Fresh shoot yield											1.00	0.97***
Fresh root yield												1.00

SP: Sprouting percent, CMDS: Cassava mosaic disease severity, CBBS: Cassava bacteria blight severity, CADS: Cassava anthracnose disease severity, ***: significant at 0.001, **: significant at 0.01, *: significant at 0.05, ns: not significant at 0.05

Table 4.17 In 2014/2015 and 2015/2016 planting seasons, mean squares from analysis of variance (ANOVA) of some shoot and root characteristics of four cassava varieties at three Nigerian location

Source of variation	DF	Sprout	CAD severity	Stay green	No of Harvest	Fresh root yield (t ha^{-1})	Harvest index	Fresh shoot yield (t ha^{-1})	No of roots/plot	Root dry matter (%)
Location	2	0.55***	29.48***	126.34***	486.07***	2759.93***	1.12**	2170.58***	5072.36***	1806.07***
Year	1	0.18**	0.87***	247.47***	25.51**	41.92ns	0.17ns	16.46ns	1767.36***	1588.05***
Rep(env)	12	0.03ns	0.10ns	3.02***	7.56**	167.55***	0.03***	567.15***	134.70**	14.91***
Genotype	3	0.68***	2.11***	95.28***	67.31***	3354.33***	0.33***	645.31**	3985.66***	210.41***
Rep*gen(env)	36	0.02ns	0.06ns	1.88**	3.95ns	66.37ns	0.02***	190.72*	175.01**	6.41ns
Env*gen	15	0.10***	0.50***	8.74***	19.57***	538.03***	0.10***	296.46*	1138.27***	46.63***
Stem portion	2	3.63***	0.19ns	3.23*	164.73***	25.66ns	0.03*	408.96*	3235.66ns	5.04ns
Genotype*stem portion	6	0.11***	0.03ns	0.76ns	13.63***	68.88ns	0.02**	203.89ns	225.20ns	6.42ns
Rep*gen*stem por(env)	136	0.03ns	0.05ns	0.82ns	2.71ns	66.60ns	0.01ns	130.43ns	91.30ns	5.75ns
Stem length	1	1.77***	0.11ns	6.41**	319.94***	41.11ns	0.00ns	361.32ns	4876.00***	0.57ns
Genotype*stem length	3	0.01ns	0.15ns	0.31ns	3.26ns	75.69ns	0.02ns	196.85ns	192.86ns	15.72**
Stem por*stem length	2	0.02ns	0.13ns	1.08ns	0.06ns	76.11ns	0.04**	210.14ns	15.06ns	7.05ns
Gen*stem por*stem length	6	0.02ns	0.18*	0.26ns	5.70ns	78.22ns	0.01ns	43.69ns	131.09ns	5.83ns
Standard Error		0.02	0.07	1.03	3.51	58.21	0.01	128.75	124.41	4.64
R^2		0.83	0.88	0.86	0.80	0.80	0.78	0.69	0.75	0.82
Coefficient of variation (%)		18.93	18.20	18.36	28.18	34.14	19.73	40.83	44.36	35.98

R^2: Coefficient of determination

4.4.2 Mean, SE and CV for some growth parametres as influenced by stem properties during two planting seasons (2014/2015 and 2015/2016) in three Nigerian locations

Across locations at 1 MAP, basal stem at 30 cm had the highest sprouting ability (95%) while top stem at 15 cm had the lowest sprouting ability (50%); this means that there was 47% reduction in sprouting ability. However top stem at 15 cm was less severe to CMD and CAD (1.22 and 1.38). Ikenne and Tsonga gave 8% and 16% reduction in sprouting ability when compared with Ibadan while mean CMD and CBB were less severe in Tsonga followed by Ikenne (Table 4.18). At 3 and 9 MAP, Ikenne showed the highest mean plant height (91.34 and 202.75 cm) while at 6 MAP, Ibadan had the highest mean plant height (166.99 cm).

Across locations at 3, 6 and 9 MAP, the biggest mean stem girth was recorded at Ibadan followed by Ikenne. Tsonga had the lowest plant height and stem girth when compared with Ibadan and Ikenne locations (Figure 4.6).

Root size score were highest at Ibadan for IBA010040 (6), IBA011412 (7) and IBA070593 (6) and at Tsonga for TMEB419 (5) (Figure 4.7). Number of roots and FRY were highest in Ibadan for IBA010040 (73,471 ha^{-1}, 18.04 t ha^{-1}) and IBA070593 (58,329 ha^{-1}, 15.26 t ha^{-1}). Number of roots was highest at Tsonga for IBA011412 (50,878 ha^{-1}) and TMEB419 (54,754 ha^{-1}) and fresh root yield was highest at Ikenne for IBA011412 (16.37 t ha^{-1}) and TMEB419 (8.49 t ha^{-1}).

4.4.3 Mean, standard error and coefficient of variation for FRY, fresh stem yield and RDMC as influenced by stem properties at three locations in Nigeria during 2014/2015 and 2015 /2016 planting seasons

Basal stem at 30 cm gave the highest FRY at Ibadan (24.39 t ha^{-1}) and Tsonga (9.41 t ha^{-1}) while it was mid stem at 30 cm that gave the highest at Ikenne (26.42 t ha^{-1}) (Table 4.19). Mid stem at 30 cm across sites gave the highest FRY (19.11 t ha^{-1}) where Ikenne, Ibadan and Tsonga contributed 43.8%, 40.5% and 15.6% respectively to the yield. Mean across sites also showed that basal stem at 30 cm gave the highest stem yield (13.54 t ha^{-1}) and top stem portion produced the lowest (6.39 t ha^{-1}). Mean RDMC of all the treatments across location showed that Ikenne gave the highest RDMC (30.5%) followed by Ibadan (24.7%) and Tsonga gave the lowest (17.2%). Mean RDMC across sites was

Table 4.18 Mean effects of stem portion and lengths of stem cutting on plant sprout, CMD and CAD severity at Ibadan, Ikenne and Tsonga in 2014/2015 and 2015/2016 planting seasons

		Plant sprout (%)				CMD severity				CAD severity			
Stem part	Stem length (cm)	IBN	IKN	TSG	Mean across sites	IBN	IKN	TSG	Mean across sites	IBN	IKN	TSG	Mean across sites
Basal stem	15	0.89	0.87	0.79	0.85	1.53	1.35	1.07	1.31	2.15	1.33	1.00	1.49
Basal stem	30	0.98	0.96	0.92	0.95	1.49	1.35	1.07	1.30	2.00	1.38	1.00	1.46
Mid stem	15	0.83	0.75	0.63	0.74	1.38	1.33	1.06	1.25	1.98	1.42	1.00	1.47
Mid stem	30	0.94	0.85	0.83	0.87	1.40	1.33	1.08	1.27	2.17	1.35	1.00	1.51
Top stem	15	0.57	0.49	0.45	0.50	1.43	1.24	1.00	1.22	1.73	1.42	1.00	1.38
Top stem	30	0.76	0.64	0.58	0.66	1.49	1.42	1.09	1.33	2.02	1.35	1.00	1.46
Minimum		0.57	0.49	0.45	0.50	1.38	1.24	1.00	1.22	1.73	1.33	1.00	1.38
Maximum		0.98	0.96	0.92	0.95	1.53	1.42	1.09	1.33	2.17	1.42	1.00	1.51
Mean		0.83	0.76	0.70	0.76	1.45	1.34	1.06	1.28	2.01	1.38	1.00	1.46
SE(±)		0.34	0.31	0.29	0.31	0.59	0.55	0.43	0.52	0.82	0.56	0.41	0.60
CV (%)		18.05	22.63	25.35	21.62	4.00	4.33	3.03	3.16	7.89	2.54	0.00	3.01

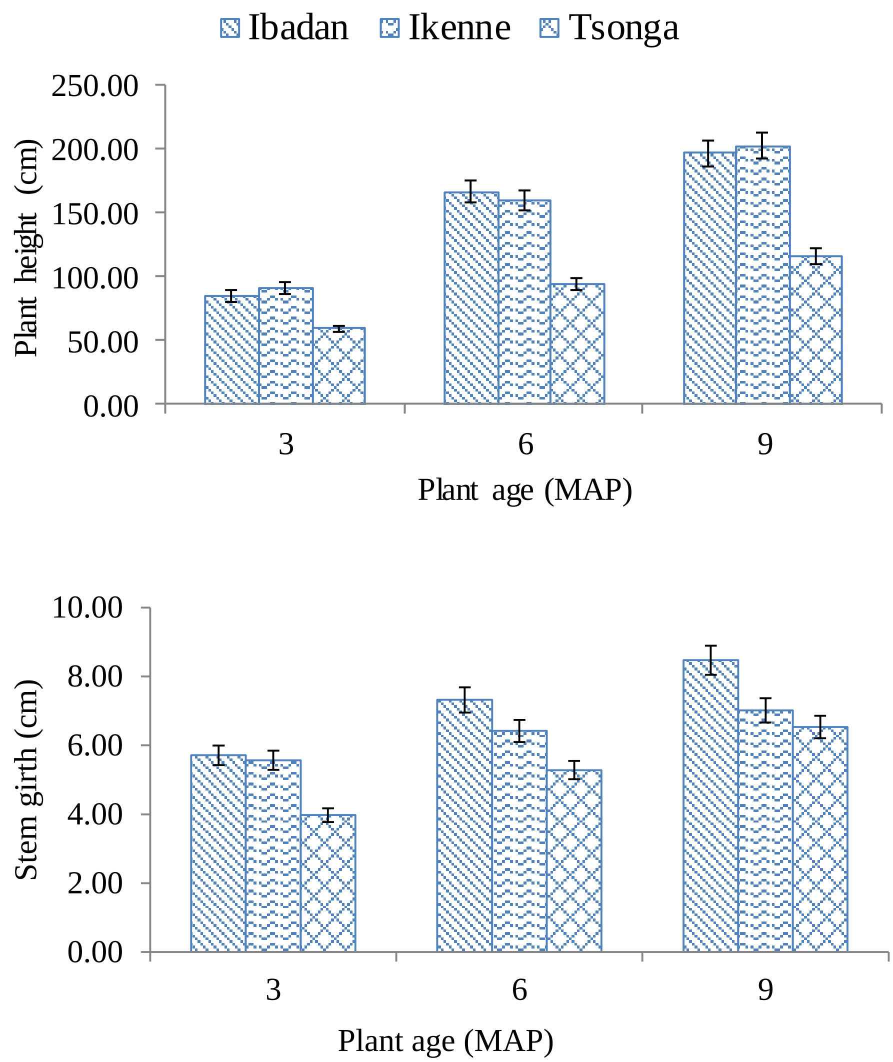

Figure 4.3 Periodic mean plant height and stem girth of four cassava varieties at Ibadan, Ikenne and Tsonga in the two planting seasons.
I signifies error bars at P≤0.05.

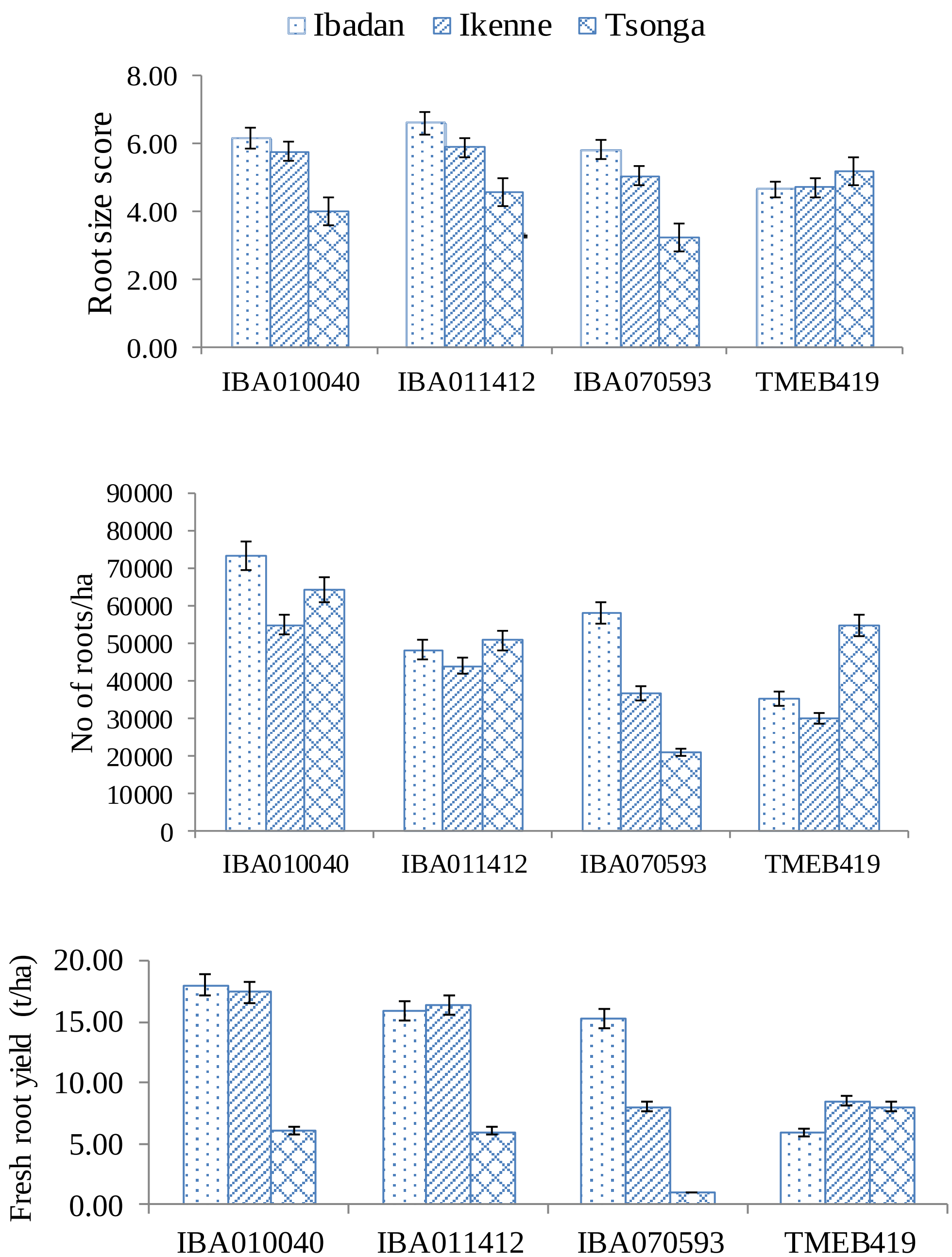

Figure 4.4 Average root size score, number of roots/ha and FRY (t ha^{-1}) of four cassava varieties at 12 MAP in Ibadan, Ikenne and Tsonga in the two planting seasons
I signifies error bars at P≤0.05

Table 4.19 Mean effects of stem portions and lengths of stem cutting on plant height, stem girth and number of 25 cm fresh plantable cuttings/plant at Ibadan, Ikenne and Tsonga in 2014/2015 and 2015/2016 planting seasons

		Plant height (cm)				Stem girth (cm)				No of 25 cm plantable cuttings/plant			
Stem portion	Stem length (cm)	IBN	IKN	TSG	Mean across sites	IBN	IKN	TSG	Mean across sites	IBN	IKN	TSG	Mean across sites
Basal stem	15	145.26	154.05	91.93	130.42ab	6.88	6.73	5.04	5.82a	3.46	3.55	2.45	3.15ab
Basal stem	30	150.95	162.23	96.89	136.69a	6.34	6.34	4.80	5.71ab	3.77	3.97	2.65	3.46a
Mid stem	15	145.07	151.02	86.99	127.69b	6.33	6.41	4.80	5.85a	3.58	3.42	2.23	3.08ab
Mid stem	30	150.26	157.47	97.37	135.03a	6.20	6.47	4.97	5.88a	3.70	3.69	2.49	3.29a
Top stem	15	141.38	147.38	79.18	122.65c	6.01	6.25	4.77	6.12a	3.37	3.25	2.05	2.89b
Top stem	30	144.67	148.27	88.51	127.15b	6.10	6.34	5.57	6.06a	3.51	3.16	2.30	2.99b
Minimum		141.38	147.38	79.18	122.65	6.01	6.25	4.77	5.71	3.37	3.16	2.05	2.89
Maximum		150.95	162.23	97.37	136.69	6.88	6.73	5.57	6.12	3.77	3.97	2.65	3.46
Mean		146.27	153.40	90.14	129.94	6.31	6.42	4.99	5.91	3.56	3.50	2.36	3.14
SE(±)		1.49	2.33	2.79	2.14	0.13	0.07	0.12	0.06	0.06	0.12	0.09	0.09
CV (%)		2.50	3.72	7.58	4.04	4.88	2.59	6.07	2.60	4.25	8.50	8.96	6.63

Table 4.20 Mean effect of stem portions and lengths of stem cutting on fresh storage root and stem yield and RDMC at Ibadan, Ikenne and Tsonga in 2014/2015 and 2015/2016 planting seasons

		FSRY ($t\ ha^{-1}$)				FSY ($t\ ha^{-1}$)				RDMC (%)			
Stem portion	Stem length (cm)	IBN	IKN	TSG	Mean across sites	IBN	IKN	TSG	Mean across sites	IBN	IKN	TSG	Mean across sites
Basal stem	15	16.95	25.48	6.77	16.40[b]	11.92	10.33	4.39	8.88[c]	24.38	30.98	16.44	23.93[b]
Basal stem	30	24.39	21.96	9.41	18.58[a]	16.45	14.65	9.52	13.54[a]	25.56	30.68	17.15	24.46[ab]
Mid stem	15	19.34	22.10	7.21	16.22[b]	12.45	10.35	3.05	8.61[c]	24.79	31.90	17.93	24.87[a]
Mid stem	30	22.30	26.42	8.63	19.11[a]	13.87	12.32	6.47	10.89[b]	26.43	30.15	16.94	24.50[a]
Top stem	15	10.25	22.40	4.66	12.43[c]	7.57	9.67	1.94	6.39[d]	22.03	29.53	18.16	23.24[b]
Top stem	30	21.88	22.17	7.81	17.28[ab]	12.44	9.58	5.50	9.17[bc]	24.72	30.03	16.87	23.87[b]
Minimum		10.25	21.96	4.66	12.43	7.57	14.65	9.52	6.39	22.03	29.53	16.44	23.24
Maximum		24.39	26.42	9.41	19.11	16.45	9.58	1.94	13.54	26.43	31.90	18.16	24.87
Mean		19.18	23.42	7.41	16.67	12.45	11.15	5.14	9.58	24.65	30.54	17.25	24.15
SE (±)		2.07	0.81	0.67	1.19	0.59	0.85	1.16	0.99	0.60	0.34	0.27	0.41
CV (%)		26.46	8.48	22.29	19.08	12.80	10.85	4.60	9.39	6.00	2.74	3.84	4.20

Table 4.21 Mean stem yield (t ha^{-1}) in six environments as influenced by cassava variety and stem portion

S/N	Cassava variety	Stem portion	Env 1	Env 2	Env 3	Env 4	Env 5	Env 6	Mean[a]	SE(±)	CV (%)
1	IBA010040	Basal	8.39	19.01	12.60	13.71	5.10	9.25	11.34[ab]	1.98	42.85
2	IBA010040	Top	7.75	13.93	13.25	8.76	3.36	2.55	8.27[c]	1.95	57.80
3	IBA010040	Mid	12.37	19.60	13.18	10.65	3.88	8.23	11.32[ab]	2.15	46.48
4	IBA011412	Basal	13.56	15.21	15.16	14.68	9.19	9.24	12.84[a]	1.17	22.33
5	IBA011412	Top	11.19	11.18	16.43	6.82	3.65	6.94	9.37[bc]	1.84	48.09
6	IBA011412	Mid	11.40	14.29	16.67	13.40	4.45	5.91	11.02[ab]	1.98	44.02
7	IBA070593	Basal	10.47	17.15	12.15	10.99	3.97	3.13	9.64[bc]	2.16	54.84
8	IBA070593	Top	5.77	8.87	8.83	5.24	0.82	0.18	4.95[d]	1.54	76.12
9	IBA070593	Mid	12.36	13.93	10.84	5.43	3.03	1.38	7.83[c]	2.14	66.92
10	TMEB419	Basal	13.61	7.24	10.53	11.62	9.33	8.58	10.15[b]	0.93	22.42
11	TMEB419	Top	8.89	7.15	8.05	9.62	4.53	4.76	7.17[c]	0.87	29.60
12	TMEB419	Mid	12.17	9.15	9.31	11.21	7.32	5.40	9.09[bc]	1.01	27.28
		Mean[b]	10.66b	13.06a	12.25ab	10.18b	4.89c	5.46bc	9.42		
		Minimum	5.77	7.15	8.05	5.24	0.82	0.18	4.95		
		Maximum	13.61	19.60	16.67	14.68	9.33	9.25	12.84		
		SE(±)	0.71	1.25	0.83	0.90	0.73	0.90	0.62		
		CV (%)	23.11	33.27	23.39	30.75	51.73	57.21	22.90		

Mean[a]: mean across environments, mean[b]: mean across treatments, Env 1: Ibadan 2015, Env 2: Ibadan 2016, Env 3: Ikenne 2015, Env 4: Ikenne 2016, Env 5: Tsonga 2015, Env 6: Tsonga 2016 highest for mid stem at 30 cm (24.9%) where Ikenne contributed 42.8% to it (Table 4.20).

Basal and mid stem portion of TMEB419 and IBA010040 produced the highest stem yield at Ibadan (13.61 and 19.60). Basal and mid stem portion of IBA011412 produced the highest stem yield at Ikenne (16.67 and 14.68) and basal stem portion of TMEB419 and and IBA010040 produced the highest stem yield at Tsonga (9.33 and 9.25). In four environments (IBN 2015, IKN 2016, TSG 2015 and TSG 2016) and in two environments (IBN 2016 and IKN 2015), top stem portion of IBA070593 and TMEB419 produced the lowest stem yield respectively (Table 4.20).

Basal stem of IBA010040 at 30 cm produced the highest dry root yield at Ibadan (6.87 t ha^{-1}) and mid stem at 30 cm of the same variety was highest at Ikenne (5.97 t ha^{-1}). However, at Tsonga, basal stem of TMEB419 at 30 cm produced the highest (3.82 t ha^{-1}). Treatment mean across sites showed that mid stem of IBA010040 at 30 cm produced the highest DRY (4.67 t ha^{-1}) where Ibadan, Ikenne and Tsonga contributed 30.6%, 42.6% and 18.8% respectively to it (Table 4.22).

Table 4.23 shows the phenotypic correlations and levels of significance among qualitative and quantitative morphological characteristics of four cassava varieties. The majority of the plant features studied was found to be interrelated. Sprouting percent was significantly correlated with CMD severity (r = 0.33*), CAD severity (r = 0.38*), plant height (r = 0.25*), root size score (r = 0.25*) and FRY (r = 0.29*). Sprouting percent was also negatively correlated with stem girth and number of roots ha^{-1} (r = -0.07 and -0.06). FRY was correlated significantly with plant height (r = 0.53**), stem girth (r = 0.57**), number of roots ha^{-1} (r = 0.45*) and number of harvested plants/plot (r = 0.70***). However, plant HI and RDMC were not significantly correlated with FSRY.

4.4.4 Genotype + Genotype × Environment (GGE) biplot analysis for FRY (t ha^{-1}) across six environments

As illustrated in Figure 4.5, partitioning G × E using GGE biplot analysis revealed that the first two principal component axes (PCA 1 and PCA 2) accounted for 60.7% and 23.7% of G × E sum of squares for FRY, respectively, explaining a total of 84.4% variation. The best genotype with respect to location was accurately identified and as display, the best variety in various environments was shown using GGE biplot. The best

Table 4.22 Mean effects of varieties; stem portion and lengths of stem cutting on DRY (t ha^{-1}) at Ibadan, Ikenne and Tsonga in 2014/2015 and 2015/2016 planting seasons

S/N	Cassava Variety	Stem portion	Stem length (cm)	Ibadan	Ikenne	Tsonga	Treatment mean
1	IBA010040	Basal	15	4.41	5.21	0.86	3.49
2	IBA010040	Basal	30	*6.87*	5.63	2.28	4.42
3	IBA010040	Mid	15	4.78	4.72	1.33	3.61
4	IBA010040	Mid	30	5.41	*5.97*	2.64	*4.67*
5	IBA010040	Top	15	2.82	4.13	0.74	2.57
6	IBA010040	Top	30	5.62	5.60	2.07	4.43
7	IBA011412	Basal	15	3.10	4.38	1.57	3.02
8	IBA011412	Basal	30	4.08	3.72	1.73	3.18
9	IBA011412	Mid	15	3.83	4.28	0.50	2.87
10	IBA011412	Mid	30	2.55	4.35	1.66	2.85
11	IBA011412	Top	15	2.14	3.78	0.64	2.19
12	IBA011412	Top	30	2.91	4.46	2.09	3.15
13	IBA070593	Basal	15	2.43	2.84	0.19	1.82
14	IBA070593	Basal	30	5.35	3.22	0.51	4.54
15	IBA070593	Mid	15	3.00	2.75	0.29	2.01
16	IBA070593	Mid	30	5.12	2.57	0.28	2.66
17	IBA070593	Top	15	0.98	1.53	0.08	0.86
18	IBA070593	Top	30	3.22	1.44	0.04	1.57
19	TMEB419	Basal	15	1.99	3.62	1.83	2.48
20	TMEB419	Basal	30	2.37	2.34	*3.82*	2.85
21	TMEB419	Mid	15	1.57	2.85	1.14	1.85
22	TMEB419	Mid	30	2.08	2.91	3.15	2.71
23	TMEB419	Top	15	1.56	4.15	1.27	2.33
24	TMEB419	Top	30	0.91	2.62	2.20	1.91
	Minimum			0.91	1.44	0.04	0.86
	Maximum			6.87	5.97	3.82	4.67
	Location mean			3.30	*3.71*	1.37	2.83
	Standard error (±)			0.67	0.76	0.28	0.58
	Coefficient of variation (%)			48.51	33.38	74.01	34.93

Table 4.23 Phenotypic correlation among qualitative and quantitative morphological characteristics of four cassava varieties evaluated at Ibadan, Ikenne and Tsonga in 2014/2015 and 2015/2016 planting seasons

Variables	Sprouting percent	CMD Severity	CAD Severity	Plant height	Stem girth	No of harvests	No of roots/ha	Fresh root yield	Harvest index	Root size score	Root dry matter
SP	1.00	0.33*	0.38*	0.25*	-0.07ns	0.67***	-0.06ns	0.29*	0.14ns	0.25*	0.18ns
CMDS		1.00	0.62***	0.36*	0.31*	0.29*	-0.12ns	0.11ns	0.22*	0.19ns	0.38*
CADS			1.00	0.42**	0.44**	0.36*	-0.01ns	0.42**	0.39*	0.57***	0.10ns
Plant height				1.00	0.76***	0.64***	0.07ns	0.53**	-0.34*	0.24ns	0.56**
Stem girth					1.00	0.45**	0.23*	0.56**	0.01ns	0.45**	0.45**
No of harvests						1.00	0.11ns	0.70***	0.11ns	0.50**	0.51**
No of roots/ha							1.00	0.45**	-0.11ns	0.27*	0.24ns
Fresh root yield								1.00	0.21ns	0.62**	0.21ns
Harvest index									1.00	0.63**	-0.20ns
Root size score										1.00	0.16ns
Root dry matter											1.00

SP: Sprouting percent, ***: significant at 0.001, **: significant at 0.01, *: significant at 0.05, ns: not significant at 0.05

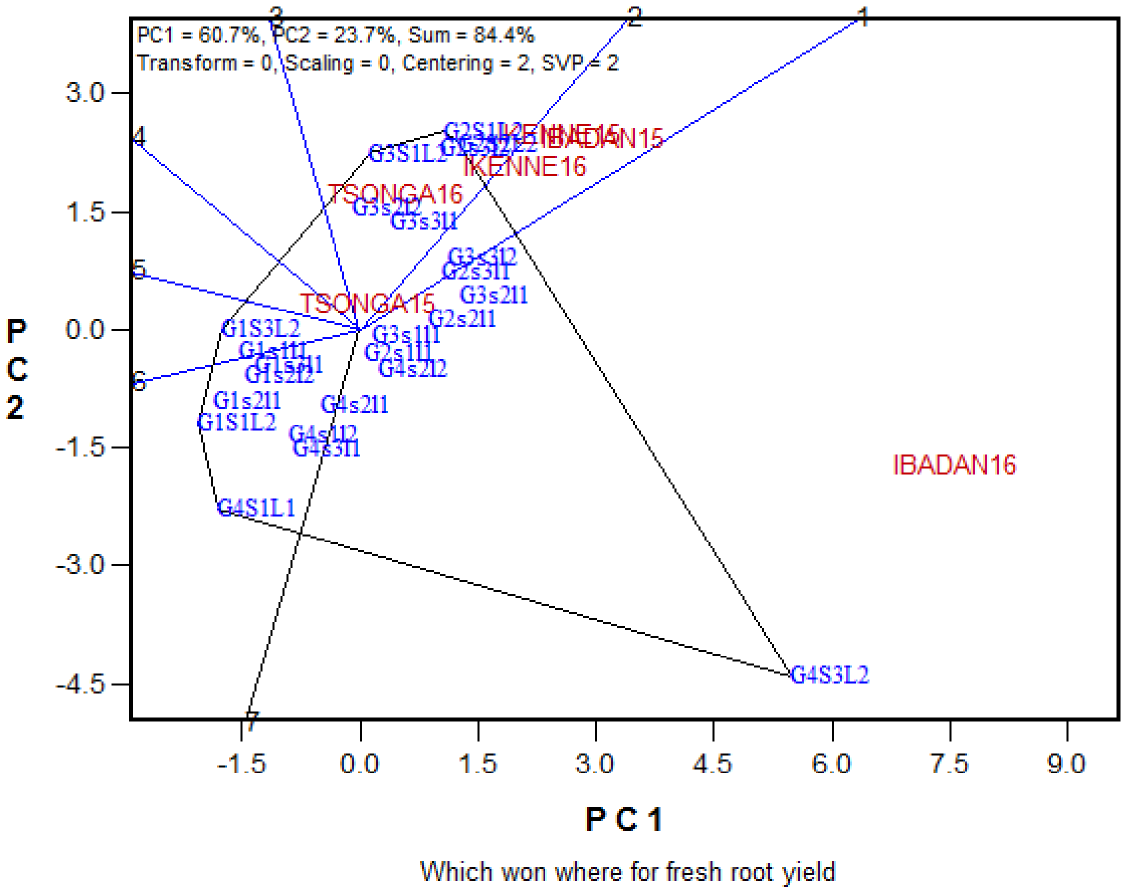

Figure 4.5 The polygon view showing the best performer (which won where) for fresh root yield

Cassava varieties: G1: TMEB419; G2: IBA010040; G3: IBA011412 and G4: IBA070593.

Stem portion: S1: Basal stem, S2: Mid stem and S3: Top stem

Stem length: L1: 15 cm and L2: 30 cm

Environment: Ibadan 15, Ibadan 16, Ikenne 15, Ikenne 16, Tsonga 15 and Tsonga 16

performer in five out of the six tested environments was G2S1L2 (Basal stem of IBA010040 at 30 cm), hence IBA010040 was detected as the variety of interest (higher fresh root yield) across the six environments. In contrast, G4S3L2 (Top stem of IBA070593 at 30 cm) was low in fresh root yield in all environments, as indicated by its small PCA 1 scores (low fresh root yield) and relatively small PCA 2 scores (relatively stable).

Figure 4.6 shows the stability performance of four cassava varieties, three stem portions and two lenghts of stem cuttings on mean FRY. Based on their mean performance across all environments, the varieties and treatments with an arrow indicating the highest value were ranked along the average environment co-ordinate (AEC x-axis). Thus, variety IBA011412 had the highest mean fresh root production, with all six stem portions and lengths of stem cuttings closer to the AEC x-axis arrow, whereas variety IBA070593, which was further away from the AEC x-axis arrow had the lowest FRY. Hence, FRY of G4S3L2 with the longest projection from the AEC x-axis was very unstable and G2S2L2 with scarcely noticeable projections from the AEC x-axis was stable.

Figure 4.7 depicts the GGE biplot's discriminating power versus representativeness view. The length of the environment vectors (the lines that connect the test environment to the biplot origin) is proportional to the standard deviation within the respective environments and is a measure of the discriminating power of the environments. It was discovered that Ibadan16, which had the longest projection from the biplot origin, was the most discriminating of the six settings studied (i.e. provided much information about the differences among varieties). Tsonga 15, on the other hand, was found to be less discriminating of all the tested varieties because of its shortest vector from the biplot origin, but it was found to be more typical (characteristically representing) of other test environments due to its smaller angles with the AEAs.

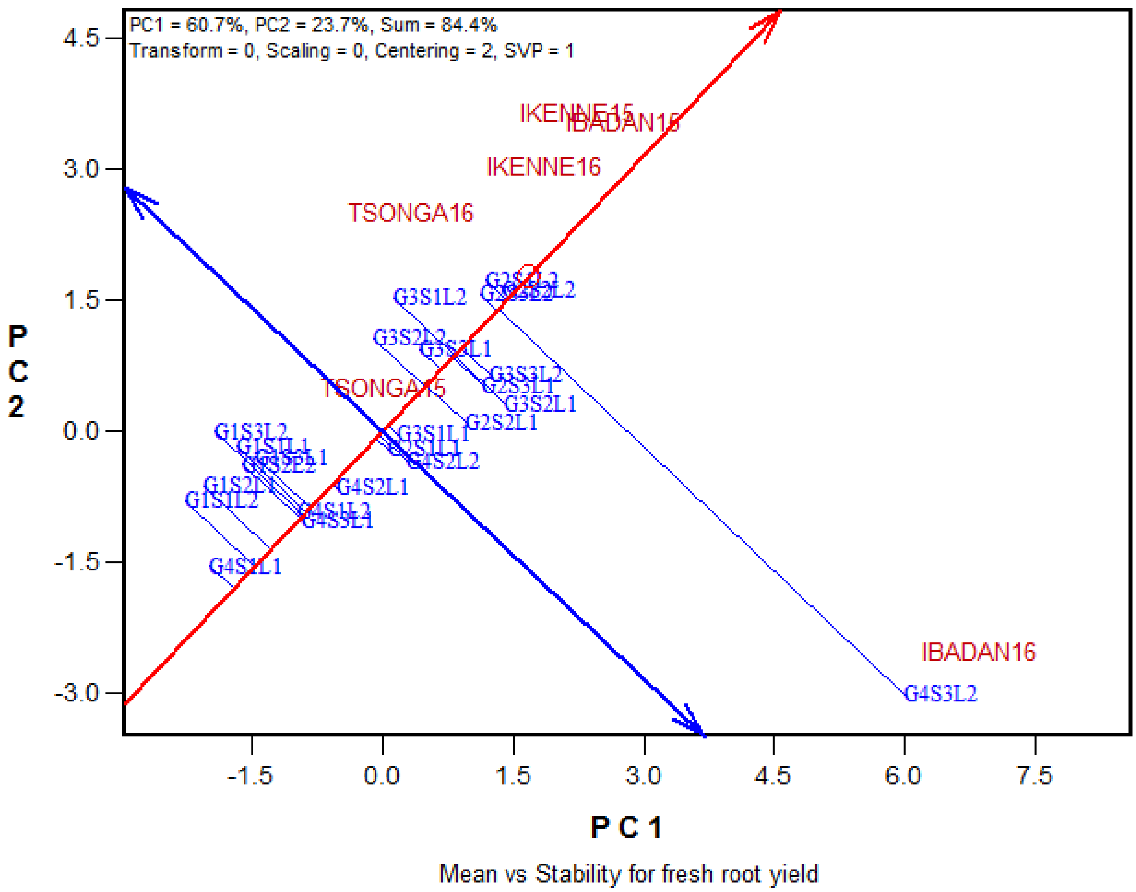

Figure 4.6 Mean Performances and Stability of four cassava varieties, three stem portions and two lenghts of stem cutting in six environments

Cassava varieties: G1: TMEB419; G2: IBA010040; G3: IBA011412 and G4: IBA070593.

Stem portion: S1: Basal stem, S2: Mid stem and S3: Top stem

Stem length: L1: 15 cm and L2: 30 cm

Environment: Ibadan 15, Ibadan 16, Ikenne 15, Ikenne 16, Tsonga 15 and Tsonga 16

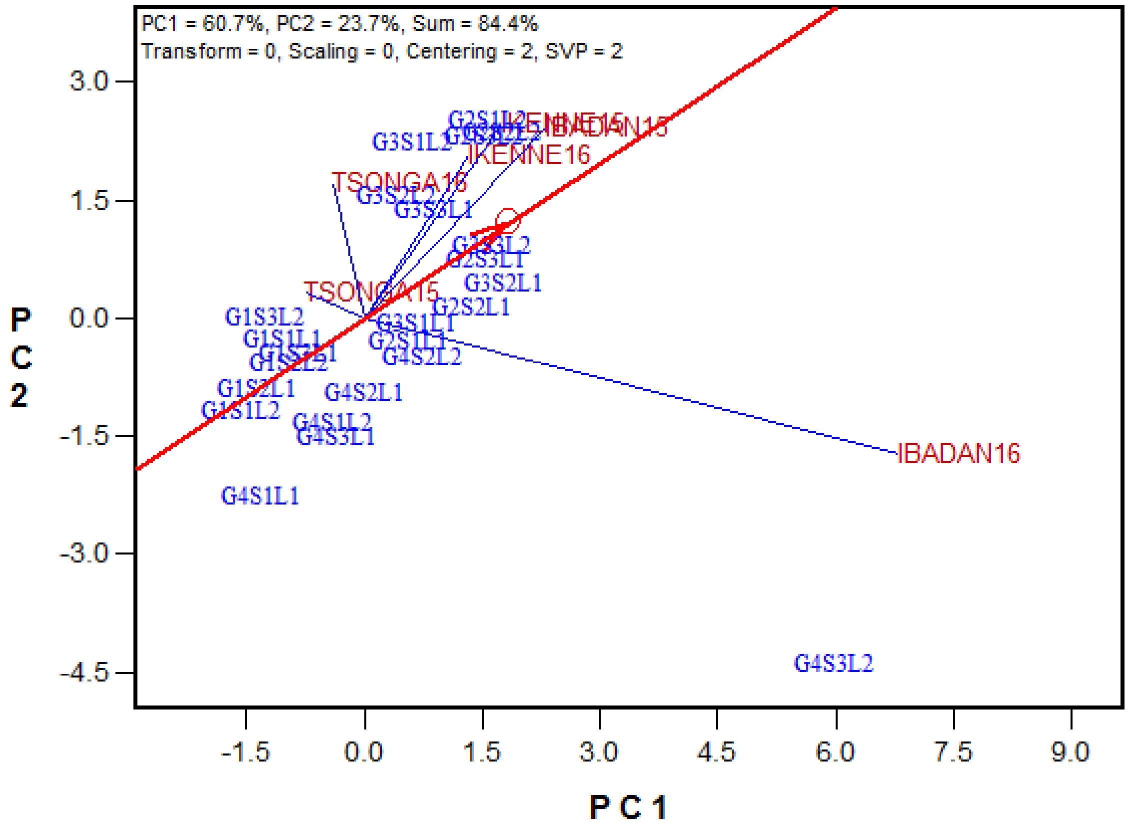

Figure 4.7 Discriminating power and representativeness of the six environments

Cassava varieties: G1: TMEB419; G2: IBA010040; G3: IBA011412 and G4: IBA070593.

Stem portion: S1: Basal stem, S2: Mid stem and S3: Top stem

Stem length: L1: 15 cm and L2: 30 cm

Environment: Ibadan 15, Ibadan 16, Ikenne 15, Ikenne 16, Tsonga 15 and Tsonga 16

CHAPTER FIVE

DISCUSSION

5.1 Major planting systems among cassava farmers

Rapid adoption and integration of cassava into the traditional farming and food systems of Africa was because of its supposed low inputs, relative ease of cultivation and processing. Cassava farmers in Africa are most interested in the bigger storage roots, which are processed and eaten by humans (Salick *et al*., 1997). Majority of cassava farmers in Ibadan planted only for the roots and intercropped cassava with short-term crops mostly maize, according to the findings of this study's survey. This was similar to the findings of Makinde and Ayoola (2007), who found that cassava farmers in south western Nigeria intercropped cassava with a variety of crops. Cassava (Manihot spp.) is one of Nigeria's key basic food crops, alongside yams, rice, maize, sorghum, and millet and it is primarily produced with several other crops in the tropics, according to NEEDS (2004). Slant planting was used by many farmers on ridges. Not too many cassava farmers in Ibadan use mineral fertilisers and herbicides on their farms' soils.

5.2 Application of inorganic fertiliser and its resultant effects on cassava growth and yield

Cassava grows in diverse agro-ecological zones. In SSA, fertility of soil is thought to be declining, and inorganic fertiliser is required to sustain soil fertility in permanent agricultural systems like ours (Jonas *et al*., 2012). Despite the continued usage of land and production of cassava on marginal soils, inorganic fertiliser availability, profitability, and utilization have been low (El-Sharkawy, 2004). According to Howeler (2001), soils from the experimental fields used in this study were found to be adequate in exchangeable bases and micronutrients, had almost neutral pH values and are inherently low in available phosphorus, potassium and total nitrogen. This study therefore demonstrated the importance N, P and K in cassava production. Cassava feeds heavily on potassium, according to Nguyen *et al*. (2002), but it also needs nitrogen, phosphorus and micronutrients to achieve good yields. Apparently, mineral fetilisers applied were used up during the growing period of cassava.

Although no equivalent studies have been published for the improved cassava varieties employed in this study (TMS-IBA010040, TMS-IBA011412, TMS-IBA070593, and TMEB419), the findings conform to those reported for numerous other cassava varieties. Olojede *et al*. (2002) harvested 27.9 t ha^{-1} of FRY for NR 8420 and TMS 82/02033 in Southeastern Nigeria, with 3.82–7.32 roots per stand for them. In comparison to the local best, Baiyeri *et al*. (2008) harvested the most cassava roots $plant^{-1}$ and had the highest FRY per hectare.

In this study, the highest root output was obtained from plots where 500 kg NPK 15-15-15 ha^{-1} were applied. This was similar to Edet et al. (2013)'s findings, who obtained 33 t ha^{-1} cassava root production using 600 kg NPK 15-15-15 ha^{-1} under optimal management practices. Ukaoama and Ugbonnaya (2013) found a very high yield of 39.50 t ha^{-1} when NPK was sprayed at sufficiently high rates of 300 kg N/400 kg P/200 kg K/ha. In line with the results obtained from this study, Osundare (2014) also found that a careful and well-balanced mix of NPK 15-15-15 at 400 kg ha^{-1} gave a yield of 7.90 t ha^{-1} higher than the yield obtained from the application of N, P, K from single fertiliser sources, implying the necessity for a careful and balanced combination of these three nutrient elements to attain the desired level of cassava root production. Yomeni (2011) found that applying 400 kg NPK 15:15:15 ha^{-1} increased FRY by 67.06% and 46.47% in Onne and Ogurugu, respectively. Significant cassava growth cannot be achieved with NPK lower than 200 kg ha^{-1} (Macalou *et al*., 2018).

Inorganic fertiliser application increased fresh root production from 22.8 to 29.2 t ha^{-1}, according to Mathias and Kabambe (2015), whereas yield without fertiliser additions was 21 t ha^{-1}, implying that proper soil amendments improve root yield. They also discovered that inorganic fertiliser had a significant impact on branch $plant^{-1}$, root $plant^{-1}$, and root length, while manure had no effect. According to Aderi *et al*. (2010), morphotypes and fertiliser rates have a strong interaction, with all morphotypes having the highest root output at 300 kg ha^{-1}. Macalou *et al*. (2018) also found number of tuber per plant and fresh tuber yield increased by 49% and 133% respectively on the plot which received 300 kg ha^{-1} of NPK 15-15-15 compared to the controls.

In addition, Vinh and Phien (1998) found that using NPK fertilisers boosted cassava yields by 71–112% as compared to using no fertiliser. Also Enesi *et al*. (2021) evaluating TME419 and TMS581, found that as 75 kg N ha^{-1}, 20 kg P ha^{-1} were mixed with 90 (F1), 135 (F2), and 180 (F3) kg K ha^{-1}, respectively, fertiliser enhanced cassava RDM yields by 15.38%, 23.1% and 16.7%, respectively, when compared to control (F0). Hence, cassava root dry matter yielded to fertiliser application and RDMC is dependent on variety and location.

Phosphorus omission reduced fresh root yield when compared to complete nutrient fertiliser application across varieties. This agrees with the findings of Uwah *et al*. (2013), who found that applying N between 80 and 120 kg ha^{-1} and K at 80 kg ha^{-1} seems to be acceptable for best root output. Tewedros *et al*., 2021 found that the increamental rate of N from 40 kg ha^{-1} to 80 kg ha^{-1} resulted in a corresponding reduction in number of branch/plant and plant height whereas the application of P from 23 kg ha^{-1} to 46 kg ha^{-1}, no significant differences were observed.

Individual administrations of N, P, or K ferilisers boosted cassava production considerably, according to Wilson and Ovid (2008). Chua *et al*. (2020) discovered that applying 40, 80, or 120 kg K_2O ha^{-1} increased yield by up to 39% and 21% on cassava roots harvested respectively at 8 and 10 MAP, as compared to no fertiliser use. In the same vein, Suyamto and Howeler (2001) found that applying 50 kg ha^{-1} of KCl increased FRY of cassava from 11.88 to 18.42 t ha^{-1} than using solely N and P fertiliser and to produce an output of 28 t ha^{-1}, an average rate of 68 kg N, 45 kg P_2O_5, and 68 kg K_2O ha^{-1} is required.

Molina and El-Sharkawy (1995) discovered that moderate application of fertiliser (N, P, and K) produced the highest FRY, leaf area, and foliage and stem production. In the sokoto rock phosphate (SRP) plot, Ogeh and Adeoye (2012) discovered that the solitary cassava farming system produced the highest fresh root yield (38.27 t ha^{-1}) with 45 kg P_2O_5 ha^{-1}. In this study, plants in unfertilised plots did not lodged before harvest, thus, exhibited a high stem production. This conformed with the findings of Marino *et al*. (2009) who found that plants in unfertilised plots were considerably shorter than plants in fertilised plots, implying that as plant height increases, so does the likelihood of the plant lodging.

According to Aina *et al*. (2009), cassava varieties could be chosen for environmental adaptability due to the significant G x E effects for FRY. It also implies that variations in yield are tested in a variety of conditions in order to select good performance for certain environments (Maroya *et al*., 2012). According to Peprah *et al*.

(2013), evaluating dry matter content may be done efficiently in fewer environments, whereas identification of varieties for high fresh root yield requires multiple environments. The environment has a big impact on fresh root output, which is a polygenic character (Cach *et al*., 2006). Varieties perform differently in each location; genotypic differences between varieties investigated at different locations are an evidence of this.

5.3 Effects of stem portions and lenghts of stem cuttings on growth and yield of cassava

According to Tongglum *et al*. (2001), stakes 15–20 cm long had 73.7 to 95.0% sprouting, while stakes 5–10 cm long had only 59.9% sprouting. In this study, plots with a 30 cm long basal stem portion yielded similar results. This was further supported by Oka *et al*. (1986), who discovered that cuttings made from the basal and mid parts of the stem germinated at a considerably faster rate than cuttings made from the top part of the stem. This means that stem cuttings taken from the stem's base will have a better chance of preserving their viability, establishing more quickly, and yielding well than those from the mid and top part of the stem, which have a lower plant survival rate and are more prone to dryness and pathogen invasion. Similar findings were reported by Onwueme and Sinha (1991).

Due to its limited sprouting potential, the top stem, which is 15 cm long, was unable to utilize available soil nutrients for its growth. Because many plants in the plots did not survive; the highest score for stem girth was recorded. According to Yomeni (2011), in the field, there is low sprouting probability of shorter cuttings due to quick dryness. However, Okpara *et al*. (2022) reported that at 3 MAP, percent establishment, plant height, and leaf area index significantly increase by planting the middle and basal stem portions, but there was little effect on the number of store roots plant^{-1}. The top portion of the stem, however, was the best for storage root yield, yielding the highest on average but rooting in mist chamber before transplanting is recommended.

Longer cuttings, according to Lahai *et al*. (2013), formed a canopy that grew quickly. When planting for RDMC and FRY, the basal and mid stem portions, both 30 cm long could be used. These findings backed up Eze and Ugwuoke's (2010) findings that the traditional cassava planting material is chosen because of its ease of establishment, post-plant survival, and high yield. However, cassava farmers need regular access to high quality planting materials of improved varieties. In terms of retention of dry matter in storage root and final harvest, Bridgemohan and Bridgemohan (2014) found that stem cuttings with three nodes was superior to one node. To have the best output, Carvahlo *et al*. (1993) suggested using stem cuttings with 57% nodes and a minimum length of 20 cm. The increase in yield due to fertiliser treatment was outweighed by the quality of stem cuttings (Molina and El-Sharkawy, 1995).

The fact that CAD has a greater impact on vigorous plants could explain the positive correlation between FRY and CAD severity. This was similar to Ssemakula and Dixon's findings (2007). CBB severity and fresh root yield had a significantly negative relationship. This supported the findings of Ikotun *et al*. (2000) and explained the detrimental influence of disease and pest on fresh root output. Number of leaves/plant and LAI had less significant influence on fresh root yield. Similar relationships were found by Lahai *et al*. (2013) and Lebot (2009), although Ntawuruhunga et al. (2001) discovered that storage root weight and storage root number have a significant negative relationship. There was a favourable association between plant height and the number of plants gathered per plot. This matched the report of Iwo *et al*. (2012), who showed that number of stems per stand and nodes per stem were positively correlated.

The GGE biplot is a useful tool for crop variety release decision-making since it enables to identify stable and best-performing varieties in test situations (Farshadfar *et al*., 2013). Ibadan 16 was the optimal environment which had a long vector length (discriminating ability) and a modest angle (representativeness) to the average environment axis (AEA). In terms of FRY, IBA010040 was selected as a superior genotype that can consistently perform in a variety of settings. Agyemen *et al*. (2015) and Aina *et a*l. (2010) found similar results. Uchendu *et al*., 2022 observed GEI effects for all the traits measured which lead to average ranks of the genotypes in varying environments.

CHAPTER SIX

SUMMARY, CONCLUSION AND RECOMMENDATIONS

6.1 Summary and conclusion

In the tropics, cassava (*Manihot esculenta* Crantz) is an extensively produced food security crop and Nigeria is currently its world greatest grower. A defect in awareness of the elements that govern stem and root production of cassava in Nigeria has made demand to surpass availability for this commodity. Between 2014 and 2016, a survey and multi-locational trials were carried out to examine production techniques in existence and compare compound fertiliser application to single element fertiliser treatment just to improve crop productivity. The effects of omitting Nitrogen, Phosphorus and Potassium, and also stem portions and stem cutting lengths, on the growth and yield of four cassava varieties, were studied.

Survey of ninety cassava growers in three local governments in Ibadan was conducted to assess their agronomic practices and farming systems. Different fertiliser types and rates at two rates of application (45 and 75 kg ha^{-1}) of N, P_2O_5 and K_2O and three stem cutting parts (Basal, mid and top) and two lengths (15 and 30 cm) were tested so as to determine which could give increased productivity. Four Improved cassava varieties comprising of two yellow roots (TMS-IBA011412 and TMS-IBA070593) and two white roots (TMS-IBA010040 and TMEB419) were evaluated at two cassava growing agro-ecological zones which are Ibadan, Ikenne and Tsonga between April, 2014 and August, 2016. In three replicates, the experimental design was factorial in RCBD.

This study has revealed significant differences in variety performances to fertiliser applications and stem cutting parts and lengths with respective to location. This suggests the magnitude of inherent variation among the cassava varieties evaluated, thus providing basis for genetic improvement of each variety for these environments. However, the extremely significant influence of genotype by environment interaction on yield and related attributes indicated that the environment had an impact on growth and productivity of cassava. The conclusions of the study are summarized as follows:

i. High variation in growth and productivity of cassava crop in farmers' farm and researchers' field is basically due to inadequate agronomic practices and poor farming systems.

ii. Cassava varieties and each fertiliser type grew and yielded more than the control, and omitting N and K in relation to P results in low cassava root yield and yield components.

iii. Stems of fertilised cassava plant should be cut for planting between 8 – 10 MAP because of early maturity and high ratio of root to biomass which may lead to lodging.

iv. Cassava varieties growth and yield are influencd by environment. Ikenne had the best growth and yield of cassava varieties followed by Ibadan and Tsonga. Tsonga was good for white roots genotype but not favourable for yellow roots especially TMS-IBA070593.

v. Basal and mid stem cutting portions was consistently better than top and 30 cm cuttings was preferred to 15 cm in all the growth and yield indices.

6.2 Recommendations

This study recommends that for increase productivity of cassava;

i. Cassava farmers in Oyo State should improve on their agronomic and farming systems.

ii. NPK 15:15:15 at 75 kg N, P_2O_5 and K_2O ha^{-1} should be applied to TMEB419 in derived savanna.

iii. Urea+KCl at 75 kg N, P_2O_5 and K_2O should be applied to IBA011412 in rain forest ecology.

iv. A 30 cm basal stem portion should be adopted for planting.

6.3 Contributions to knowledge

i. Majority of cassava farmers in Oyo State does not apply fertiliser to the soil and always intercrop cassava. These explain the high variation in growth and productivity of cassava crop in farmers' farm and researchers' field.

ii. The application of compound fertiliser boosted the storage root production of white cassava varieties in the Derived Savanna while yellow cassava roots yielded more in Rain-Forest. Therefore, agro-ecology influenced response of cassava varieties to fertiliser application.

iii. This study discovered that applying NPK fertiliser to cassava varieties improved yield and yield components of cassava varieties and its equivalent single element fertiliser. Hence, omission of N, P or K fertiliser was discouraged.

iv. Stem and root production in quantity and quality would meet required needs if 30 cm basal stem portion is adopted.

However, the further study on this theme of suitable fertiliser formulations, fertiliser rates and stem portions and lengths of stem cutting would be to have a series of fertilisers along with a series of stem properties.

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APPENDICES

Appendix 1 Questionnaires for cassava producers

1. Local Government Area: ______________

2. Town/Village: _________________

3. Farm Size: (a)……… acres (b)…….. hectares

4. For what purpose do you produce cassava? (a) Consumption at home (b) Sale (c) Both (d) Other (specify).

5. How do you prepare your land? (a) By hand (hoe & cutlass) (b) By machine (tractor) (c) Others (specify)

6. Planting of your cassava cuttings was done on what? (a) heaps (b)Ridges (c) Flat (d) Others (specify)

7. How long (cm) was your cassava cutings? (a) 10 (b) 20 (c) 30 (d) others (specify)

8. What portion of cassava stem cutings do you plant? (a) Upper (b) Middle (c) Lower (d) others (specify)

9. How do you plant your cassava? (a) Total bury (b) Slanting (c) vertical (d) others (specify)

10. Do you intercrop cassava? List the crops: ______________________

11. At what spacing (m^2) did you plant your crop? (a) 1× 1 (b) 1 × 0.5 (c) Irregular (d) Others

12. How do you control weeds? (a) by hoe (b) using herbicide (c) Integrated (Both)

13. What part of mature cassava plant do you sell? (a) Leaves (b) Stems (c) Roots (d) Combination (e) Others (specify)

14. Do you ratoon cassava?

15. If yes, at what age? (a) 6 months (b) 9 months (c) 12 months (d) others

16. At what height? (a) 20 cm (b) 30 cm (c) 40 cm (d) > 40 cm

17. Do you apply fertiliser?

18. If yes, what quantity do you apply (how many bags)?

19. What fertiliser do you apply to your soil? (a) Inorganic (b) Organic (c) others (specify)

20. How do you apply it? (a) Broadcast (b) Ring method (c) Side placement (d) Others (specify)

21. Do you keep cassava stem after harvest?

22. If yes, where did you keep your cassava stem?

23. How long do you keep your cassava stems after harvest? (a) less than 1 week (b) 1-2 weeks (c) less than 1 month (d) more than 1 month (e) others (specify)

Appendix 2 Soil properties at planting and after harvest of cassava varieties at Ibadan, Ikenne and Tsonga in 2014/2015 planting season

	Ibadan			Ikenne			Tsonga		
Soil properties	at planting	after harvest	% reduction	at planting	after harvest	% reduction	at planting	after harvest	% reduction
pH (H_2O)	6.7	5.6	16.4	5.6	5.4	3.6	6.0	5.8	4.2
pH (KCl)	4.5	4.2	6.7	4.1	3.9	4.9	3.8	3.6	5.3
Organic Carbon (g/kg)	0.78	1.15	-46.79	0.77	1.07	-38.96	0.62	0.56	10.48
Total N (g/kg)	0.07	0.12	-71.53	0.07	0.09	-30.56	0.02	0.05	-130.43
Av. P (mg/kg)	10.76	0.11	99.02	2.66	9.43	-254.51	11.80	22.33	-89.24
Exchangeable bases (cmol/kg)									
Ca	5.14	2.63	48.83	1.97	2.31	-17.26	1.38	3.10	-124.46
Mg	0.79	0.24	70.25	0.80	1.33	-66.25	0.40	0.65	-63.50
K	0.15	0.15	0.00	0.26	0.15	42.31	0.07	0.11	-59.62
Na	0.07	0.08	-14.29	0.09	0.09	0.00	0.08	0.08	2.14
Exc. Acidity	0.09	0.00	100.00	0.02	0.25	-1150.00	0.00	0.00	0.00
ECEC	6.25	3.10	50.40	3.13	4.13	-31.79	1.93	3.94	-104.23
Micronutrients (mg/kg)									
Zn	74.45	56.23	24.47	12.62	5.82	53.92	5.63	17.26	-206.50
Cu	2.19	2.02	7.76	2.66	1.65	37.97	6.21	1.22	80.43
Mn	52.86	26.44	49.99	42.25	15.35	63.68	45.05	43.92	2.52
Fe	129.21	88.33	31.64	89.24	20.26	77.30	69.77	55.09	21.04
Particle size distribution (%)									
Sand	74.00	73.00	1.35	79.00	77.00	2.53	82.00	82.00	0.00
Silt	10.00	12.00	-20.00	9.00	5.00	44.44	8.00	8.00	0.00
Clay	16.00	15.00	6.25	12.00	18.00	-50.00	10.00	10.00	0.00
Textural classification	Sandy loam	Sandy loam		Sandy loam	Sandy loam		Sandy loam	Sandy loam	

Appendix 3 Soil properties at planting and after harvest of cassava varieties at Ibadan, Ikenne and Tsonga during 2015/2016 planting season

	Ibadan			Ikenne			Tsonga		
Soil properties	at planting	after harvest	% reduction	at planting	after harvest	% reduction	at planting	after harvest	% reduction
pH (H_2O)	6.6	6.7	-0.8	5.4	5.1	6.5	6.0	6.1	-0.8
pH (KCl)	4.8	5.6	-16.7	4.4	4.1	8.0	4.3	4.8	-10.5
Organic Carbon (g/kg)	1.36	1.10	19.10	1.32	1.53	-15.91	0.56	0.56	0.00
Total N (g/kg)	0.132	0.16	-19.79	0.122	0.67	-446.63	0.05	0.04	15.83
Av. P (mg/kg)	11.28	3.45	69.44	7.28	5.11	29.75	22.33	7.71	65.48
Exchangeable bases (cmol/kg)									
Ca	2.47	2.12	13.99	2.34	0.96	58.87	3.06	0.78	74.51
Mg	0.79	0.85	-7.48	1.3	0.38	70.96	0.55	0.25	54.55
K	0.25	0.07	70.04	0.09	0.08	16.67	0.24	0.06	77.08
Na	0.15	0.08	50.00	0.09	0.07	27.78	0.08	0.07	12.50
Exc. Acidity	0	0.00	0.00	0.23	0.28	-19.57	0.00	0.00	0.00
ECEC	3.66	3.13	14.62	4.05	1.76	56.54	3.92	1.17	70.28
Micronutrients(mg/kg)									
Zn	23.23	84.25	-262.68	7.84	37.73	-381.26	14.05	11.57	17.68
Cu	1.95	3.40	-74.36	0.71	3.83	-439.94	0.92	2.09	-127.56
Mn	131.3	162.07	-23.44	5.48	22.58	-312.12	54.02	112.89	-108.98
Fe	62.35	108.13	-73.42	47.86	176.68	-269.15	48.92	111.73	-128.40
Particle size distribution (%)									
Sand	70.00	74.60	-6.57	74.00	68.80	7.03	80.00	81.80	-2.25
Silt	13.00	10.00	23.08	5.00	8.00	-60.00	10.00	8.00	20.00
Clay	17.00	16.00	5.88	21.00	24.00	-14.29	10.00	11.00	-10.00
Textural classification	Sandy loam	Sandy loam		Sandy loam	Sandy loam		Sandy loam	Sandy loam	

Appendix 4 Fertiliser types used in this study

A: NPK 15:15:15
B: Urea
C: Potassium Chloride (KCl)
D: Triple superphosphate (TSP)

Appendix 5 Nutrient content of fertilisers used in this study

Nutrient content	N	P_2O_5	K_2O
Fertiliser		(%)	
NPK 15-15-15	14.65	15.25	15.57
Urea	45.75	0	0
Triple superphosphate (TSP)	0.25	45.73	1
Potassium chloride (KCl)	0.32	0.05	60

Appendix 6 Monthly rainfall, solar radiation, minimum and maximum temperature and relative humidity during field trials at Ibadan, Nigeria

Month	Rainfall (mm)	Solar Rad (MJ/m²/day)	Temperatures (°C) Minimum	Temperatures (°C) Maximum	Relative humidity (%)
2014/2015					
May	178.10	18.21	22.80	31.72	75.48
June	367.15	16.92	22.62	30.51	78.83
July	324.20	14.95	22.55	28.53	79.79
August	98.60	11.81	21.55	26.95	82.34
September	134.15	13.81	22.08	28.58	79.15
October	177.05	15.02	21.96	30.06	76.26
November	49.10	14.96	22.77	31.36	70.05
December	0.00	15.90	21.47	32.47	57.98
January	0.00	15.71	19.63	33.21	49.85
February	37.95	16.30	24.02	34.61	60.61
March	62.90	15.69	24.15	34.96	57.71
April	115.55	18.43	23.54	34.08	61.22
Mean	128.73	15.64	22.43	31.42	69.11
SE (±)	34.04	0.52	0.36	0.74	3.18
CV (%)	91.61	11.55	5.52	8.21	15.95
2015/2016					
May	159.40	17.09	23.12	32.49	69.26
June	207.65	15.32	22.60	29.96	73.22
July	137.35	13.49	22.29	29.11	73.74
August	98.35	12.03	22.23	28.42	76.08
September	329.70	13.20	21.95	28.98	76.67
October	124.75	14.97	22.47	30.77	74.35
November	9.85	15.06	23.12	32.25	64.78
December	0.00	17.56	18.50	32.88	46.52
January	11.10	16.13	20.84	33.62	53.58
February	0.00	16.69	22.83	35.87	63.72
March	184.90	13.46	24.12	33.83	77.77
April	192.70	17.55	23.92	33.06	80.47
Mean	121.31	15.21	22.33	31.77	69.18
SE (±)	29.68	0.54	0.43	0.67	2.98
CV (%)	84.75	12.19	6.66	7.26	14.94

SE: Standard error, CV: Coefficient of variation

Source: GIS unit, IITA

Appendix 7 Monthly rainfall, solar radiation, minimum and maximum temperature and relative humidity during field trials at Ikenne, Nigeria

Month	Rainfall (mm)	Solar Rad (MJ/m²/day)	Temperature (°C)		Relative humidity (%)
			Minimum	Maximum	
2014/2015					
August	143.89	12.46	24.11	26.21	86.62
September	279.49	12.98	24.24	26.39	88.75
October	182.29	15.22	25.24	27.48	86.24
November	139.40	15.47	26.00	28.26	84.09
December	15.61	17.29	26.05	29.48	77.20
January	6.39	17.50	24.45	29.11	70.42
February	42.32	15.30	26.60	29.25	83.08
March	85.18	14.75	26.99	29.45	82.60
April	59.39	18.49	27.07	29.13	83.00
May	141.83	15.36	27.15	28.98	83.84
June	252.97	10.53	25.70	27.39	86.17
July	102.48	12.61	24.87	26.87	86.40
Mean	120.94	14.83	25.70	28.17	83.20
SE (±)	25.14	0.68	0.32	0.36	1.43
CV (%)	72.02	15.77	4.36	4.39	5.97
2015/2016					
August	81.15	12.51	24.26	26.43	88.44
September	171.27	11.98	24.66	26.75	88.59
October	285.83	15.37	25.64	27.64	87.12
November	53.88	16.40	26.34	28.67	83.11
December	0.00	17.98	24.29	28.93	65.48
January	9.71	17.08	25.09	29.75	70.67
February	6.92	16.95	26.13	30.18	81.23
March	93.68	14.86	27.64	30.27	81.68
April	96.97	18.22	27.37	29.72	83.52
May	204.93	14.93	26.90	28.99	83.74
June	222.49	11.44	25.77	27.70	84.63
July	120.24	12.71	23.98	25.70	84.87
Mean	112.25	15.04	25.67	28.39	81.92
SE (±)	26.63	0.69	0.36	0.44	2.01
CV (%)	82.17	15.87	4.85	5.40	8.51

SE: Standard error; CV: Coefficient of variation
Source: GIS unit, IITA, Ibadan

Appendix 8 Monthly rainfall, solar radiation, minimum and maximum temperature and relative humidity during field trials at Tsonga, Nigeria

Month	Rainfall (mm)	Solar Rad (MJ/m²/day)	Temperature (°C)		Relative humidity (%)
			Minimum	Maximum	
2014/2015					
July	173.95	17.29	22.20	30.72	75.40
August	226.21	15.17	21.33	28.77	81.36
September	293.16	16.73	21.42	28.99	81.17
October	145.18	19.39	21.95	31.34	75.27
November	37.22	18.33	22.57	34.98	58.64
December	0.00	19.01	21.10	36.64	35.27
January	0.00	18.62	19.44	35.90	29.93
February	5.40	16.99	23.83	35.94	53.05
March	42.48	18.01	24.24	36.11	52.43
April	14.58	21.62	24.17	36.80	51.79
May	175.64	18.87	24.17	34.93	62.31
June	101.63	17.24	22.68	30.60	77.78
Mean	101.29	18.11	22.42	33.48	61.20
SE (±)	28.86	0.47	0.43	0.90	5.05
CV (%)	98.71	8.95	6.67	9.31	28.60
2015/2016					
July	150.75	16.52	22.20	30.59	76.32
August	221.40	14.01	21.95	28.53	83.60
September	148.56	16.61	22.06	29.14	83.45
October	87.83	18.67	22.52	31.37	76.87
November	1.93	18.96	22.61	35.35	55.27
December	0.00	19.05	18.79	35.35	27.37
January	0.00	18.58	19.88	36.65	27.44
February	0.00	19.56	22.41	38.40	32.21
March	39.02	18.46	25.15	37.42	53.84
April	81.79	21.53	24.89	36.82	58.67
May	138.80	19.50	24.14	35.70	61.58
June	248.93	17.16	22.87	32.14	70.87
Mean	93.25	18.22	22.46	33.96	58.96
SE (±)	25.62	0.55	0.53	0.99	5.98
CV (%)	95.17	10.51	8.14	10.05	35.15

Source: GIS unit, IITA, Ibadan

Appendix 9 Mean effects of fertiliser application, cassava varieties and environment on plant sprout, vigour, disease severity and incidence at Ibadan, Ikenne and Tsonga in 2014/2015 and 2015/2016 planting seasons

Fertiliser type	Fertiliser rate (kg ha^{-1})	Sprout	Vigour	CMD severity	CMD incidence	CAD severity	CAD incidence
Control	0	0.86	5.33	1.40	0.09	1.62	0.27
NPK 15:15:15	45	0.88	5.44	1.41	0.07	1.64	0.26
NPK 15:15:15	75	0.84	5.33	1.43	0.07	1.58	0.27
TSP+Urea (-K)	45	0.88	5.33	1.38	0.07	1.61	0.25
TSP+Urea (-K)	75	0.87	5.44	1.46	0.08	1.63	0.26
KCl+Urea (-P)	45	0.89	5.56	1.42	0.07	1.58	0.26
KCl+Urea (-P)	75	0.85	5.48	1.34	0.07	1.56	0.28
KCl+ TSP (-N)	45	0.88	5.28	1.38	0.07	1.59	0.25
KCl+TSP (-N)	75	0.87	5.81	1.48	0.09	1.63	0.26
Mean		0.87	5.45	1.41	0.07	1.61	0.26
Minimum		0.84	5.28	1.34	0.07	1.56	0.25
Maximumm		0.89	5.81	1.48	0.09	1.64	0.28
SE(±)		0.00	0.04	0.01	0.00	0.01	0.00
Genotype							
IBA010040		0.78	4.93	1.55	0.09	1.60	0.28
IBA011412		0.93	5.55	1.21	0.04	1.53	0.26
IBA070593		0.82	5.16	1.23	0.08	1.48	0.23
TMEB419		0.94	6.15	1.66	0.09	1.82	0.29
Means		0.87	5.45	1.41	0.07	1.61	0.26
SE(±)		0.04	0.27	0.11	0.01	0.07	0.01
Environment							
Ibadan15		0.91	5.97	1.86	0.11	2.45	0.66
Ibadan16		0.96	4.50	1.70	0.21	2.52	0.67
Ikenne15		0.86	5.37	1.70	0.11	1.53	0.23
Ikenne16		0.88	5.94	1.11	0.01	1.15	0.02
Tsonga15		0.77	6.20	1.10	0.01	1.00	0.00
Tsonga16		0.81	4.71	1.00	0.00	1.00	0.00
Means		0.87	5.45	1.41	0.07	1.61	0.26
SE(±)		0.03	0.29	0.15	0.03	0.29	0.13
Fertiliser		ns	ns	ns	ns	ns	ns
Rate		**	ns	ns	ns	ns	*
Genotype		***	***	***	***	***	ns
Fertiliser x Rate		ns	**	*	ns	ns	ns
Environment		***	***	***	***	***	***

Appendix 10 Mean effects of fertiliser application, cassava varieties and environment on fresh and dry root yield, fresh stem yield (t ha^{-1}) at Ibadan, Ikenne and Tsonga in 2014/2015 and 2015/2016 planting seasons

Fertiliser type	Fertiliser rate (kg ha^{-1})	Ibadan			Ikenne			Tsonga		
		FRY	FSY	DRY	FRY	FSY	DRY	FRY	FSY	DRY
Control	0	15.15	21.22	3.82	19.85	27.04	6.64	6.96	10.49	1.13
NPK 15:15:15	45	16.17	25.38	4.22	20.67	29.99	6.33	11.79	15.94	2.07
NPK 15:15:15	75	19.54	29.13	4.85	24.97	32.07	7.67	13.03	14.49	2.10
TSP+KCl (-N)	45	13.99	23.02	3.55	20.74	29.74	6.52	7.35	11.95	1.22
TSP+KCl (-N)	75	14.67	21.49	3.55	18.65	30.17	5.76	9.68	11.45	1.53
Urea+KCl (-P)	45	16.06	25.73	4.04	20.61	30.72	6.24	7.68	11.6	1.30
Urea+KCl (-P)	75	19.51	30.87	4.90	22.42	31.1	6.36	9.03	12.16	1.51
Urea+TSP (-K)	45	16.96	25.07	4.33	21.68	28.44	6.49	8.32	13.34	1.55
Urea+TSP (-K)	75	17.81	27.15	4.52	22.32	28.24	7.18	9.22	10.99	1.57
Mean		16.66	25.82	4.19	21.24	30.02	6.53	9.49	12.75	1.57
Minimum		13.99	21.22	3.55	18.65	27.04	5.76	6.96	10.49	1.13
Maximum		19.54	30.87	4.90	24.97	33.78	7.18	13.03	15.94	2.10
Standard error (±)		0.54	0.94	0.16	0.5	0.57	0.41	0.61	0.54	0.29
Coefficient of variation (%)		10.68	12.01	2.07	7.86	6.30	4.45	21.50	14.20	5.73

Appendix 11 Effects of fertiliser application on fresh root, fresh shoot and dry root yield (t ha^{-1}) of cassava varieties in each location in 2014/2015 planting season

Fertiliser type	Fertiliser rate (kg ha^{-1})	No of roots /plot	FRY	DRY	Fresh leaf yield	Fresh stem yield
Control	0	36.84	14.00	3.77	4.93	9.27
NPK 15:15:15	45	40.62	16.06	4.23	6.15	12.02
NPK 15:15:15	75	41.29	17.51	4.93	6.26	12.41
Urea+TSP(-K)	45	37.36	13.89	3.72	5.30	10.08
Urea+TSP (-K)	75	35.05	14.05	3.77	5.26	10.15
Urea+KCl (-P)	45	38.73	15.73	4.49	5.89	11.69
Urea+KCl (-P)	75	37.39	16.35	4.43	6.45	13.16
TSP+KCl (-N)	45	36.92	15.67	4.33	5.95	11.47
TSP+KCl (-N)	75	39.70	16.07	4.61	6.00	11.20
Means		38.07	15.67	4.33	5.93	11.63
Maximum		41.29	17.51	4.93	6.84	14.06
Minimum		35.05	13.89	3.72	4.93	9.27
SE(±)		0.57	0.36	0.13	0.17	0.43
Genotype						
IBA010040		45.36	17.76	4.79	6.59	11.24
IBA011412		36.62	19.38	4.50	7.21	13.29
IBA070593		33.06	12.39	3.59	5.11	10.22
TMEB419		36.77	12.72	4.24	4.78	11.68
Means		37.95	15.56	4.28	5.92	11.61
SE(±)		2.61	1.77	0.26	0.58	0.64
Environment						
Ibadan15		43.01	16.66	4.13	6.27	14.15
Ibadan16		48.62	15.47	3.64	6.82	10.71
Ikenne15		36.79	21.24	6.32	8.05	15.99
Ikenne16		35.78	17.19	4.74	3.72	14.55
Tsonga15		29.17	9.28	1.70	5.45	5.08
Tsonga16		33.85	12.96	4.17	5.25	8.81
Means		37.87	15.47	4.21	5.93	11.55
SE(±)		2.82	1.66	0.74	0.60	1.69
Pr.>Fertiliser		*	***	**	***	***
Pr.>Rate		ns	ns	ns	ns	**
Pr.>Genotype		***	***	***	***	***
Pr.>FertxRate		ns	ns	ns	ns	ns
Pr.>Environment		**	***	***	**	***

Appendix 12 Mean yield (t ha^{-1}) performance of cassava varieties as influenced by each location in 2014/2015 planting season

	Ibadan			Ikenne			Tsonga		
Genotype	FRY	FSY	DRY	FRY	FSY	DRY	FRY	FSY	DRY
IBA010040	18.74	25.07	4.81	24.25	27.90	7.27	6.04	11.06	1.06
IBA011412	21.28	27.07	4.20	27.29	33.41	6.90	11.12	13.93	1.43
IBA070593	13.09	26.02	3.43	18.56	30.73	6.02	0.77	2.90	0.11
TMEB419	13.04	23.60	3.77	14.42	27.05	5,23	13.92	19.91	2.86
Mean	16.54	25.44	4.05	21.13	29.77	6.36	7.96	11.95	1.37
SE±	2.07	0.74	1.94	2.88	1.45	2.31	2.90	3.54	1.79
CV (%)	25.04	5.79	15.44	27.23	9.71	14.88	72.83	59.17	22.22

Appendix 13 Mean effects of fertiliser application and cassava varieties on FRY (t ha^{-1}) at Ibadan, Ikenne and Tsonga in 2014/2015 and 2015/2016 planting season

SN	Genotype	Fert type	Fert rate	Ibadan	Ikenne	Tsonga	Trt mean
1	I010040	Control	0	15.33	18.40	11.75	15.16
2	I010040	NPK 15:15:15	45	18.61	19.50	16.29	18.13
3	I010040	NPK 15:15:15	75	20.01	25.99	7.81	17.94
4	I010040	TSP_KCl	45	18.40	27.86	10.94	19.07
5	I010040	TSP_KCl	75	20.28	25.36	11.63	19.09
6	I010040	Urea_KCl	45	19.81	26.74	10.71	19.08
7	I010040	Urea_KCl	75	22.57	18.28	11.24	17.36
8	I010040	Urea_TSP	45	20.21	19.47	9.36	16.35
9	I010040	Urea_TSP	75	18.50	20.28	9.29	16.02
10	I011412	Control	0	17.63	18.89	11.99	16.17
11	I011412	NPK 15:15:15	45	24.76	25.39	12.51	20.89
12	I011412	NPK 15:15:15	75	21.29	29.17	15.24	21.90
13	I011412	TSP_KCl	45	19.96	25.75	11.67	19.13
14	I011412	TSP_KCl	75	19.42	24.75	14.39	19.52
15	I011412	Urea_KCl	45	21.61	24.00	13.93	19.85
16	I011412	Urea_KCl	75	20.31	29.36	8.90	19.52
17	I011412	Urea_TSP	45	21.22	22.33	10.63	18.06
18	I011412	Urea_TSP	75	19.89	22.06	9.94	17.30
19	I070593	Control	0	17.54	9.92	3.38	10.28
20	I070593	NPK 15:15:15	45	16.56	13.89	1.40	10.62
21	I070593	NPK 15:15:15	75	16.51	17.42	1.04	11.66
22	I070593	TSP_KCl	45	15.38	15.72	1.03	10.71
23	I070593	TSP_KCl	75	16.39	18.28	0.88	11.85
24	I070593	Urea_KCl	45	15.08	18.56	1.56	11.73
25	I070593	Urea_KCl	75	15.29	20.18	3.06	12.84
26	I070593	Urea_TSP	45	13.51	10.75	1.29	8.52
27	I070593	Urea_TSP	75	11.14	11.81	1.25	8.06
28	TMEB419	Control	0	11.63	12.78	13.89	12.76
29	TMEB419	NPK 15:15:15	45	9.07	11.89	17.50	12.82
30	TMEB419	NPK 15:15:15	75	11.49	13.81	18.54	14.61
31	TMEB419	TSP_KCl	45	9.65	14.97	14.33	12.99
32	TMEB419	TSP_KCl	75	8.06	12.00	16.14	12.06
33	TMEB419	Urea_KCl	45	6.88	13.89	13.72	11.50
34	TMEB419	Urea_KCl	75	9.24	15.92	15.19	13.45
35	TMEB419	Urea_TSP	45	9.10	10.28	14.06	11.14
36	TMEB419	Urea_TSP	75	10.21	11.33	12.21	11.25
			Minimum	6.88	9.92	0.88	8.06
			Maximum	24.76	29.36	18.54	21.90
			Loc mean	16.07	19.26	10.21	15.18
			SE(±)	0.69	0.88	0.84	0.58
			CV (%)	28.50	30.17	54.49	25.15

Appendix 14 Yield and related components as influenced by stem portion and lengths of stem cutting in 2014/2015 planting season

Stem portion	Stem length (cm)	Sprout	Vigour	CMD severity	CBB severity	Root number /plant	Fresh rt yld (t ha^{-1})	Sht yield (t ha^{-1})	Dry rt yld (t ha^{-1})	Harvest Index
Basal	15	0.82	5.56	1.42	2.43	22.86	16.68	15.88	3.99	0.47
Basal	30	0.94	6.17	1.36	2.61	29.72	18.85	23.08	4.65	0.45
Top	15	0.47	4.23	1.26	2.21	15.50	13.62	14.17	3.29	0.44
Top	30	0.71	5.06	1.48	2.47	22.30	18.14	17.90	4.45	0.46
Mid	15	0.67	4.89	1.35	2.44	21.91	16.75	17.17	4.23	0.47
Mid	30	0.85	5.67	1.31	2.51	24.69	19.41	19.52	4.80	0.46
Mean		0.74	5.26	1.36	2.45	22.83	17.24	17.95	4.24	0.45
Minimum		0.47	4.23	1.26	2.21	15.50	13.62	14.17	3.29	0.44
Maximum		0.94	6.17	1.48	2.61	29.72	19.41	23.08	4.80	0.47
SE±		0.07	0.28	0.03	0.05	1.88	0.85	1.26	0.22	0.01
CV (%)		22.03	12.91	5.47	5.50	20.15	12.11	17.25	12.84	4.38
$P \leq F$		ns	Ns	*	ns	ns	ns	ns	ns	ns

*: significant at p≤0.05 probability level, ns: not significant

Appendix 15 Yield and related components as influenced by cassava varieties and lengths of stem cutting in 2014/2015 planting season

Genotype	Stem length (cm)	Sprout	Vigour	CMD severity	CBB severity	Root Number /plant	Fresh rt yld (t/ha)	Sht yield (t/ha)	Dry rt yld (t/ha)
IBA010040	15	0.50	4.26	1.35	2.28	22.23	17.95	15.42	4.12
IBA010040	30	0.77	4.85	1.44	2.41	29.74	23.55	20.16	5.64
IBA011412	15	0.79	5.32	1.18	2.42	23.08	20.22	18.15	3.96
IBA011412	30	0.91	5.96	1.22	2.70	27.63	21.69	22.53	4.19
IBA070593	15	0.61	4.17	1.17	2.25	17.52	11.66	13.38	3.08
IBA070593	30	0.77	5.46	1.19	2.50	23.13	17.16	19.37	4.44
TMEB419	15	0.77	5.89	1.68	2.50	18.04	12.45	15.82	3.61
TMEB419	30	0.88	6.26	1.67	2.52	21.89	12.54	18.71	3.72
Mean		0.75	5.27	1.36	2.45	22.91	17.15	17.94	4.09
Minimum		0.50	4.17	1.17	2.25	17.52	11.66	13.38	3.08
Maximum		0.91	6.26	1.68	2.70	29.74	23.55	22.53	5.64
SE (±)		0.05	0.28	0.08	0.05	1.48	1.61	1.04	0.27
CV (%)		18.15	14.83	15.70	5.90	18.32	26.55	16.37	18.32
Pr ≤ F		*	**	ns	ns	ns	*	ns	ns

*: significant at p≤0.05, **: significant at p≤0.001 probability level

Appendix 16 Effects of stem portion and lenghts of stem cutting on FRY, FSYand DRY of cassava varieties in each location in 2014/2015 planting season

Stem portion	Stem length (cm)	Ibadan			Ikenne			Tsonga		
		FRY	FSY ($t\ ha^{-1}$)	DRY	FRY	FSY ($t\ ha^{-1}$)	DRY	FRY	FSY ($t\ ha^{-1}$)	DRY
Basal	15	16.95	18.47	4.13	25.48	19.65	7.89	6.77	9.53	1.11
Basal	30	24.39	29.64	6.23	21.96	25.14	6.74	9.41	14.47	1.61
Top	15	10.25	12.65	2.26	22.40	20.59	6.61	4.66	6.45	0.85
Top	30	21.88	22.09	5.41	22.17	21.29	6.66	7.81	8.79	1.32
Mid	15	19.34	19.53	4.79	22.10	20.58	7.05	7.21	10.23	1.30
Mid	30	22.30	23.66	5.89	26.42	23.88	7.97	8.63	11.02	1.46
Mean		19.18	21.01	4.79	23.42	21.86	7.15	7.41	10.08	1.28
Minimum		10.25	12.65	2.26	21.96	19.65	6.61	4.66	6.45	0.85
Maximum		24.39	29.64	6.23	26.42	25.14	7.97	9.41	14.47	1.61
SE (±)		2.07	2.32	0.60	0.81	0.88	0.34	0.67	1.08	0.26
CV (%)		26.46	27.02	6.00	8.48	9.88	2.74	22.29	26.35	3.84
$Pr \leq F$		***	***	***	***	***	***	***	***	***

***: Significant at $p \leq 0.001$

Appendix 17 ADC Bioscience leaf area metre used to measure the length and breadth of cassava leaves in this study

Appendix 18 Field layouts for fertiliser experiment established at IITA Ibadan in 2014/2015 planting season

Date of planting: 8/05/2014; Location: BN 11 & 10.

V1 = IITA-TMS-IBA011412, V2 = IITA-TMS-IBA070593, V3 = IITA-TMS-IBA010040, V4 = TMEB419.

NPK 15:15:15 (T_1), KCl + Urea (T_2), TSP + Urea (T_3) and TSP+KCl (T_4)

Application rates: 0 = control, R_1 = 45 and R_2 = 75kg N, P_2O_5, and K_2O/ha

Each plot is 5.6 m x 5 m (28 m^2) and has 7 plants on 5 ridges

Replicate 1	Peg No Var. Trt	101 01/0040 T_3R_2	110 01/1412 T_3R_2	111 01/1412 TR_1	120 TMEB419 T_4R_2	121 TMEB419 TR_1	130 07/0593 T_2R_2	131 07/0593 T_4R_1	**Replicate 2**	204 01/1412 T_4R_1	205 01/1412 T_3R_1	214 TMEB419 TR_2
	Peg No Var. Trt	102 01/0040 T_2R_2	109 01/0040 T_0R_0	112 01/1412 T_4R_1	119 TMEB419 T_2R_1	122 TMEB419 T_4R_1	129 07/0593 T_0R_0	132 07/0593 TR_1		203 01/1412 T_4R_2	206 01/1412 T_2R_1	213 TMEB419 T_3R_2
	Peg No Var. Trt	103 01/0040 T_2R_1	108 01/0040 TR_2	113 01/1412 T_3R_1	118 01/1412 T_0R_0	123 TMEB419 TR_2	128 07/0593 T_3R_2	133 07/0593 TR_2		202 01/1412 T_4R_1	207 01/1412 T_0R_0	212 TMEB419 T_4R_2
	Peg No Var. Trt	104 01/0040 T_4R_1	107 01/0040 T_4R_2	114 01/1412 TR_2	117 01/1412 T_2R_2	124 TMEB419 T_3R_2	127 TMEB419 T_2R_2	134 07/0593 T_4R_1		201 01/1412 TR_1	208 01/1412 T_2R_2	211 TMEB419 T_4R_1
		105 01/0040 TR_1	106 01/0040 T_3R_1	115 01/1412 T_4R_2	116 01/1412 T_2R_1	125 TMEB419 T_4R_2	126 TMEB419 T_0R_0	135 07/0593 T_3R_1		136 07/0593 T_2R_1	209 01/1412 TR_2	210 TMEB419 T_3R_1

Appendix 18 cont'd

Peg No Var. Trt	215 TMEB419 TR_1	224 07/0593 T_3R_2	225 07/0593 T_4R_2	234 01/0040 T_3R_2	**Replicate 3**	235 01/0040 TR_2	308 07/0593 T_0R_0	309 07/0593 TR_2	318 TMEB419 T_4R_2	319 01/1412 T_2R_2	328 01/0040 TR_1	329 01/0040 T_3R_1	
Peg No Var. Trt	216 TMEB419 T_0R_0	223 07/0593 T_4R_1	226 07/0593 T_2R_1	233 01/0040 T_0R_0		236 01/0040 TR_1	307 07/0593 T_2R_2	310 TMEB419 TR_2	317 TMEB419 T_2R_2	320 01/1412 T_0R_0	327 01/1412 TR_2	330 01/0040 TR_1	
Peg No Var. Trt	217 TMEB419 T_2R_1	222 07/0593 T_3R_1	227 07/0593 TR_1	232 01/0040 T_2R_1		301 07/0593 T_4R_1	306 07/0593 T_2R_1	311 TMEB419 T_3R_2	316 TMEB419 T_3R_1	321 01/1412 T_4R_2	326 01/1412 T_2R_1	331 01/0040 T_3R_2	336 01/0040 T_2R_2
Peg No Var. Trt	218 TMEB419 T_2R_2	221 07/0593 T_2R_2	228 01/0040 T_4R_2	231 01/0040 T_3R_1		302 07/0593 T_4R_2	305 07/0593 T_3R_1	312 TMEB419 TR_1	315 TMEB419 T_0R_0	322 01/1412 T_3R_1	325 01/1412 T_4R_1	332 01/0040 T_2R_1	335 01/0040 T_4R_2
Peg No Var. Trt	219 07/0593 TR_2	220 07/0593 T_0R_0	229 01/0040 T_4R_1	230 01/0040 T_2R_2		303 07/0593 TR_1	304 07/0593 T_4R_1	313 TMEB419 T_4R_1	314 TMEB419 T_2R_1	323 01/1412 T_3R_2	324 01/1412 TR_1	333 01/0040 T_0R_0	334 01/0040 T_4R_1

Appendix 19 Field layouts of stem cutting parts and lengths experiment established at IITA Ibadan in 2014/2015 planting season

DOP: 14/05/2014; Location: C 22

V1 = IITA-TMS-IBA011412, V2 = IITA-TMS-IBA070593, V3 = IITA-TMS-IBA010040, V4 = TMEB419.

Stem portions: B = Basal, M = Middle, T = Green

Length of stem cuttings: L_1 = 15 cm and L_2 = 30 cm

Each plot size is 5.6 m x 4 m (22.4 m^2), comprising of 7 plants on 4 ridges.

Replicate 1	Peg No Var. Trt	101 TMEB419 TL_1	108 07/0593 ML_1	109 07/0593 BL_1	116 01/0040 BL_2	117 01/0040 ML_1	124 01/1412 TL_2	Replicate 2	201 07/0593 TL_1	208 01/0040 ML_1	209 01/0040 BL_1	216 01/1412 BL_2	217 01/1412 ML_1
	Peg No Var. Trt	102 TMEB419 BL_2	107 07/0593 BL_2	110 07/0593 TL_1	115 01/0040 TL_1	118 01/0040 TL_2	123 01/1412 BL_2		202 07/0593 BL_1	207 01/0040 BL_2	210 01/0040 TL_1	215 01/1412 TL_1	218 01/1412 TL_2
	Peg No Var. Trt	103 TMEB419 ML_1	106 TMEB419 ML_2	111 07/0593 ML_2	114 01/0040 ML_2	119 01/1412 ML_2	122 01/1412 ML_1		203 07/0593 ML_1	206 07/0593 ML_2	211 01/0040 ML_2	214 01/1412 ML_2	219 TMEB419 ML_2
	Peg No Var. Trt	104 TMEB419 TL_2	105 TMEB419 BL_1	112 07/0593 TL_2	113 01/0040 BL_1	120 01/1412 TL_1	121 01/1412 BL_1		204 07/0593 TL_2	205 07/0593 BL_1	212 01/0040 TL_2	213 01/1412 BL_1	220 TMEB419 TL_1

Appendix 19 cont’d

	Peg No Var. Trt	301 01/0040 BL_1	Replicate 3	302 01/0040 TL_2	311 01/1412 TL_1	312 01/1412 BL_1	321 07/0593 BL_1	322 07/0593 TL_1
	Peg No Var. Trt	224 TMEB419 TL_2		303 01/0040 ML_1	310 01/1412 ML_2	313 TMEB419 TL_1	320 07/0593 ML_1	323 07/0593 ML_2
	Peg No Var. Trt	223 TMEB419 BL_2		304 01/0040 BL_2	309 01/1412 TL_2	314 TMEB419 ML_2	319 07/0593 TL_2	324 07/0593 BL_2
	Peg No Var. Trt	222 TMEB419 ML_1		305 01/0040 ML_2	308 01/1412 ML_1	315 TMEB419 TL_2	318 TMEB419 BL_2	
	Peg No Var. Trt	221 TMEB419 BL_1		306 01/0040 TL_1	307 01/1412 BL_2	316 TMEB419 BL_1	317 TMEB419 ML_1	

Appendix 20 Cassava production budget with application of 500 kg ha^{-1} of NPK 15:15:15 fertiliser used in this study

SN	Item	Number	Measure	Unit price (₦)	Cost (₦)	Total cost (₦)	%total cost
1	**Land preparations**					35,000	14.439
a	Cut trees	10	wd	700	7,000		
b	Cut into short logs	10	wd	700	7,000		
c	Carry off the field	5	wd	700	3,500		
d	Clearing	10	wd	700	7,000		
e	Ploughing	5	wd	700	3,500		
f	Harrowing	5	wd	700	3,500		
g	Ridging	5	wd	700	3,500		
2	**Acquisition of planting materials**					31,700	13.078
a	Locate the seller	1	wd	500	500		
b	Contact the seller	1	wd	200	200		
c	Cutting the stems	2	wd	700	1,400		
d	Packing or tying the stem	2	wd	700	1,400		
e	Purchase the stems	60	bundles	400	24,000		
f	Load stems inside vehicle	1	wd	700	700		
g	Transport to the farm	1	wd	700	700		
h	Off-load the stems	1	wd	700	700		
i	Cut stems into planting size	2	wd	700	1,400		
j	Pack cuttings inside bag	1	wd	700	700		
3	**Planting**					11,700	4.827
a	Hire labour for planting	15	wd	700	10,500		
b	Transport labour to farm	1	wd	500	500		
c	Lay cuttings on ridges	1	wd	700	700		

4	**Spraying of pre emergence herbicide**					28,300	11.675
a	Locate the seller	1	wd	500	500		
b	Contact the seller	1	wd	200	200		
c	Purchase the herbicide	1	cartoon	24,000	24,000		
d	Pack the herbicide	1	wd	500	500		
e	Transport to the farm	1	wd	500	500		
f	Off-loading the herbicide for use	1	wd	500	500		
g	Spray the herbicide	3	wd	700	2,100		
5	**Supplying of missing stands**					4,000	1.650
a	Counting the number of missing stands	1	wd	700	700		
b	Making cuttings	1	wd	700	700		
c	Hiring labour	3	wd	700	2,100		
d	Transport labour to farm	1	wd	500	500		
6	**Weeding**					14,500	5.982
a	Hiring labour	20	wd	700	14,000		
b	Transport labour to farm	1	wd	500	500		
7	**Application of fertiliser**					76,700	31.642
a	Locate the seller	1	wd	500	500		
b	Contact the seller	1	wd	200	200		
c	Purchase fertiliser	10	bags	6,500	65,000		
d	Load fertiliser into vehicle	1	wd	500	500		
e	Transport to the farm	1	wd	3,000	3,000		
f	Off-load fertiliser	1	wd	500	500		
g	Apply fertiliser	10	wd	700	7,000		
8	**Harvest**					40,500	16.708
b	Transport labour to farm	1	wd	500	500		
c	Uproot roots	10	wd	700	7,000		
d	Detach stock	5	wd	700	3,500		

e	Detach and pack leaves	5	wd	700	3,500	
f	Detach stems	5	wd	700	3,500	
g	Tie stems	5	wd	700	3,500	
h	Detach roots	5	wd	700	3,500	
i	Assemblage of stems	5	wd	700	3,500	
j	Assemblage of roots	5	wd	700	3,500	
k	Hire vehicle	1	vehicle	5,000	5,000	
l	Arrange in vehicle	5	wd	700	3,500	
9	**Contingency**					20,000
10	**Interest (10% of the total cost)**					26,240
	GRAND TOTAL COST					288,640
	Sale					
	Roots	20	tonnes	20000	400,000	
	Stems	12	tonnes	4000	48,000	
	Leaves	12	tonnes	1000	12,000	
		Total			460,000	
		Profit			171,360	
	Grand total less application of fertiliser				211,940	
	Sale					
	Roots	15	tonnes	20000	300,000	
	Stems	12	tonnes	4000	48,000	
	Leaves	9	tonnes	1000	9,000	
		Total			357,000	
		Profit			145,060	
	Profit due to fertiliser application/hectare					26,300

Appendix 21 Mean yield ($t\ ha^{-1}$) performance of cassava variety as influenced by each location in 2014/2015 planting season

	Ibadan			Ikenne			Tsonga		
Cassava variety	FRY	FSY	DRY	FRY	FSY	DRY	FRY	FSY	DRY
IBA010040	18.74	25.07	4.81	24.25	27.90	7.27	6.04	11.06	1.06
IBA011412	21.28	27.07	4.20	27.29	33.41	6.90	11.12	13.93	1.43
IBA070593	13.09	26.02	3.43	18.56	30.73	6.02	0.77	2.90	0.11
TMEB419	13.04	23.60	3.77	14.42	27.05	5,23	13.92	19.91	2.86
Mean	16.54	25.44	4.05	21.13	29.77	6.36	7.96	11.95	1.37
SE±	2.07	0.74	1.94	2.88	1.45	2.31	2.90	3.54	1.79
CV (%)	25.04	5.79	15.44	27.23	9.71	14.88	72.83	59.17	22.22