EFFECT OF NPK COMPOUND FERTILIZER ON CASSAVA *(Manihot esculenta* Crantz) YIELD IN ULTISOLS OF SIKASSO, MALI

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A Thesis Submitted to the Graduate School in Partial Fulfillment of the Requirement for the Master of Science Degree in Soil Science of Egerton University

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DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and has not been presented before in this or any institution for any award of a degree.

Signature: ………………………………….. Date: ………………………..

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Recommendation

This thesis is the candidate's original work and has been prepared with our guidance and assistance and is submitted with our approval as the official university supervisors.

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DEDICATION

I humbly dedicate this work to my beloved family, friends and employer whom I owe a lot to the success. May God bless you in a mighty way.

ACKNOWLEDGEMENT

I thank the all mighty God for given me the strength and the health to accomplish this master program. I acknowledge Egerton University for given the chance to realize my dream. My special acknowledgment goes to my supervisors Prof. Amos Musandu, and Prof. Samuel Mwonga, of Egerton University Department of Crops, Horticulture and Soils for their tireless support during this master program. The study was made possible by the generous support of the American people through the U.S. Agency for International Development (USAID-Mali) and Michigan State University through the Borlaug Higher Education for Agricultural Research and Development (BHEARD), l'Institut d'Economie Rurale (IER/Mali) for the support over my person and all those who contributed generously in one way or another towards my success. May God bless you all.

ABSTRACT

Cassava is an important food crop grown across Mali which is cultivated on Ultisols in Sikasso region situated in the southern part of the country. The lack of recommended inorganic fertilizer is among the main constraints in cassava production in the country. The N, P and K inorganic fertilization is not well practiced due to its high cost and no effective fertilizer use packages. This study aimed at determining the effect of four NPK fertilizer (15-15-15) rates (0kg, 100kg, 200kg and 300kg) ha^{-1} applications on the yield of two cassava genotypes. The two genotypes, *Bonima* (local) and *Sika* (introduced from Ghana) were used in a randomized complete block design (RCBD) experiment with three replicates in two sites, Finkolo and Loulouni during one rainy season. The fertilizer rates were applied in splits at equal quantity, two weeks after planting and the rest two months later. Analysis of soil nutrients before planting and plant N, P and K uptake were performed to assess the optimum inorganic fertilization rate for higher yield. Data on plant height, numbers of branches, number of stem, stem diameter, number of tubers by plant, fresh tuber weight, and yield efficiency were collected. Data on cassava production input and output per hectare were also collected. Data collected were subjected to analysis of variance using Statistical Analysis System (SAS version 9.3). The Least Significant Difference (LSD) at p=0.05 was used to separate means. On cassava growth parameters, the higher NPK fertilizer rate which was 300 kg ha^{-1} increased plant height by 29 and 27% compared to the one from 100 kg ha^{-1} and the control plot respectively at 8 months after planting (MAP). The 300 kg ha^{-1} had increased also the cassava stem diameter by 25% compared to the control. On yield parameters, the number of tuber per plant and cassava fresh tuber yield increased by 49% and 133% respectively in plot which received 300 kg ha^{-1} of NPK. A correlation between NPK inorganic fertilizer rates and fresh tuber yield was determined. The number of branches per plant and number of tuber per plant were found to be strongly correlated. The agronomic Nutrient use efficiency (NUE) was found to increase with additional NPK rates up to 300 kg ha^{-1}. The NPK inorganic fertilizer effect was significant on cassava leave phosphorus content. The leave content in nitrogen and potassium were influenced by site effect making Finkolo more favorable. The simple cost-benefit analysis revealed that cassava production is a beneficial activity in the study sites in Sikasso region. In Loulouni and Finkolo the application of 300 Kg ha^{-1} of inorganic NPK gave 1300.56 $ and 486.26 respectively which were the highest value of the net benefit from one hectare of cassava. These results will form a basis for NPK inorganic fertilizer recommendations in cassava production in Sikasso and policy brief in cassava production in the country.

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LIST OF ACRONYMS AND ABBREVIATIONS

ANOVA	:	Analysis of Variance
CRI	:	Crops Research Institute
CPS/SDR	:	Cell of Planification and Statistic/Rural development sector
EMS	:	Expected means square
FAO	:	Food and Agriculture Organization
IER	:	Institut d'Economie Rurale
IITA	:	International Institute for Tropical Agriculture
LSD	:	Least Significance Difference
NPK	:	Nitrogen Phosphorus and Potassium compound fertilizer
MAP	:	Month after planting
UNDP	:	United Nation Development Program
UNESCO	:	United Nations Educational, Scientific and Cultural Organization
USDA	:	United State Department of Agriculture
SAS	:	Statistical Analysis System
WAAPP	:	West African Agricultural Productivity Program

CHAPTER ONE

INTRODUCTION

1.1 Background information

Cassava was expected to serve as the food tool for Africa green revolution which failed in 1990s when based on rice due to lack of permanent water supply source in Africa (Anthony *et al.,* 2003). The major limiting factor on cassava production in Africa is low soil fertility. There has been a misconception that cassava can have a good yield on a low fertile soil (Hervé, 2011). According to research from Asia; cassava produces 5 to 10 t ha^{-1} in a very acidic and infertile soil. In contrast, it produces 30 to 40 t ha^{-1} in a fertile soil and can yield up to 60t ha^{-1} under good irrigation (Howeler, 2014). According to FAO, the average fresh tuber yield of cassava in sub Saharan Africa is 5 to 8 t ha^{-1}, which is much lower than its potential yield of 40 to 60 t ha^{-1} (FAO, 2004). The bas-fond (shallow land) provides an average yield of 11 t ha^{-1} in southern Mali which is lower than the national averages of 15-20 t ha^{-1} (Kjeld *et al.,* 2012). The average cassava fresh yield of six median producer countries including Ghana, Nigeria, Tanzania, Ivory Coast, Uganda, Democratic Republic of Congo was estimated to be 11.9 t ha^{-1} on a study with 538 cassava fields (Akoroda, 1992).

In Nigeria Som (2007) showed that a cassava crop producing a yield of 30 t ha^{-1} extracts 187 kg N, 33 kg P and 233 kg K ha^{-1}. A study led by the National Root Crops Research Institute in Nigeria stated an optimum root yield obtained by applying 90 kg N, 18 kg P and 75 kg K ha^{-1} on *Ultisols* testing low in N and K and medium in P (NRCRI, 1990).

The relationship between soil types and nutrient availability is moreover important and has been shown to be among factors which determine the types and quantities of fertilizer required by cassava crop (Hervé, 2011). In Nigeria, cassava production was limited by wrong site selection of suitable soil and unavailability of database record on available soil nutrient. Therefore, soil analysis is required to assess its suitability (Oniya *et al.*, 2013). In cassava production, inorganic fertilizer is required for higher yield (Adjanohoun, 2006). Besides fertilizer use, the soil types and varieties adaptation should be greatly considered for durable cassava production.

Mali, a Sahelian country, where cassava is grown in all the regions under different irrigation methods has remained a neglected zone for research. In the crop, we got two main cassava growing area in Mali (Segou and Sikasso) plus the rest of regions except Kidal. Cassava consumption is based on the production region and genotype. In Sikasso region, the majority of cassava tubers are boiled and processed to make '*Atieké*' (meal appreciated in urban zones), gari, and starch. In Segou region and the rest, it is consumed fresh or boiled.

In 2011, through West African Agricultural Productivity Programme (WAAPP), Institut d'Economie Rurale (IER) started a research on cassava in Mali. The first research aimed at determining cassava growing areas and genotypes, a collection of local cassava varieties and exotics brought from Ghana through Crops Research Institute (CRI) of Kumasi to Mali. Those genotypes namely *CSIR-CRI Ampong, CSIR-CRI Buroni Bankyehemaa, CSIR-CRI Sikabankye and CSIR-CRI Doduduade* which are high tuber yielding and disease resistant genotypes. Therefore, the need for research on cassava production under general aspects was necessary. This research seeks to find out the responses of two cassava genotypes under various soil types with different NPK fertilizer rates application in Sikasso region. Agricultural production in Mali is mainly based on the rainfall availability and climate variability which influences the rainfall duration and distribution. This poor rainfall distribution in return can lead to cereal scarcity in the country. Cassava, a root and tuber crop which can tolerant a minimum humidity may play a big role in food security when enough information on it is available to producers. The results will form a basis for NPK inorganic fertilizer recommendations in cassava production in Sikasso.

1.2 Study limitation

The experiment was planted late and missed the ideal time for planting cassava in the region. The cassava crop, therefore, experienced drought spell in its early growth period before it could establish enough root biomass. This made it more vulnerable to the drought spell not normally experienced in the first few months of the cassava growing season. The study would have been more ideal if more sites in the region and more cassava genotypes were assessed. Lastly, the harvesting was done at nine month after planting (MAP) instead of 12 months because of lack of time for the master programme.

1.3 Statement of the problem

In Mali, cassava is among food crops that have an important place in daily diets in the country especially in urban areas. In Sikasso region cassava is produced on Ultisols characterized by natural low fertility, resulting in low cassava yield. Although NPK inorganic fertilizers are used by some farmers; its application rates are ineffective as farmers do not apply adequate amounts. The low level of soil fertility, lack of knowledge on NPK application response to local and improved cassava genotype merit an investigation for the benefit of knowledge. The low application rates are attributed to the high cost of NPK inorganic fertilizer. The lack of proper guidelines on fertilizer application rates for cassava is relayed to a lack of research on the subject. Therefore this study assessed NPK fertilizer use rates on growth and yield of two cassava genotypes and their cost-benefit in Sikasso.

1.4 Objectives

1.4.1 General objective

To contribute to increased cassava production through enhanced knowledge on NPK fertilizer application rates for improving food security in Mali.

1.4.2 Specific objectives

The specific objectives of this study are:

1. To determine the effect of NPK fertilizer application rates on growth and yield of two cassava genotypes.
2. To determine the effect of NPK fertilizer application rates on N, P, and K uptake of two cassava genotypes.
3. To determine the cost benefit analysis of NPK fertilizer application rates on cassava production.

1.5 Hypotheses

1. NPK fertilizer application has no effect on growth and yield of two cassava genotypes.
2. NPK fertilizer has no effect on the N, P and K uptake of the two cassava genotypes.
3. NPK fertilizer application has no financial benefit on cassava production.

1.6 Justification

Cassava is consumed in Mali as a secondary food a long side cereals such as millet, sorghum, maize and rice (FAO, 2013b). The country, like others Sahelian countries experiencing drought stress and rain irregularity can use cassava to play a role as food security crop. Cassava crop drought tolerant and its ability to produce minimum yield in a low fertile soil makes it valuable in regions where rainfall is low or it seasonal distributions are irregular (Yahaya *et al.*, 2016). However, the production of roots and tubers plants in Mali has not been considered adequately by agriculture political planning in terms of research and sub-sector organization.

In international scale, the crop benefited a common support as it had been chosen by donors to be the crop which can ensure food security in Africa because of its multiple uses (Anthony *et al.*, 2003). Although there are few literatures on cassava production in Mali, ''*Atiéké*'' a derived product from cassava is mainly consumed between breakfast and lunch and during dinner time nowadays in urban areas in the country. Seeing this growing interest over the crops there is a need to determine a recommended NPK inorganic fertilizer application rates under cassava through this study to maximize its production in the country and boost the efforts for food security.

CHAPTER TWO
LITERATURE REVIEW

2.1 Cassava production in Mali

Although cassava's origin is Latin America, Africa is the largest producer in terms of surface area cultivated and production. Africa records over 50% of cassava land cultivated in the world. Asia ranks second while Latin America and the Caribbean rank third. Its yield potential in Africa is lower than the global average; the main reason being that cassava is grown mostly in polyculture in Africa (Regina, 2010).

In Mali, apart from Kidal region in the north, cassava is grown in all regions of the country. In 2011, about 24 cassava genotypes had been identified as being grown in the country (Dembelé *et al.,* 2013). The national acreage of cassava has been estimated to be 4,323 hectares between 2007 and 2011. The national average of cassava production in Mali from 2007 to 2011 was estimated to be 71,610 tonnes. Ségou region recorded the highest hectare under cassava cultivation (1,394 hectares), followed by Sikasso region (910 hectares) during the same period. Moptie region has an area of 632 hectares, While in Kayes, Koulikoro, Timbuktu, Gao, and Bamako regions the areas covered by cassava during the same period was below 600 hectares.

From 2007 to 2011, Ségou region recorded the highest cassava production (23,707) tonnes followed by Sikasso (14,196 tonnes). Moptie, Kayes and Timbuktu regions recorded 11,294, 9,722 and 6,813 tonnes respectively. Gao and Koulikoro regions production were below 3,000 tonnes, where Bamako region produced 264 tonnes of cassava during the same period.

In Mali, root and tuber crops including yams, potatoes cassava and sweet potato are complementary foods; while the consumption of rice is higher than other cereals in urban areas in contrast to the rural areas (FAO, 2013b).

Due to its growing importance cassava production has seen significant increase in the regions with the highest acreage. For example, cassava production increased by 33.11% and 19.82% respectively in Ségou and Sikasso region between 2007 and 2011 (Dembelé *et al.*, 2013).

2.2 Cassava as food security crop

Poverty, malnutrition and food insecurity are very common in Africa. Cassava (*manioc or tapioca*) was introduced in Africa from South America in the sixteenth century. Cassava's beneficial attributes in combating food insecurity during this period saw its cultivation quickly spread across Africa. The crop has become the second most important food in African diet (Felix *et al.*, 2002).

In 2020, African population is projected to double to 1.2 billion. Then the growth rate of urban population is expected to be faster (Anthony *et al.*, 2003). To ensure the projected increase in food demand is achieved, a greater percentage of the increase in food production has to be met by the African farmers. Since the 1920s and 1930s, cassava cultivation had been promoted by British colonial authorities concerned about the frequent famines in grain consuming areas of East and South Africa caused by drought locusts. Gradually, cassava has been recognized to be the main hope for combating human starvation in sub-Sahara Africa. Cassava has a great potential in the effort for food sufficiency and security in Nigeria (Anthony *et al.*, 2003).

The important position occupied by cassava had been shown by Food and Agricultural Organization (FAO), where it was the fifth important crop in Africa from 1980s to 1985 after maize, potatoes, rice and wheat. But from 1995 to 2011 it was recognized as the second most important crop in Africa (FAO, 2013a). At present, cassava feeds up to 500 million farmers in Africa without taking into account processors and traders around the world. In the tropical and sub-tropical belt of the world, Cassava is a staple food for hundreds of millions of people and can yield as high as 25 to 40 t ha^{-1}. Unfortunately, national yields are below this range with the world's average yield of cassava being around 10 t ha^{-1} (Donald, 2000).

2.3 Cassava cropping systems

2.3.1 Monocropping

In the main cassava growing regions of Mali namely, Sikasso, Koulikoro and Ségou, cassava is mostly grown in a monocropping system (Dembelé *et al.*, 2013). In Nigeria, a study in six states (Benue, Cross Rivers, Enugu, Kogi, Ondo, and Oyo), showed that mixed cassava cropping system is more male-dominated than sole cropping system. The study also revealed that the cassava monocropping system is more economically profitable than mixed one while the later provides opportunities of all-year-round farm incomes to serve as a better poverty-alleviating mechanism (Ajayi, 2014). This monocropping is motivated by economic profit like in southern Brazil, the constant demand all along the year of cassava as raw material for starch industry had led to widespread of monocropping on the same plot (FAO, 2013c).

In Colombia a study about cassava grown in nine cropping systems (bare fallow, cassava + 4 t ha^{-1} of chicken manure at 1 X 0.8 m, cassava monoculture, cassava minimum tillage, Cassava + 8 t ha^{-1} of chicken manure, cassava +4 t ha^{-1} of chicken manure for main crop, cassava + *Chamaecrista rotundifolia*, cassava rotation and cassava intensive tillage) in the Andean hillsides demonstrated that, cassava monoculture led to a heavy deterioration of soil organic matter, pH and exchangeable cations (Thierfelder *et al.*, 2004). When produced in the same plot, cassava yield is limited by the declining soil fertility and root rot (Moreno, 1987).

2.3.2 Intercropping

Throughout the world cassava intercropping experiments conducted in Colombia, Nigeria, Thailand and Indonesia generally show that intercropping cassava with maize, cowpea or peanut, slightly reduces cassava yields, but results in high gross and net income. The intercropping use efficiently the land than growing crops separately. In Nigeria intercropping system, cassava is planted alongside crops such as yam, maize and vegetable; where yam is generally planted at the top of the mound, and cassava is planted on the side or the slope of the mound or ridges (Stefan *et al.*, 2015).

In Mali, cassava production is concentrated around the Central Delta of Niger in the lake plains and rivers side, in Moptie zone. In all these cassava growing areas intercropping with sorghum, groundnut, maize, and vegetable are very common (Dembelé *et al.*, 2013). However in Kayes region in Western part of the country, cassava is grown intercropped such as vegetables, tomatoes, onions, okra or courgette.

2.3.3 Rotation systems

In many parts of Mali cassava farmers frequently include it in a rotation system. The rotation technique applied differs in each cassava growing region. In Sikasso region, the most frequent rotation is cassava/groundnut/cassava, maize/cassava and cereal/cassava (Dembelé *et al.*, 2013). In Other regions of Mali, the rotation systems although basically similar may include other crops. In Ségou, located in the Centre of Mali cassava/cereal/ *fonio*/ or cassava/ cereal/groundnut are observed. In Koulikoro in the Western part of the country, cassava is grown according to the rotation maize/millet/cassava. In the Central Delta of Niger in Mopti, cassava/rice rotation is more commonly practiced (Dembelé *et al.*, 2013).

2.4 Constraints of cassava production in West African

Planting of unimproved traditional varieties, post-harvest root deterioration, infertile soil and inadequate farming practices are some of the abiotic and biotic factors affecting cassava production (Simon *et al.,* 2011).

2.4.1 Soil fertility constraints

In sub-Saharan Africa (SSA) cassava is often considered by farmers as a crop suitable for growing in poor soils and thus not requiring fertilizer application. Consequently, the decline in soil fertility has resulted from the low levels of fertilizer use combined with the increase in land use intensity and an increase in the role of cassava in smallholder farming systems (Fermont *et al.,* 2008).

For maximum production, crop plants regularly need larger quantities of nutrients than available in soil solution at given time. As plants take up nutrient ions from the soil solution, the soil solution is replenished with ions from clay mineral and humus by cationic exchange, by the slow decomposition of soil mineral, and by the more rapid decomposition of organic matter. It is seldom, nevertheless that the rate of renewal for all essential elements is fast enough to achieve maximum crop production, for this reason, the use of fertilizers is required. From the soil, plant accumulates nitrogen, phosphorus and sulfur. In other words, plants nearly always contain a higher percentage of these elements than the soil in which plants are growing. Conversely, soils mostly contain more iron, calcium, potassium, magnesium and manganese than plants growing in them (Roy *et al.*, 1971).

Cassava is grown in a variety of soil, but ultisols, oxisols and entisols are the main soil types associated with cassava production (Moreno, 1987). Although the crop grows well or with no fertilizer, it responds well to infertile soil at inorganic fertilization (Howeler and Cadavid, 1990). The application of 50 to 100 kg of N ha^{-1} is recommended in soil with low organic matter or available N for cassava crop cycle. In most tropical soil where K supply is very low, 100 Kg of K ha^{-1} is recommended (Howeler and Cadavid, 1990). The use of inorganic fertilizer was shown to significantly improve cassava yield from 8.83 to 10.34 t ha^{-1} (Ayoola and Makinde, 2007a). Adjanohoun (2006) stated that NPK fertilizer application on cassava leads to a positive response in root yield.

In cassava cuttings (plantation material) production, the use of inorganic fertilization is recommended and the general guidelines of cassava production in Nigeria recommend the application of 100 kg ha^{-1} of dolomite, 300 kg ha^{-1} of NPK (10-18-18) two months after planting for a yield objective of 30 t ha^{-1} of cassava tubers. In case of using single inorganic

NPK sources, 150 kg ha^{-1} of urea, 100 kg of phosphate tricalcic and 250 kg ha^{-1} of KCl allow a yield gain of 30 t of tubers per hectare (Justin *et al.,* 2015). The exact quantity of fertilizers to apply under a given cassava production depends on several factors but generally differs from one soil type to another (Stefan *et al.,* 2015). During the first 2-3 months after planting it is recommended to supply 50-100 kg N ha^{-1} in form of urea or another fertilizer compound. In light textured soil two applications of N is recommended, one at planting and another three months after.

Adjanohoun (2006) working in Benin demonstrated that the production of one tonne of fresh cassava roots by 12 months old plant required 5 kg of nitrogen, 3 kg of phosphorus and 8 kg of potassium. Trials on cassava in Thailand concluded that an annual inorganic fertilization of 100 kg N; 50 P_2O_5 and 100 K_2O ha^{-1} maintained or increased cassava yield during 30 years of continuous cultivation (Chumpol *et al.,* 2002). In a fertilization study on five cassava genotypes in Ghana, the economic rate has been shown to be 60 N, 30 P_2O_5 and 90 K_2O kg ha^{-1} (Parkes *et al*., 2012).

For better quality and higher cassava root yield, it is recommended to use a combination of N, P and K in fertilizer mixtures (Sughai, 2010). In an inorganic complexes fertilization study in Nigeria, a yield of 11.77 t ha^{-1} from the application of 400 kg ha^{-1} of NPK (15-15-15) was not significantly different from the yield of 10. 97 obtained through the application of 2.5 t ha^{-1} of organic matter and 200 kg ha^{-1} of NPK (Ayoola and Makinde, 2007a). A combined NPK (15-15-15) inorganic fertilizer of 400 kg ha^{-1} gave a yield of 7.90 t ha^{-1} which was higher than the yield obtained from the application of N, P, K from single fertilizer source of urea, single superphosphate and muriate of potash respectively (Osumdare, 2014).

Despite that low soil fertility being the main constraint to cassava production in SSA, agronomic research remains low. It is known that organic inputs are important for sustaining crop production and soil fertility, but unfortunately not available in sufficient quantities in many cases to satisfy the nutrient requirements of crops (Pieter *et al.,* 2012). The practice of natural vegetation burning sometimes used in tropical production system has been demonstrated not to improve cassava yields (Pieter *et al.*, 2012).

The use of organic fertilizer has some advantages; nutrients are released more slowly and stay for longer period in the soil (Sharma and Mittra, 1991). The reduction of fertilization costs plus the increase of biological activity are the main benefits considered in organic fertilizer use (Seifritz, 1982). It is recommended to apply 10 t ha^{-1} of organic fertilization using poultry or any animal manure or 15 to 20 t ha^{-1} if the soil has a low fertility level (Justin *et al.,* 2015). A fertilization research program in the International Institute for Tropical Agriculture (IITA) indicated that a combination of 3 to 5 t ha^{-1} of dung or compost with inorganic nourishment holding the correct equilibrium of N, P and K is the most effective way to increase cassava yield and maintain the soil's productive capacity (Howeler, 2012).

The addition of organic sources could increase cassava yield through improving soil physical properties, water holding capacity, and organic carbon content apart from supplying good quality of nutrients (Santhi and Selvakumari, 2000). In Pakistan, research concluded that the higher cassava tuber yield due to organic manures could be attributed to favorable changes in soil, which might have resulted in loose and friable soil condition and enable better tuber formation (Mohamed *et al.,* 2007). The study also showed that the organic manure added to the soil acted not only as a source of nutrient but might have influenced their availability too (Mohamed *et al.,* 2007). The two inter-related properties in soil fertility build up and maintenance are soil organic matter and soil organic carbon. It is believed that soil chemical properties are improved by soil organic matter in three ways: act as a source of carbon and nutrients, then increases cation exchange capacity and stimulates biological activity (Asadu *et al.,* 1997). Salami and Sangoyomi (2013) demonstrated that cassava yield was not affected by soil acidity in the range of 5.4 to 6.4. Gbadegesin *et al.* (2011) demonstrated a positive and significant correlation between soil pH and cassava tuber.

2.4.2 Agro-ecological condition

Cassava plant is assumed to get mature at 12 months after planting but experimentations showed that the Tropical Manioc Selection (TMS) varieties bulk earlier than the local varieties; they are not suitable for intensive commercial production because they take 13 to 15 months to attain maximum bulking. Cassava under continuous cultivation planted by farmers will be harvested in less than 12 months and before it has attained its maximum yield (FAO and IFAD, 2005).

In cassava production, the planting method should be adapted to soil humidity condition. When the soil is poorly drained and too wet, the cuttings must be planted on ridges or mound which protect roots from flooding water; leading to less tuber rots. In a heavy and humid soil, it is preferable to plant at the depth of 5 to 10 cm but deeper in a dry and friable textural soil, protecting cuttings against the high temperature and lack of humidity in the topsoil (FAO, 2013c).

Cassava is described as a hardy crop because it grows well under harsh climatic and environmental conditions (Henry and Hershey, 2002). According to illustration in Java island of Indonesia, cassava has been grown in a mosaic of different soils and climate with chosen varieties over the past two to three centuries (Howeler, 2014). In general, most crops are produced in areas where soil and climatic conditions are suitable for their growth. Cassava thrives in areas where the production of other crops is constrained by unfavorable soil or climatic conditions (Howeler, 2005). Moreover, cassava is known to be a very drought-tolerant and water-efficient crop; it is also exceptionally tolerant of high soil acidity and low levels of available phosphorus (Howeler, 2005). Cassava is a lowland tropics plant. It desires a warm, moist climate where mean temperature ranges from 25 to 29°C. It does not grow well under cold climates with growth stopping at temperature below 10°C (Nagib and Nassar, 2002).

Although cassava is drought-tolerant, when available moisture is low, the cassava plant stops growth and shed some of its older leaves to diminish transpiration. When moisture becomes available, the plant restarts growth and produces new leaves. The ideal soil for cassava is a light, sandy loam soil of medium fertility. Drainage is important for its production. (Nagib and Nassar, 2002). The exposure of the crop to prolonged drought (for at least two months) during the tuber-formation and root-thickening stage decreases root yields by 32 to 60% (Boansi, 2017). In tropical climates, it is believed that the dry season has about the same effect on cassava as low temperature in other parts of the world (Yahaya *et al.*, 2016).

2.4.3 Pest and diseases

Cassava pests and diseases have not been adequately studied in Mali and therefore literature on pest and diseases effect about cassava production is lacking (Dembelé *et al*., 2013). In general, the major pests and diseases which attack cassava are divided into leaf diseases, stem diseases, and pests.

Cassava bacterial blight is considered to be the most serious diseases which is widely spread in West Africa; it is a viral disease transmitted through infected planting material and caused by whiteflies mainly *Bemisia tabaci*. The root rot, another common disease mainly occurs in poorly drained soils and during prolonged intense rainy periods. These diseases equally are common in Asia, Africa and Latin America.

Cassava bacterial blight incidence and severity can be reduced by measures such as the application of fertilizers, changing of planting date, finally by mulching and intercropping

(Adeniji and Obigbesan, 1976; Zinsou *et al.,* 2004). Avoiding maximum inoculum from diseases vectors by late planting date of cassava which can reduce disease incidence and severity (Ambe, 1993). Leaf curling is caused by mealybug toxin injection. Cassava mites are also important pest present in cassava production regions. The *Mononychellus tanajoa,* causes damage in sub-Saharan Africa and Latin America mainly in lowland areas with long dry season. African mosaic of cassava, anthrancnose and the bactriose are the main cassava disease in West Africa (Justin *et al.,* 2015). Fruit flies shoot flies, leaf-cutter ants, burrowing bugs and cassava hornworm are others important pest found in Latin America. The diseases and pest infection incidence can lead to 20 to 60% of yield loss (Dahniya, 1994).

2.4.4 Germplasm availability

Research on cassava germplasm in Africa started in 1967 through the foundation of International Institute of Tropical Agriculture (IITA). This led an early study on cassava varieties resistant to cassava mosaic disease (CMD) and cassava bacterial blight (CBB) for the benefits of food security in sub-Saharan Africa (Manyong *et al.,* 2000). The need of a short cycle genotypes and good for transformation into ''Atiéké''and ''*Gari*'' constitute a constraint in terms of germplasm availability in local cassava production in Mali (Dembelé *et al.,* 2013).

2.4.5 Other constraints

In Mali, the availability of moisture is a major constraint of cassava production in parts where there are produced during the dry season. There is an inadequate use of irrigation technology in cassava production. Cassava production in the extensive system leads to low yield. The use *(Pelou),* a traditional seedbed preparation material doesn't encourage young people on cassava production due to the hard labour required. The free movement of grazing animals in cassava growing areas is also a big challenge (Levasseur *et al.,* 2001 and Diarra, 2011).

2.5 Cassava as an industrial crop

In Mali, the study of cassava use in industry is gaining importance. In fact, cassava sector in the country benefited from a study in 2012 about its ability in the production of bio-ethanol. Thus according to condition well fitted by cassava crop. It is believed to provide good yields up to 20 t ha^{-1} in southern Mali (where the study was done), greater than sweet sorghum; it's being relatively well-known to farmers provide an advantage, especially smallholders in contrast to sugar cane most often grown in major schemes; cassava can be used in case of food crisis (in contrast to *Jatropha curcas*); and finally it is believed to be relatively environmentally friendly (Kjeld *et al.,* 2012).

The largest cassava producer in the world is Nigeria which produces 34 million tonnes of tuber a year (FAO, 2004). The country uses the crop as raw material in industrial sector, in addition to the production of traditional food products such as *gari, lafun and fufu* other cassava derived products in Nigeria include: alcohol/ethanol, pellets, food and soft drinks industries, adhesives, starch, confectionery, wood, fermented and un-fermented flour, (Jackson *et al.*, 2014). Nigeria is the best example where the production and transformation chain of cassava is well developed. Cassava production, processing and marketing served for employment, and source of food for Nigerians (Jackson *et al.*, 2014). In 2005, Nigeria exported 77% of world's dried cassava (Ajibola, 2000). Although cassava is used in Nigerian industry the quantity is still low for example in 2001, 16% of its cassava production was used as an industrial material in the country (Jackson *et al.,* 2014).

2.6 Adoptions of cassava improved varieties

In Mali, the reasons for cassava improved varieties adoption is not available since the initiative is recent and need studies to implement the idea. In one of cassava growing countries, Ghana in West Africa, a study on cassava improved varieties revealed that high yield, suitability for consumption and *gari* processing were among reasons on the adoption of *Bankye hemaa* variety. Its resistance to cassava mosaic diseases has been also mentioned (Victor and Emmanuel, 2012). In the same country, another study showed that land size and extension officer's visits and participation in field demonstrations have high influence in the adoption of improved varieties (Patricia and Victor, 2015).

2.7 Cassava production and soil depletion

2.7.1 Soil erosion

Soil erosion, a natural process can be accelerated by some agricultural practices and land management. Some evidence about cassava to increase soil erosion has been shown by Howeler (1981) where the erosion index of cassava, in Colombia on a volcanic ash soil with 60% slope, was 9.8 considerably greater compared to the ones of pasture (1.0), sugar cane (1.1) and pineapple (1.7). Soil erosion in cassava cultivation arises during planting and harvesting time. It is amplified by soil slope.

In Ghana, a study concluded that cassava production has the tendency to increase the effect of soil erosive forces than most of others crops, especially when the producer doesn't use a technique to protect the soil against the rain falling impact, solar radiation and wind during the first 2 and 3 months of growth. (Kueneman *et al.*, 2012). Generally, cassava is planted in sandy or sandy loam soil with a poor aggregate stability and on slop already eroded, partially because cassava is one of the rare crops which can yield on degraded soil (FAO, 2013c).

2.7.2 Soil nutrient balance

Cassava is reputed to be an exhausting crop of soil regarding to it nutrient's uptake. At the end of its cycle, immobilization of 25 t ha^{-1} of cassava tubers are high and correspond in an average of 151 kg of N, 52 kg of P_2O_5, 245 kg of K_2O, 120 kg of CaO and 48 kg of MgO (Pouzet, 1988; Raffaillac and Nedelec, 1984). Throughout Africa in recent years with the settlement of small industrials transformation units; cassava growing soil productivity decreases in an alarming manner due to the increase production via an increase in area covered by the crop (Troupa and Koné, 2003). Soil nutrient-depleting crop attributed to cassava has been classified as myth through an experiment of eight-year in Ghana forest zone where the high rainfall and sandy soil cause faster decomposition of organic matter, leaching, and soil erosion. Transition and the savanna zones had a slow speed of those parameters. The study concluded that cassava yields decrease under a continuous rotation of cassava/maize even with fertilizer use. A similar experiment without fertilizer in transition concluded that cassava tubers gain diminishes at a slower rate than in the forest zone (Felix *et al*., 2002). Some agronomic practices like cassava growing soil management influences nutrient availability. This has been supplemented in an assessment led by (Aiyelari *et al.*, 2002). Which demonstrated that the Higher level of organic carbon, exchangeable Ca, Mg and K, total N, extractable P, are greater in the soil where zero till is practiced.

2.8 Media soil in cassava growing areas in Mali

In Mali, the USDA Soil taxonomy has indicated three major soil types which are ultisols, alfisols and aridisols.

2.8.1 Ultisols

Ultisols commonly known as red clay soil are seen to be weathered soils of warm and humid climate. They are formed on older geological sides in parent material already deeply weathered. The ultisols order is the same as acrisol or alisol in the actual FAO soil classification (FAO/UNESCO, 1990). In the tropics, these soils are the second common among the rest (Driessen and Dudal, 1991). Large areas of Southern part of USA are cover by it. The clay accumulation (argillation), low base supply and non perudic (wet across the year), water regime within the subsoil are factors which determine ultisols (Soil Survey Staff, 1975).

The majority of ultisols are formed in parent materials having low basic cations under forest vegetation. With depth, the concentrated basic cations in surface horizons and base saturation percentage declines caused by biocycling by native vegetation. These soils formed from acidic parent materials where rainfall is more than potential evapotranspiration during a greater portion of most of the year. The degradation in soil fertility is caused by the harvesting of native forests. Savannah vegetation has replaced forests due to timber harvest in some tropical regions. A major constraint to agriculture use of ultisols is it low nutrient, high extractable aluminum content, low base status, and high subsoil acidity. Liming and fertilization can overcome this limitation (Buol *et al*., 2011).

The water supply for agriculture is not generally a limitation in Ultisols, but plant nutrients are seen to be the main deficiency factors. Moreover the release of bases by weathering is usually equal to or less than the removal by leaching, and ideally, most of the bases are held in the upper few centimeters of soil by the vegetation (Henry and John, 1980). Because of the very low nutrient rate demand by forest compared to cultivated crops, many ultisols serve well in timber production. The trees root systems rapid increase allows them to perform on ultisols, but contain few nutrients to sustain food crops cultivation (Buol, 2008). About soil types and cassava production, the Sikasso ultisols from 2007 to 2011 has given an average production of 14,196 tonnes with a mean yield of 15.6 t ha^{-1} (Dembelé *et al*., 2011).

2.8.2 Alfisols

Alfisols are similar to ultisols but are less acidic and less intensively weathered. There are located in the same climatic region as ultisols and are by nature fertile than the latter. About 10% of the glacier-free land surface is occupied by alfisols and there are more common than ultisols. They are responsive to good management and have a natural fertility allowing them to be used widely for farming and forestry activities. Worldwide, alfisols make up under a large range of abiotic condition, there are present in tropical, temperate, and boreal regions. From parent materials rich in bases or less weathered and leaching regimes, Alfisols are characterized by an adequate supply of exchangeable calcium, magnesium, potassium, and in some cases sodium in the subsoil. Range, forest, pasture, and cultivated crops are practice in alfisols (Buol *et al*., 2011). The native fertility of theses soil is expressed by the high level of base saturation of most pedons and the existence of large assets of plant nutrient in the highly base-saturated C horizon (Buol *et al*., 2011).

Even though Alfisols contain significant amounts of weatherable minerals that supply bases through weathering, it can evolve into ultisols when weathering and leaching increase to cause a complete loss of weatherable minerals and base saturation less than 35 % (Henry and John, 1980). The alfisols during 2007 to 2011 of Kayes and Moptie region realized a mean yield of 17.8 t ha^{-1} with an average production of respectively 9,722 tonnes and 11,294 tonnes (Dembelé *et al.,* 2011).

2.8.3 Aridisols

Constitute a soil too dry for mesophytic crops to grow. There are the most abundant soil types in the world. With a light color rich in carbonates, vegetated with bunchgrasses and shrubs. Aridisols can be productive when irrigated and fertilized. They present a little organic matter plus an accumulation of calcium and sodium. For plant growth when the soil is warm enough (8 > oC), aridisols are not humid in any part as much as 90 successive days. Its leaching is limited by the few concentration of water in a small volume which makes many Aridisols soil showing morphologically distinct horizons. Its can occurs outside the desert region when the soils are coarse and retain little water or because runoff when excessive due to steep slopes or the fine texture of surface horizons (Henry and John, 1980). The lack of water availability limits its agricultural use. Aridisols with inner sponginess acceptable for deep leaching is advice to be designated for irrigation to avoid difficulties of salinization and alkalization arising from salt contained in irrigation water. In non-saline aridisols, nitrogen level is generally low, while other main plant nutrient elements are frequently ample, especially K from feldspars and mica. The micronutrients provisions are normally abundant, while high pH can make them unavailable. The supply of iron and trace elements by foliar application might be essential for satisfactory farming (Buol *et al.*, 2011). In Timbuktu Aridisols, cassava gave 16.2 t ha^{-1} as average yields from 2007 to 2011with an average production of 6,813 tonnes (Dembelé *et al*., 2011).

Generally, cassava production required a well-drained soil, not extremely stony or shallow (30 cm and more). However its can tolerate great levels of aluminum and manganese in the soil, but extremely sandy, salts affected, clayey or waterlogged soil showed a poor growth of cassava (Stefan *et al*., 2015).

CHAPTER THREE
MATERIALS AND METHODS

3.1 Experiment sites

This experiment was conducted in two sites located in the wider Sikasso administrative region of southern part of Mali (Figure 1).The first site is located at Loulouni *commune* which belongs to Kadiolo *cercle*. The village is located at coordinates 10°54'0'' North and 5°36'0'' West The *commune*, which includes a town and 28 villages, covers an area of 1,052 km^2. The elevation of Loulouni is at an altitude of 455 meters above sea level. The average annual rainfall is around 1,200 mm and extents from May/June to October/November while the dry season sets in from November to May. The average annual temperature ranges between 21 to 32°C (PNUD, 2015). The dry season in the southern part of the country takes 6 months from November to April (Mali-Météo, 2007). The soils are classified as ultisols (FAO/UNESCO, 1990). Cotton, rice, maize, sorghum, groundnut, millet, sweet potato, potato, cassava and yam are the main crops grown in the zone.

The second site is located at Finkolo which is a rural *commune* of Sikasso *cercle*. Finkolo host a research station of the Institut d'Economie Rurale (IER) where the experiment was conducted. Finkolo *commune* covers 477 km^2 and includes 8 villages and is located in coordinates of 11° 5'59'' North and 5°30'49'' West. It is located at an altitude of 330 meters above sea level. The average annual rainfall is 1,100 mm and its distribution is the same as Loulouni *commune*. The annual average temperature ranges between 24 and 32°C. The soils are also classified as ultisols (FAO/UNESCO, 1990). The major crops grown in the zone are yam, maize, sorghum, groundnut, millet, sweet potato, potato, fonio, rice, and cassava. The two zones are important cassava producers in Sikasso.

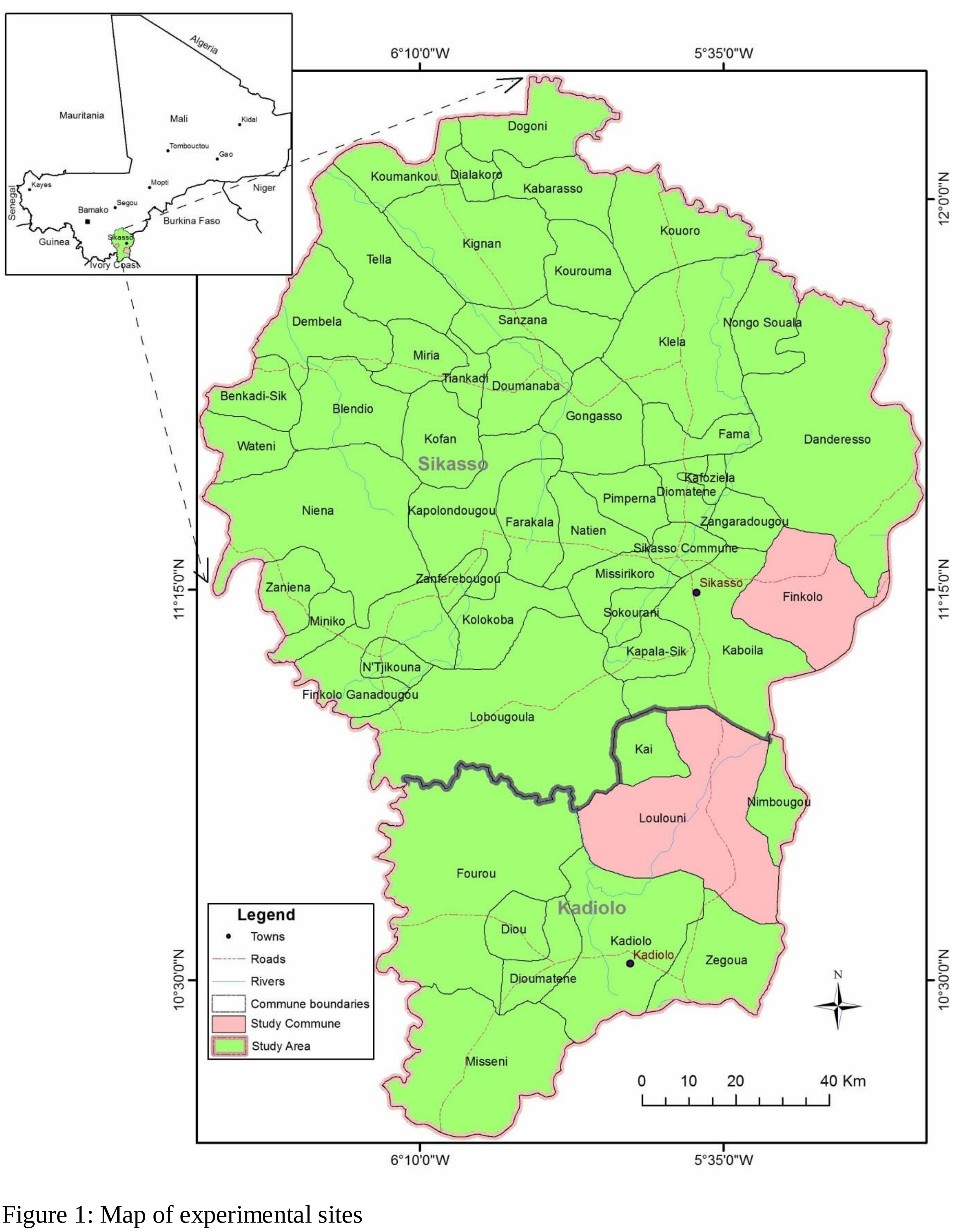

Figure 1: Map of experimental sites

Source: Adapted from Ethiopian Mapping Agency, by Geoffry Maina environmental science Egerton University 2016.

Table 1: Rainfall in the study areas (mm) during the study period

Site	2016										2017		
	Mar	**Ap**	**May**	**Jun**	**Jul**	**Ag**	**Sep**	**Oct**	**Nov**	**Dec**	**Ap**	**Mar**	**Jun**	**Total**
Loulouni	0	0	102	191	247	313	136	35	21	0	0	163	91	1,299
Finkolo	5	80	54	215	379	271	270	61	27	0	23	158	140	1,683

Source: Finkolo Research Station and Loulouni Agriculture Sub-Sector Office (2016-2017)

Table 2: Monthly temperature (°C) mean in Sikasso during the experiment period

Years	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2016	32.1	32.2	30.7	28.1	26.3	25.9	26	28.7	28.1	26.2
2017	32.1	31.8	29.5	28.4						

Source : Météo/Mali-Sikasso (2016/2017)

Table 3: Monthly mean relative humidity in Sikasso zone (%) during the experiment period

Years	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2016	33	53	61	70	7	81	80	67	55	39
2017	33	46	65	89						

Source : Météo/Mali-Sikasso (2016/2017)

3.2 Experimental design and treatment combination

3.2.1 Experimental design

The experiments were set up in a randomized complete block design (RCBD) with three replications; this result in 2 x 4 x 2 x 3 = 48 unit plots split equally between the two sites. Each unit plot had 5 lines of 4 m with 1 m between lines which is 160 m^2 by replication and a total of 480 m^2 for one experimental unit. One meter of alleys between subplots and two meters between replications.

3.2.2 Treatment combination

The experiments were set up in a randomized complete block design (RCBD) with three replications. The study involved two factors; two cassava genotypes and four NPK inorganic fertilizer rates per experimental site. The two factors combined gave 8 treatments per study site. The four NPK fertilizer rates will be; 0 Kg NPK, 100 Kg NPK (equivalent of 15kg N ha^{-1}, 15kg P ha^{-1} and 15kg K ha^{-1}), 200kg NPK (same as 30kg N ha^{-1}, 30kg P ha^{-1} and 30kg K ha^{-1}) and 300 Kg NPK (equal to 45kg N ha^{-1}, 45kg P ha^{-1}, and 45kg K ha^{-1}). The two genotypes that were considered are *Bonima* (a local genotype) and *Sika* (an improved drought and disease tolerant genotype from Ghana). The local genotype, *Bonima*, was obtained from the farmers whereas the improved genotype was supplied by IER. The treatment combinations used are summarized in Table 1 below. The experiment was set up in two locations, Loulouni and Finkolo.

Table 4: Experiment treatments combination

Treatment	Site	NPK Fertilizer Kg Nutrient/ha			Cassava Genotype
		N	P	K	
1. S_1 NPK_1G_1	Loulouni	0	0	0	Bonima
2. S_1 NPK_1 G_2	Loulouni	0	0	0	Sika
3. S_1 NPK_2 G_1	Loulouni	15	15	15	Bonima
4. S_1 NPK_2 G_2	Loulouni	15	15	15	Sika
5. S_1 NPK_3 G_1	Loulouni	30	30	30	Bonima
6. S_1 NPK_3 G_2	Loulouni	30	30	30	Sika
7. S_1 NPK_4 G_1	Loulouni	45	45	45	Bonima
8. S_1 NPK_4 G_2	Loulouni	45	45	45	Sika
9. S_2 NPK_1 G_1	Finkolo	0	0	0	Bonima
10. S_2 NPK_1 G_2	Finkolo	0	0	0	Sika
11. S_2 NPK_2 G_1	Finkolo	15	15	15	Bonima
12. S_2 NPK_2 G_2	Finkolo	15	15	15	Sika
13. S_2 NPK_3 G_1	Finkolo	30	30	30	Bonima
14. S_2 NPK_3 G_2	Finkolo	30	30	30	Sika
15. S_2 NPK_4 G_1	Finkolo	45	45	45	Bonima
16. S_2 NPK_4 G_2	Finkolo	45	45	45	Sika

S_1: Loulouni, **S_2:** Finkolo, **NPK_1:** 0 kg of NPK ha^{-1}, **NPK_2:**100 kg of NPK ha^{-1}, **NPK_3:** 200 kg of NPK ha^{-1}, **NPK_4**: 300 kg of NPK ha^{-1}, **G_1:** Bonima genotype, **G_2:** Sika genotype

3.2.3 Field layout

The experiment was set at two sites in Loulouni and Finkolo, in each site there were a total of 24 plots representing the two cassava genotypes, four levels of NPK and replicated three times. The cassava was planted at a spacing of 1 m within rows and 1 m between rows. The rows were separated by alleys of 1m between plots and 2 m between replications. The plot size was 4 m by 5 m resulting in 5 cassava lines per plot and 20 cassava plants per plot. The total areas of the experimental plots per site were of 480 m^2. The field layout is shown in Figure 2.

Block 1	Sika NPK_3	Sika NPK_2	Bonima NPK_1	Bonima NPK_2	Bonima NPK_4	Sika NPK_1	Sika NPK_4	Bonima NPK_3
Block 2	Sika NPK_1	Sika NPK_3	Bonima NPK_1	Bonima NPK_2	Bonima NPK_4	Bonima NPK_3	Sika NPK_2	Sika NPK_4
Block 3	Bonima NPK_2	Sika NPK_3	Bonima NPK_1	Sika NPK_2	Bonima NPK_4	Sika NPK_4	Sika NPK_1	Bonima NPK_3

4 m; 5 m; 1 m

Figure 2: Field layout

3.3 Experiment procedure

Before land preparation, a composite of soil sample was collected from 30 different points on each experimental site for the need of soil physico-chemical analysis.

3.3.1 Land preparation and planting

The land was cleared of weeds and prepared for planting using hand implements. The seed beds were made into ridges of 4 meter long of one meter from each other. Cassava planting materials were cut into 20 cm long pieces and planted horizontally in the ridges by placing the 2/3 underground. They were then planted at 1 m within row and 1 m between rows. The NPK inorganic fertilizer (15-15-15) was applied by placing the NPK fertilizer treatment beside each cassava plant. This spot application technique has been shown to increase the nutrient uptake efficiency by the plant (Bationo and Buerkert, 2001).

3.3.2 Management of trial

Cassava trial was planted on 1st and 2nd October 2016 in Loulouni and Finkolo respectively. The harvesting was done at the end of June month in 2017 at 9 MAP. The two sites experienced a drought time of 4 months which took place from December to March, although Finkolo received 26 mm rain during the dry season in April 2017. From the rain season Loulouni and Finkolo experimentation received 310 and 408.5 mm respectively and complementary irrigation was done to minimize the effect of drought. Loulouni's trial was set up Bottomland alluvial deposits (*Bas-fond*), where soil moisture is retained longer than in Finkolo. In Finkolo the experiment was setup in the glacis soil.

The cuttings were treated by fungicide before planting preventing cutting fungal damage. Weeding was done two weeks after planting and repeated as needed. During the trial, termite attack was observed in Finkolo site and Feradan (Cabofuran or $C_{12}H_{15}NO_3$) was used to control its damage in the trial. Fertilizer rates were applied in splits application at half rate, two weeks after planting and the rest two months later in spot application technique.

Due to late planting, the trial experienced drought stress in the early growth stage of cassava and irrigation was applied before the application of the second split of NPK on the two sites. Irrigation was applied on Wednesday and Saturday each week but there were challenges of water availability in Loulouni in the later part of the dry season. The irrigation was stopped in early May with the beginning of rainy season in the two zones.

3.4 Data collection

The data collection included four components soil sampling and analysis, plant tissue sampling and analysis, plant growth and yield parameters measurement, and basic data for simple cost benefit analysis. Soil and plant tissue analysis were done by le Laboratoire Sol Eau Plant (Labosep) of Sotuba in Mali.

3.4.1 Soil sampling and analyses

Samples from topsoil (0-20 cm) and subsoil (20-40 cm) from each experimental site (Loulouni and Finkolo) were collected for soil characterization. The soil analyses included physical and chemical analysis. In the physical analysis, soil texture was determined using the hydrometer method (Niang, 2004). Chemical analysis was focused on the pH in H_2O (soil water ratio of 1: 2.5) using a pH meter, exchangeable bases K^+, Ca^{2+}, Mg^{2+}, Na^+, Cation Exchange Capacity (CEC) using ammonium acetate solution method, total nitrogen using the Kjeldahl method, available phosphorus and soluble potassium was extracted using Mehlich I extractant and analysed using colourimetric spectrometry and flame spectrophotometry, respectively, and organic carbon was analysed using the Walkley-Black wet-oxidation method (Ayoola and Makinde, 2007b).

3.4.2 Plant tissue sampling and analyses

Plant tissue samples were collected from fully expanded leaves at 4 months after planting. A total of 20 leaves from the net-plot of each treatment were collected (Howeler, 2014). The samples were cleaned using tap water in the laboratory then dried in an oven at 70℃ or below. After drying to constant weight, the samples were milled, sieved to pass through 1 mm sieve, and stored for N P K uptake analysis. The plant nutrient uptake were assessed for N, P and K by wet digestion method of plant material and analyzing the N by Kjeldahl method, P by the vanadium yellow method and K by flame photometer analyses (George *et al*., 2013).

3.4.3 Plant growth and yield measurements

Plant growth and performance indicators counting in form of plant height, numbers of branches, number of stems, stem diameter, number of tubers per plant, and fresh tuber yield were measured. The measurements of plant growth were taken on 6 plants in the net-plot of each treatment at 4, 6, and 8 months after planting. The selected cassava plants were tagged for the indicated measurements. The plant height was measured from the stem part above soil up to the tallest branch of the plant. The numbers of branches were counted on those attached directly to the main stem. Stem from the cutting was also counted. Stem diameter was taken at 2 cm above the soil. The tuber yield was taken at 9 months after planting and expressed in a number of tubers per plant and in tonnes per hectare of fresh tubers.

3.4.4 Nutrient use efficiency

Using the treatments yield data obtained, the two genotypes N K P nutrient use efficiency were assessed in each zone using the formula below (Gerloff and Gabelman, 1983):

$$NUE = \frac{YieldwithNPK(kg/ha) - YieldwithoutNPK(kg/ha)}{TotalNPKadded(kg/ha)} = kgfreshyield/kgNPK$$

Where: YE= Yield use efficiency;

TuberYield with NPK (kg/ha): Yield obtained by application of NPK

Yield without NPK (kg/ha): Yield obtained without NPK application

Total NPK (kg/ha): Quantity in kg/ha of NPK applied

3.4.5 Data for simple cost benefit analysis

Data was collected on variable costs of cassava production including labor costs, seedling, fertilizers, pesticides and harvesting. The price of cassava tubers in the local market of Loulouni and Finkolo were collected during the cassava harvest season. These data were used in cost benefit analysis. The cost benefit analysis was based on the tubers yield per hectare (Ebukiba, 2010).

Net Benefit= Gross margin – Cost input

Where

Gross margin = Yield X price/Kg

Cost input = all the charges for one hectare

3.5 Data analysis

The data collected on cassava from each site were analyzed combined. They were subjected to analysis of variance (ANOVA). When significant, the separation of means was done using the LSD test at P=0.05. Correlation between fertilizer rates versus fresh tuber weight, number of branches, number of tuber per plant, plant height and stem diameter were assessed. Regression analysis was performed between fertilizer rates *vis a vis* fresh tubers weight and a number of branches. The input from land preparation to harvesting data was computed against the gross benefit through the price of a kg of cassava tuber. Finally, NPK use efficiency was determined for each genotype in the two sites. All the statistical analysis was performed using SAS software version 9.3.

3.6 Experimental model and expected means squares (EMS)

The model of the experiment is as given below.

Genotype = 2; Locations = 2; Fertilizer rates= 4; Replications = 3

$Y_{(ijklm)} = \mu + L_i + \beta_{j(i)} + G_k + LG_{ik} + F_l + LF_{il} + GF_{kl} + LGF_{ikl} + \varepsilon_{ijklm}$

Where:

μ = Overall means

L_i = Effect of the i^{th} location

$Bj_{(i)}$ = Effect of the j^{th} blocking in i^{th} location

G_k = Effect of k^{th} genotype

LG_{ik} = Interaction effect between i^{th} location and k^{th} genotype

F_l = Effect of l^{th} fertilizations

LF_{il} = interaction effect between i^{th} location and l^{th} fertilization

GF_{kl} = Interaction effect between k^{th} genotype and l^{th} fertilization

LGF_{ikl} = Interaction effect among i^{th} location, k^{th} varieties and l^{th} fertilization

ε_{ijklm} = Random component error.

Table 5: Expected means square

		Location	Replication	Genotype	Fertilization	Error	
		2	**3**	**2**	**4**	**3**	
		F	**R**	**F**	**F**	**R**	
Source of Variation	**df**	**i**	**J**	**k**	**L**	**m**	EMS
L_i	1	0	3	2	4	3	$\delta^2_e + 24\ \delta^2_{\beta j} + 72\delta^2_L$
$\beta_{j(i)}$	4	0	1	2	4	3	$\delta^2_e + 24\ \delta^2_{\beta j}$
V_k	1	2	3	0	4	3	$\delta^2_e + 72\delta^2_V$
LV_{ik}	1	0	3	0	4	3	$\delta^2_e + 36\ \delta^2_{LV}$
F_l	3	2	3	2	0	3	$\delta^2_e + 36\ \delta^2_F$
LF_{il}	3	0	3	2	0	3	$\delta^2_e + 18\ \delta^2_{LF}$
VF_{kl}	3	2	3	0	0	3	$\delta^2_e + 18\ \delta^2_{VF}$
LVF_{ikl}	3	0	3	0	0	3	$\delta^2_e + 9\delta^2_{LVF}$
ϵ_{ijklm}	28	1	1	1	1	1	δ^2_e

CHAPTER FOUR
RESULTS AND DISCUSSION

4.1 Soil characteristics

Chemical and physical properties of the soils at the two sites are presented in Table 6. They both were classified as sandy loamy texture and low in organic carbon. The soils were medium acidity, as soil pH from 4.5 to 7 is considered medium for the nutritional requirement of cassava plant (Howeler, 2002). The exchange capacities (CEC) were low but exchangeable bases were of moderate levels with low nitrogen level and very low of phosphorus content. The soil from the two study sites had low natural fertility status.

Table 6: Chemical and physical properties of top and subsoil experimental site

	Loulouni site		**Finkolo site**	
	Depth			
Parameters	0-20 cm	20-40 cm	0-20 cm	20-40 cm
pH (H_2O)	5.78	5.79	5.80	5.81
Organic carbon (% C)	0.64	0.43	0.55	0.42
Available phosphorus (ppm)	1.28	0.83	7.41	---
Total Nitrogen %N	0.03	0.01	0.02	0.01
CEC meq/100g	4.32	3.11	3.07	2.92
Ca exchangeable (mg/Kg)	334	194	194	176
Mg exchangeable (mg/Kg)	100.8	57.6	58.8	51.6
K exchangeable (mg/Kg)	117	58.5	35	35
Na exchangeable (mg/Kg)	1.32	1.32	1.32	1.32
Sand %	63	75	58	67
Silt %	33	23	40	31
Clay %	4	2	2	2
Textural class	Sandy Loam	Sandy Loam	Loam	Sandy Loam

4.2 Effect of NPK fertilizer, genotype and site on cassava growth parameters

4.2.1 Effect of NPK fertilizer on cassava growth parameters

The effect of NPK inorganic fertilizer on cassava height is presented in Figure 3. The cassava plants heights were significantly ($p<0.05$) increased by NPK fertilizer application. Cassava plant receiving 300 kg ha^{-1} of NPK had significantly taller plants than plots which received 0 and 100 kg ha^{-1} of NPK. The differences were observed at 8 MAP periods where the highest rate of application at 300 kg ha^{-1} NPK had 27 to 29% higher plant than 0 and 100 kg ha^{-1} of NPK. The plant heights were not significantly influenced by fertilizer application at either 4 MAP or at 6 MAP. Then, the application of 0, 100 and 200 kg ha^{-1} of NPK gave a plant height of 99, 97 and 110 cm respectively were not significantly different. While the height of 126 cm from 300 kg ha^{-1} application was found to be significantly different from 0 and 100 kg ha^{-1} of NPK, but not from the height gotten by the application of 200 kg ha^{-1} of NPK. At 8 MAP the environment condition especially rainfall, made the cassava to take up more nutrient resulting in bigger height increase for plots with higher NPK doses. The lack of differences in plant height at the lower NPK application implies that the amount of nutrients supplied were not adequate for showing a difference in plant height. The results showed that cassava plants responded well to high NPK (300 kg ha^{-1}) application at the middle stages of growth (8 MAP). This means that to obtain higher cassava growth high NPK rates are necessary. Environmental conditions had an effect on plant growth (rooting) which made the plant able to benefit from the 2nd split application of NPK. This study is in agreement with findings in Indonesia which showed that the growth of cassava was positively affected by the application rate of fertilizer (Streck *et al.,* 2014). Dermiyati1 *et al.* (2015) demonstrated that increasing dose of chemical fertilizer increased cassava plant height.

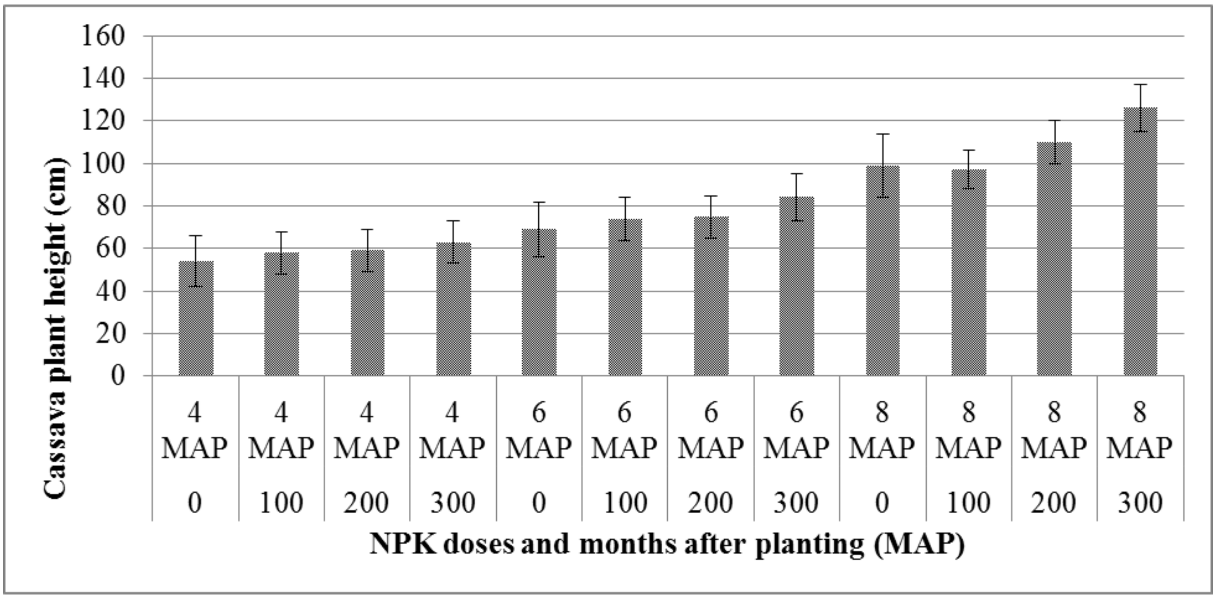

Figure 3: Effect of NPK doses on cassava mean height

The cassava stem numbers were not significantly affected by NPK fertilizer. However, the number of branches per plant was significantly affected by NPK fertilizer at 6 and 8 MAP as presented in Figure 4. At 6 MAP the highest NPK rate of 300 kg ha^{-1} had an average of 2.05 branches per plant which was significantly different from the number of branches gotten by 0, 100 and 200 kg ha^{-1} of NPK respectively. The same trend was observed at 8 MAP. This implies that more we add NPK inorganic fertilizer more is the number of branches per plant. The finding is similar to Leo *et al.* (2015) study in Malawi which showed a significant effect of inorganic fertilizer on cassava number of branches per plant.

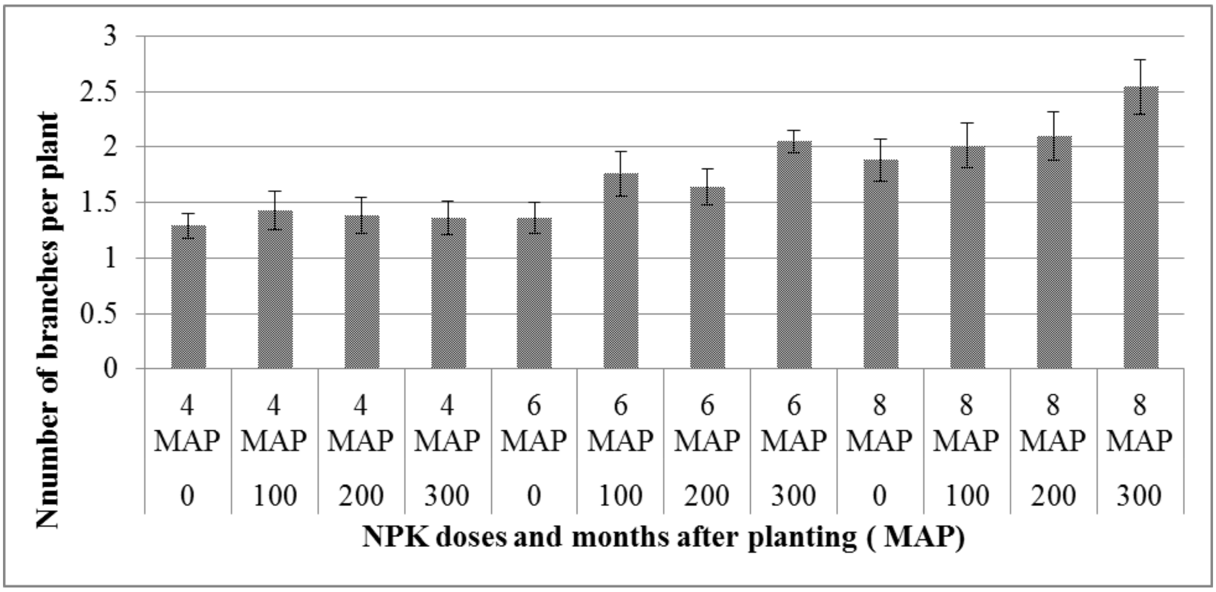

Figure 4: Effect of NPK fertilizer doses on the mean number of branches per plant in cassava

Cassava stem diameter was found to be significantly affected by NPK fertilizer only at 8 MAP as presented in Figure 5. The stem diameter from the application of the two higher rates of 200 and 300 kg ha^{-1} were not significantly different, but significantly differed from stems obtained by the application of 100 kg ha^{-1} of NPK and the control. The stem diameter of cassava plants which received 200 and 300 kg ha^{-1} of NPK were 6.68 cm and 6.12 cm respectively. The treatment applied with 300 kg ha^{-1} of NPK had at 8 MAP increased cassava stem diameter by 25% compared to the control. These differences in stem diameter may be attributed to the more nutrient availability with high NPK fertilizer, especially from the 2nd split application. This study is consistent with findings in Nigeria in which cassava stem diameter were found to significantly increase as the N and K rates were increased (Uwah *et al.,* 2013).

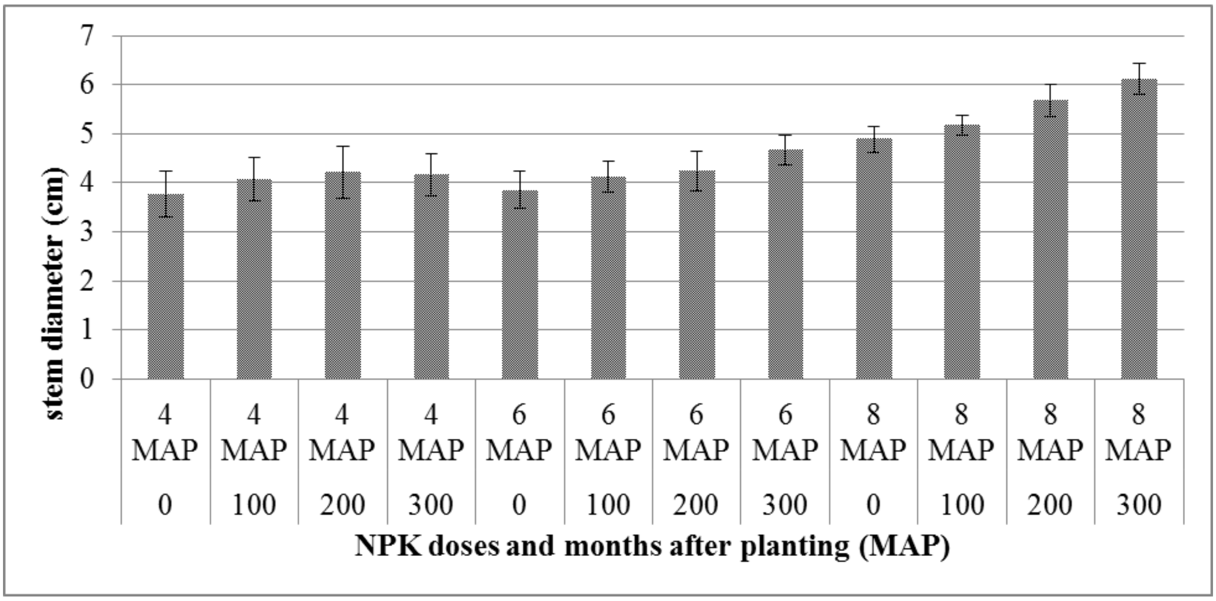

Figure 5: Effect of NPK fertilizer on cassava mean stem diameter

4.2.2 Effect of genotype on cassava growth parameters

The cassava plant heights of the two genotypes were found to be significantly different at all observation times as presented in Figure 6. *Bonima* genotype had significantly ($p<0.05$) taller plants than *Sika* at 4, 6 and 8 MAP. *Bonima* genotype achieved a height of 78, 99 and 136 cm at 4, 6 and 8 MAP respectively; while *Sika* got 33, 52 and 80 cm at 4, 6 and 8 MAP respectively. *Bonima* growth rate in height was 74% between 4 and 8 MAP; while *Sika* recorded 143% during the same time. The difference in height and the growth rate is attributed to the genotype characteristic. This means that that *Bonima* was able to achieve greater height with the same resources when compared to *Sika*.

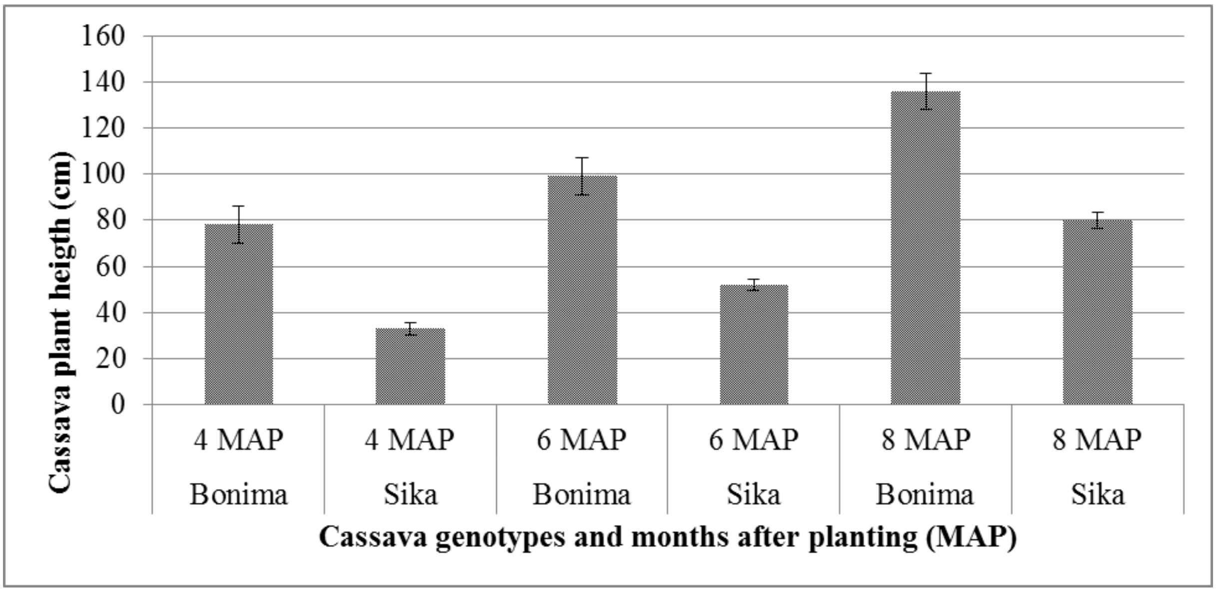

Figure 6: Effect of cassava genotype on mean plant height

Cassava stems numbers were not affected by genotype. However, the number of branches per plant was found to be significantly affected by the cassava genotype as presented in Figure 7. The mean number of branches of the two cassava genotypes had increased from 1.09 to 1.65 for *Bonima* and 1.34 to 2.06 for *Sika* respectively, during the periods of 4 to 8 MAP. From 6 to 8 MAP the number of branches remained constant. This study agrees with a previous finding by Allemann *et al.* (2004) in South Africa which showed that cassava crop branching characteristics is affected by the genotype. A higher number of branches per plant is important to expose cassava leaves to sunlight for photosynthesis and increased translocation for more photosynthate accumulation (Okogun *et al.,* 1999). On another hand, cassava stem diameter had been found not to be significantly affected by genotype differences.

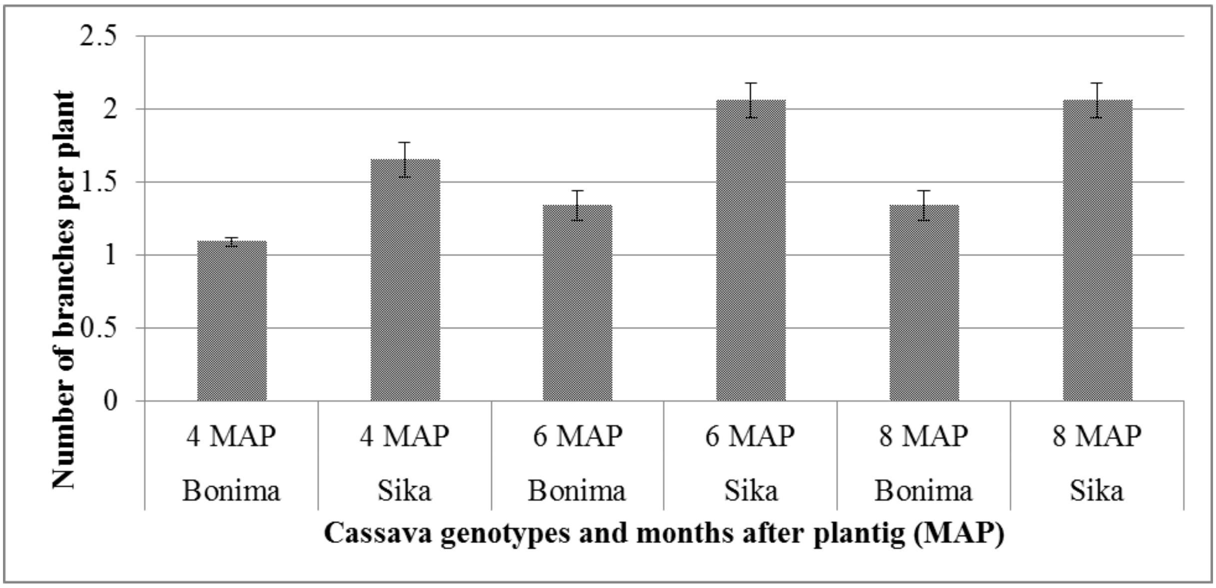

Figure 7: Effect of genotype on mean number of branches in cassava

4.2.3 Effect of site on cassava growth parameters

The effect of site on cassava plant height is presented in Table 7. Cassava plant height was found to be significantly ($p<0.05$) higher in Loulouni than Finkolo. In Loulouni site, cassava had grown from 83 cm at 4 MAP to 119 cm at 8 MAP which was an increased rate of 43%, while in Finkolo cassava had grown from 34 cm at 4 MAP to 98 cm at 8 MAP which was 188% increase rate. The growth rate was higher in Finkolo than Loulouni during the period of 4 to 8 MAP. It was observed that the environmental condition for early plant growth was more favorable in Loulouni. The difference in growth rate among the two sites may be attributed to the quantity of rainfall obtained (Table 1).

Table 7: Effect of site on mean height of cassava plant

	Cassava plant height (cm)		
Site	**4 MAP**	**6 MAP**	**8 MAP**
Loulouni	83^{A}	96^{A}	119^{A}
Finkolo	34^{B}	55^{B}	98^{B}
LSD $_{(0.05)}$	5.0	7. 9	12.1

Means with the same letter within a column are not significantly different at p=0.05 level of significance

Cassava stem number was found to be significantly ($P<0.05$) affected by site from 4 to 8 MAP as presented in Table 8. The number of cassava stem in Loulouni didn't change much from 4 MAP (1.86) to 8 MAP (1.87) but in Finkolo it increased from 1.46 to 1.61 during the same time. In Loulouni the early growth of cassava was attributed to the higher availability of soil humidity which was not the case in Finkolo.

Table 8: Effect of site on mean number of cassava stems

	Number of stems		
Site	**4 MAP**	**6 MAP**	**8 MAP**
Loulouni	1.86^{A}	1.87^{A}	1.87^{A}
Finkolo	1.46^{B}	1.61^{B}	1.61^{B}
LSD $_{(0.05)}$	0.144	0.186	0.186

Means with the same letter within a column are not significantly different at p=0.05 level of significance

Site effect on cassava number of branches was also found significant at only 4 MAP and is presented in Table 9. The cassava number of branches in Loulouni (1.66) was 55% higher than it number obtained in Finkolo (1.07). The site effect had been short because it disappeared at 6 and 8 MAP. The site effect on cassava number of branches is effective at the early growth stage.

Table 9: Effect on mean number of branches in cassava plants

	Number of branches per plant		
Site	**4 MAP**	**6 MAP**	**8 MAP**
Loulouni	1.66^{A}	1.73^{A}	1.73^{A}
Finkolo	1.07^{B}	1.66^{A}	1.66^{A}
LSD $_{(0.05)}$	0.11	0.28	0.28

Means with the same letter within a column are not significantly different at p=0.05 level of significance

Cassava stem diameter was found to be significantly affected by the site during all the observations times except at 8 MAP as shown in Table 10. At 4 MAP in Loulouni the stem diameter was 5.15 cm which was 127% higher than stem diameter in Finkolo (2.5 cm). This was due to the environmental stress caused by drought in Finkolo during the cassava plant early growth. The favorable environmental conditions allowed fast early growth of cassava in Loulouni. At 6 MAP the stem diameter in Loulouni decreased to 5.13 cm because of drought. While it increased in Finkolo form 2.59 to 3.30.

Table 10: Effect of site on cassava stem mean diameter

	Cassava stem diameter (cm)		
Site	**4 MAP**	**6 MAP**	**8 MAP**
Loulouni	5.51^{A}	5.13^{A}	5.62^{A}
Finkolo	2.59^{B}	3.30^{B}	5.33^{A}
LSD $_{(0.05)}$	0.29	0.45	0.55

Means with the same letter within a column are not significantly different at p=0.05 level of significance

On cassava plant height, only the site by genotype interaction effect was found to be significant among site by level of fertilizer and genotype by level of fertilizer interactions as shown in Figure 5. *Bonima* and *Sika* had higher plant heights in Loulouni than Finkolo during the observation times except for *Sika* genotype at 8 MAP which had similar heights in both sites. This height differences may be due to the higher natural soil fertility in Loulouni (Table 6).

Table 11: Effect of site by genotype interaction on cassava mean height

Site	MAP	Cassava mean height (cm)	
		Bonima	**Sika**
Finkolo	4	39.67^{A}	28. 92^{B}
	6	63.67^{A}	46.75^{B}
	8	113.25^{A}	82.33^{B}
Loulouni	4	115.75^{A}	4 9.75^{B}
	6	134.33^{A}	57.67^{B}
	8	160^{A}	78^{B}

Means followed by the same letter in a row are not significantly different at p=0.05
MAP: Months after planting

About the stem number among the three interactions studied namely site by level of fertilizer, genotype by level of fertilizer and site by genotype interaction, only site by genotype interaction was found to be significant from 4 to 8 MAP as presented in Figure 8. The number of stems for *Sika* and *Bonima* genotypes was constant in each site from 4 to 8 MAP. But its number in Loulouni was significantly higher from the ones in Finkolo for the two genotypes during the observation times. This implies that the favorable environmental conditions of Loulouni site were responsible for the increase of cassava plant stem number. This study is in agreement with findings in Brazil by Alfred (2002), which attributed the variations in stem number characteristics on cassava cultivar, cultural practices and climatic conditions. However, cassava cultivar having strong apical dominance develops only one stem.

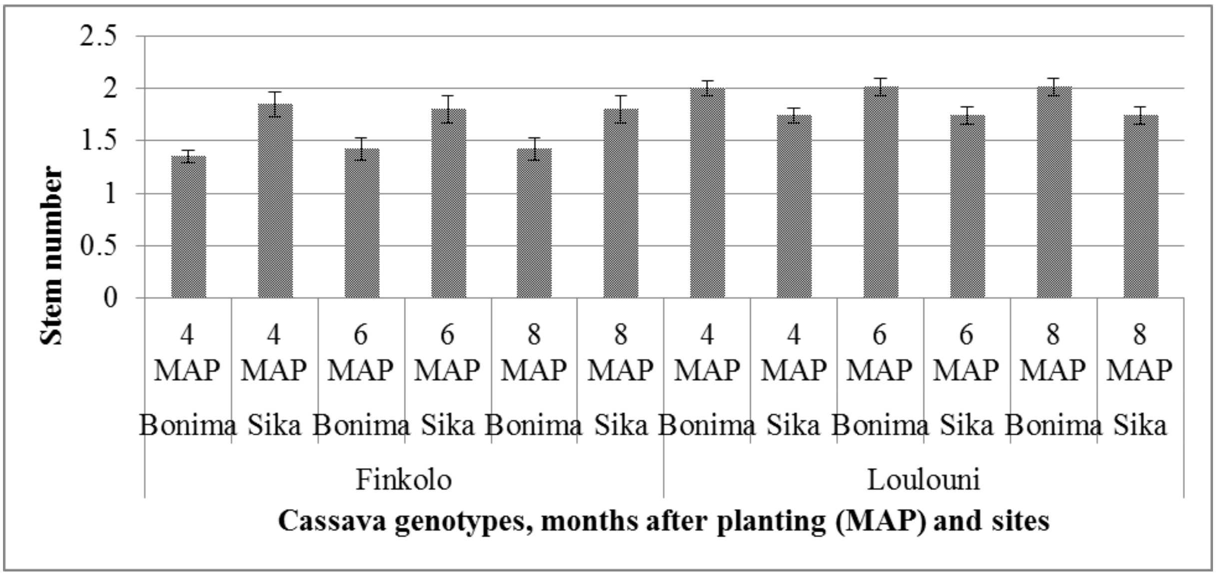

Figure 8: Effect of site by genotype interaction on cassava stem mean number

The number of branches per plant was found to be significantly affected only by the site by genotype interaction at 4 MAP as presented in Figure 9. In Loulouni, a number of branches at all-time for *Sika* genotype was found to be similar but was significantly different from *Bonima's*. The *Bonima* genotype itself did not show a significant difference during the observation times. In Finkolo, *Sika* genotype number of branches at 6 and 8 MAP were similar but differ from the one at 4 MAP. The same trend for *Bonima* genotype was observed. This implies that besides the genotype effect, the environmental conditions have an effect on the number of branches. Finally, no significant interaction effect was observed on cassava stem diameter.

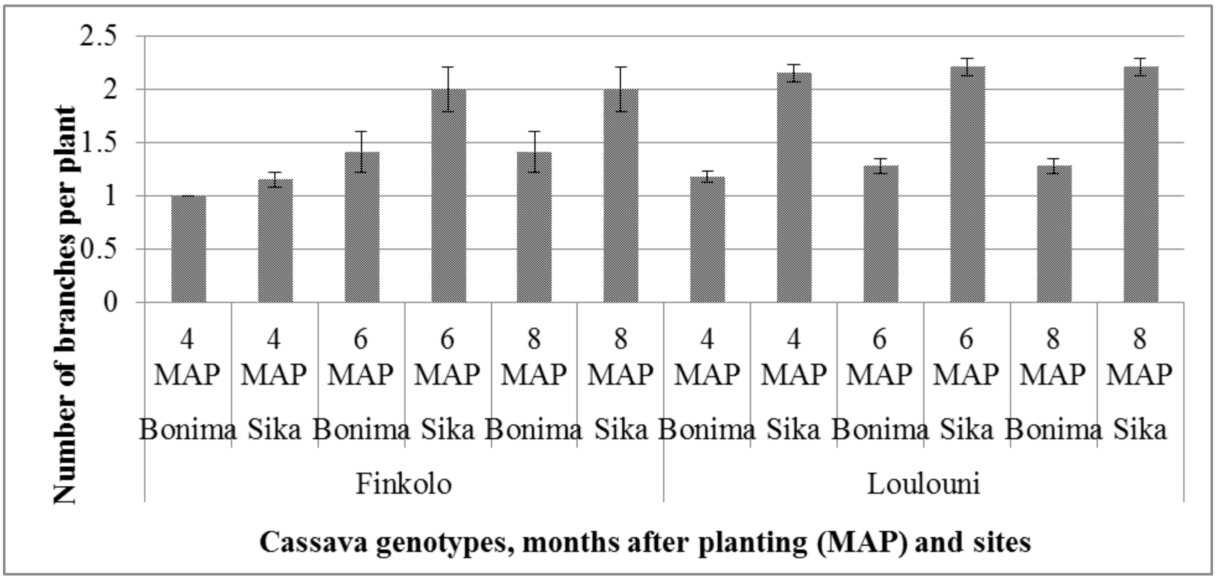

Figure 9: Effect of site by genotype interaction on cassava mean number of branches

4.3 Effect of NPK fertilizer, genotype and site on cassava yield parameters

4.3.1 Effect of NPK fertilizer on cassava yield parameters

The number of tuber per plant was significantly affected by NPK inorganic fertilizer as presented in Figure 10. The tuber produced by the application of the highest rate of inorganic NPK, 300 kg ha^{-1} (6.63 tubers per plant) was not significantly different from the number produced by the application of 200 Kg ha^{-1} of NPK (4.08 tubers per plant). However, the number of tubers per plant was significantly different from the number obtained through the application of 100 kg ha^{-1} of NPK and the control. The control and 100 kg ha^{-1} of NPK tuber number were not significantly different from each other. The application of 300 kg ha^{-1} of NPK had increased the number of tuber per plant by 49% compared to the control. The study showed an increasing number of tuber per plant with higher rates of inorganic NPK fertilizer. This finding is in agreement with a previous study in Kenya and Uganda by Anneke *et al.* (2010) which found that the application of 100, 50 and 100 kg ha^{-1} of N, P and K inorganic fertilizer respectively resulted in an increase in a number of storage roots per plant. In Malawi, the same trend was observed by Leo *et al.* (2015) when they showed a significant inorganic fertilizer effect on the number of tubers per cassava plant through the application of 200 kg ha^{-1} of the NPK compound 23:21:0:4S. The positive contribution of cassava number of tuber to yield gain was shown in a study by Amarullah *et al.* (2016) in which the number of tubers and the tuber weight during maximum vegetative phase was found to be positively correlated with the yield.

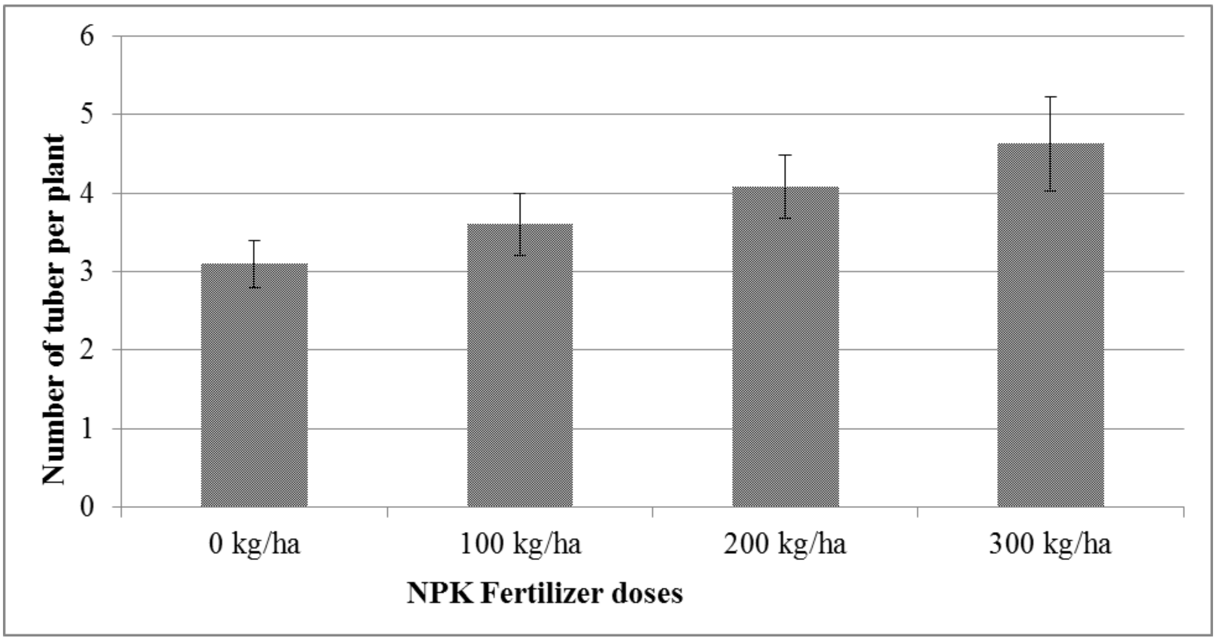

Figure 10: Effect of NPK fertilizer on mean number of cassava tubers per plant

Application of NPK fertilizer was found to significantly increase cassava fresh tuber yield (Figure 11). The yield obtained by the application of 0, 100, 200 and 300 kg ha^{-1} of NPK was 3982, 6451, 6537 and 9291 kg ha^{-1} respectively. The fresh tubers weight of the plot receiving 300 kg ha^{-1} of inorganic NPK was significantly higher than all other treatments. However, the application of 100 and 200 kg ha^{-1} of NPK were similar but higher than the control.

The 300 kg ha^{-1} of inorganic NPK had increased the tuber yield by 133% compared to the control. The cassava yields obtained from this study were low compared to other studies done in the region. This was mainly attributed to a prolonged drought the experiment experienced in the earlier growth period and the fact that the harvest was done after 9 months.

Fresh tuber yield from this study lacked an optimum time to yield it potential as suggested by Michael *et al.* (2015) in Nigeria who found, that for a cassava genotype to gained an optimum root yields a prolonged harvest beyond 12 months after planting is needed. In Nigeria, the application of 600 kg ha^{-1} of NPK (15-15-15) at 12 MAP produced 30.8 and 33.6 t ha^{-1} respectively from *TMS 92/0326* and *TMS 30572* genotypes (Edet *et al.*, 2013). This finding is similar to the findings of Ojeniyi *et al.* (2009) which showed significant positive responses of cassava to N, P, and K fertilizers in Asia, Latin American, Nigeria and another sub Saharan African countries. Also, a similar study in Malawi showed a significant inorganic fertilizer effect on cassava fresh tuber yield (Leo *et al.*, 2015).

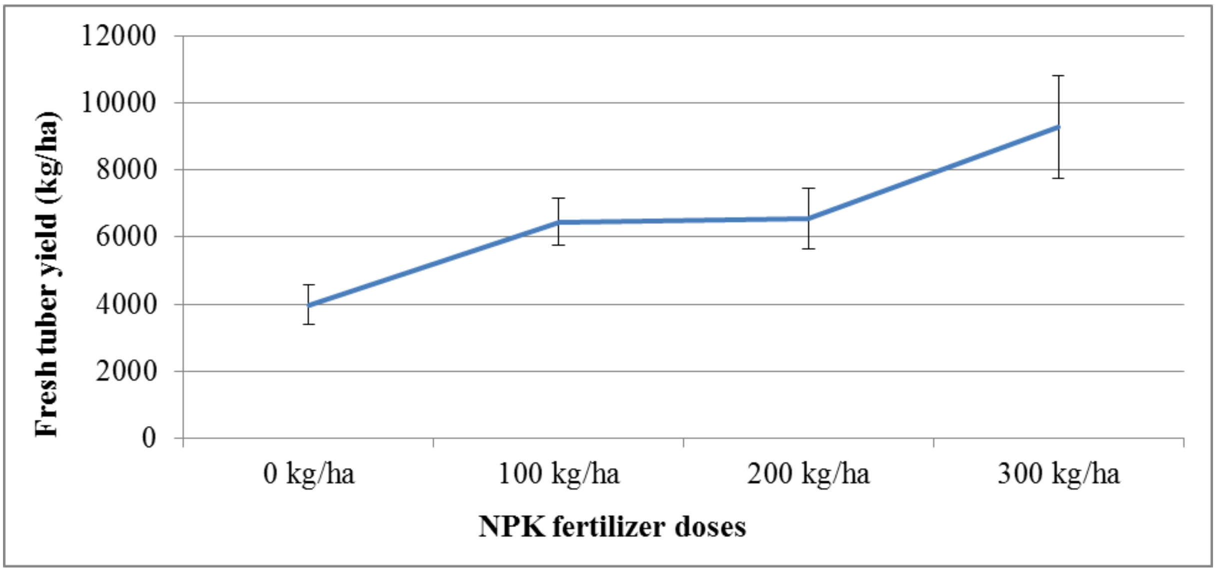

Figure 11: Effect of NPK fertilizer on mean cassava fresh tuber yield

4.3.2 Effect of genotype on cassava yield parameters

The number of tubers per plant was found to be significantly affected at harvest by the genotype. The *Sika* genotype had 4.9 tubers per plant which were 75% higher than *Bonima's* which had 2.8 tubers per plant. This difference was due to the genetic capacity of *Sika* to yield more tubers per plant than *Bonima* genotype.

Similar to tuber per plant, cassava fresh tuber yield also was found to be significantly affected by genotype. *Sika* genotype produced a yield of 8378 kg ha^{-1} which was 76% higher than the yield obtained by *Bonima* genotype (4753 kg ha^{-1}). The average production of *Sika* genotype was the twice of *Bonima's* genotype. In a comparative study for higher cassava genotype root yield between local and improved genotypes in Cameroon, the improved varieties did achieve a fresh tuber yield two times higher than that of the local one called *Ntolo* (Papa *et al.,* 2013).

4.3.3 Effect of site on cassava yield parameters

The number of tuber per plant in cassava was not affected by site. However, the fresh tuber yield was found to be significantly affected by site. Cassava fresh tuber yield in Loulouni (7476 kg ha^{-1}) was 32% higher than the fresh tuber yield obtained in Finkolo (5654 kg ha^{-1}). The more severe drought conditions during the early growth and less fertile soils in Finkolo compared to Loulouni were probably responsible for the poorer performance of cassava in this site.

The impact on the yield by these conditions was not reversed probably as the cassava plant was harvested in the nine months and did not have enough time to reach their potential yield (Michael *et al.,* 2015). The finding is similar to study from Indonesia showing that, cassava tuber yield was positively influenced by environment effect (Kartika, 2014). However, cassava numbers of tubers per plant were not significantly affected by either site by level of fertilizer, site by genotype, and nor genotype by level of fertilizer.

The cassava fresh tuber yield was significantly affected only by site by level of fertilizer interaction as presented in Figure 12. The application of 300 kg ha^{-1} of inorganic NPK recorded a yield increase of 112% in Loulouni compared to the control, 163% in yield increased was observed in Finkolo. The differences between the two sites yield may be due to drought stress experienced by the two sites with different responses according to the site environmental conditions. It is known that, the critical period for water deficit effect in cassava is from 1 to 5 MAP corresponding to the stages of root initiation and tuberization; during which time water deficit for at least 2 months can reduce storage root yield between 32 to 60% (Connor *et al.,* 1981).

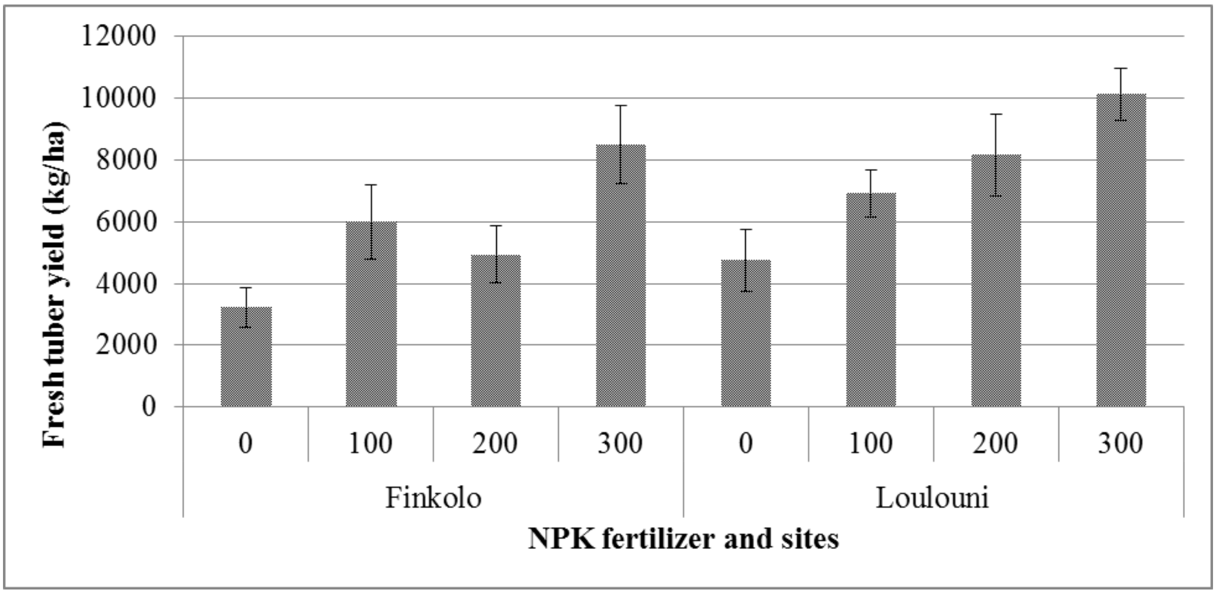

Figure 12: Interaction effect of site by NPK fertilizer on cassava mean fresh tuber yield

4.5 Correlation of cassava growth and yield parameters

Correlation between NPK inorganic fertilizer rates, fresh tuber yield, number of branches, number of tuber per plant, plant height and stem diameter are shown in Tables 12 and 13.

In Loulouni, Pearson correlation coefficients analysis (Table 12) shows the correlation between NPK inorganic fertilizer rates and fresh tuber yield; a strong correlation between the number of branches and number of tuber per plant was found. The number of tubers per plant and fresh tuber yield were found also to be strongly correlated. But there was a negative correlation between cassava plant height and number of branches by plant. Cassava stem diameter was also found to be correlated to the number of branches and number of tuber by plant. These findings are similar to the results obtained by Ntawuruhunga *et al.* (2001) in Uganda, in which cassava yield was positively correlated with root number per plant, stem girth and suggested that these traits contributed to the yield.

Table 12: Correlation of cassava growth parameters and yield in Loulouni

	NPK level	Plant height	Branch numbers	Stem diameter	Number of tubers/plant	Fresh tuber yield
NPK level	1.00000					
Plant height	0.0554ns	1.00000				
Branch numbers	0.2060ns	0.6681**	1.00000			
Stem diameter	0.2328ns	-0.0118ns	0.5670**	1.00000		
Number of tubers/plant	0.4854*	-0.4135*	0.7167***	0.5689**	1.00000	
Fresh tuber yield	0.6533**	-0.4030*	0.6076**	0.3306ns	0.7180***	1.00000

Ns: not significant; *Significant at p=0.05; ** significant at p=0.01; *** Significant at p=0.001

In Finkolo site, no strong correlations were found among the six parameters (Table 13). However, a significant correlation between a number of tubers per plant and number of branches per plant was found. Cassava stem diameter and plant height were also found to be correlated. This finding is similar to study by Amarullah *et al.* (2016) in which correlations between cassava growth parameters (plant height, stem diameter,) and yield components (number of tuber per plant and fresh tuber yield) were recorded. This implies that, from the maximum vegetative phase, growth parameters begin to show a significant positive contribution to the tuber weight. In addition, the weight of fresh tuber increased at tuber filling phase and thereafter (Amarullah *et al.*, 2016).

Table 13: Correlation of cassava growth parameters and yield in Finkolo

	NPK level	Plant height	Branch numbers	Stem diameter	Number of tubers/plant	Fresh tuber yield
NPK level	1.00000					
Plant height	0.3360ns	1.00000				
Branch numbers	0.2060ns	-0.4848*	1.00000			
Stem diameter	0.3440ns	0.6146**	0.0332ns	1.00000		
Number of tubers/plant	0.2144ns	-0.323ns	0.5829**	0.1571ns	1.00000	
Fresh tuber yield	0.3800ns	-0.0695ns	0.6422**	0.3231ns	0.3380ns	1.00000

Ns: not significant; * significant at p=0.05; ** significant at p=0.01; *** Significant at p=0.001

4.5 Regression of NPK fertilizer rates on cassava growth parameters and yield

Regression analysis between fertilizer rates versus fresh tubers yield and a number of branches are presented in Figures 13 to 24. In Loulouni, the regression analysis showed that cassava number of branches, the number of tuber per plant as well fresh yield of the two cassava genotypes increase as the NPK inorganic rates increase. The *Sika* genotype showed a higher coefficient of regressions presented in Figures (14, 16 and 18). The finding is similar to study by Onubuogu *et al.* (2014) in Nigeria which found that, cassava output was significantly related to the increases in fertilizer dose.

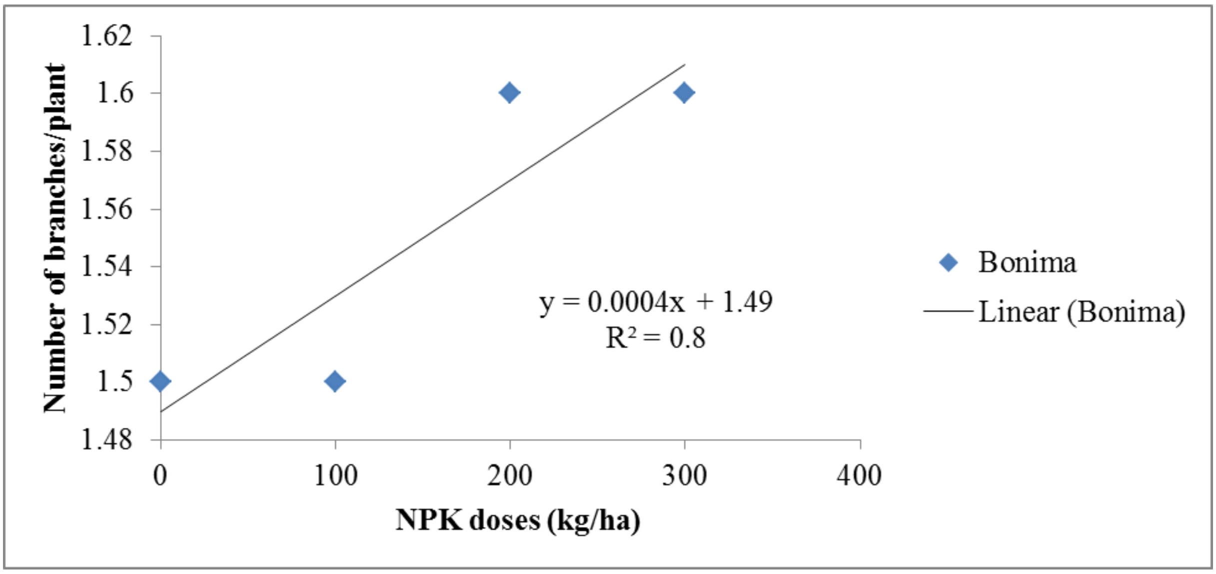

Figure 13: Regression of Bonima genotype mean number of branches per plant and the four NPK doses in Loulouni site

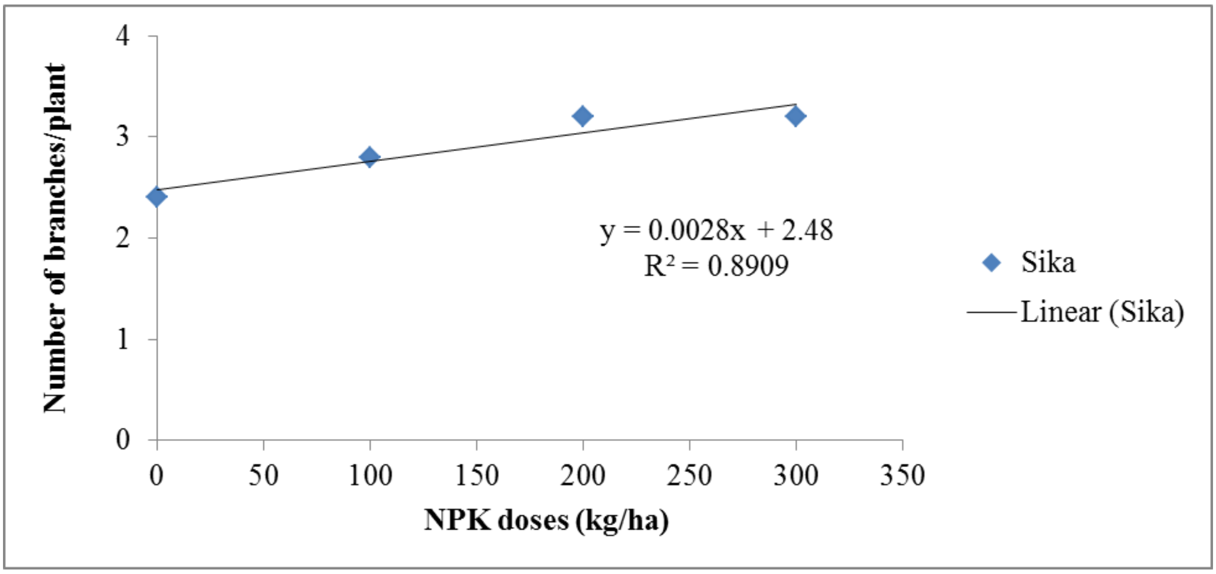

Figure 14: Regression of Sika genotype mean number of branches per plant and the four NPK doses in Loulouni site

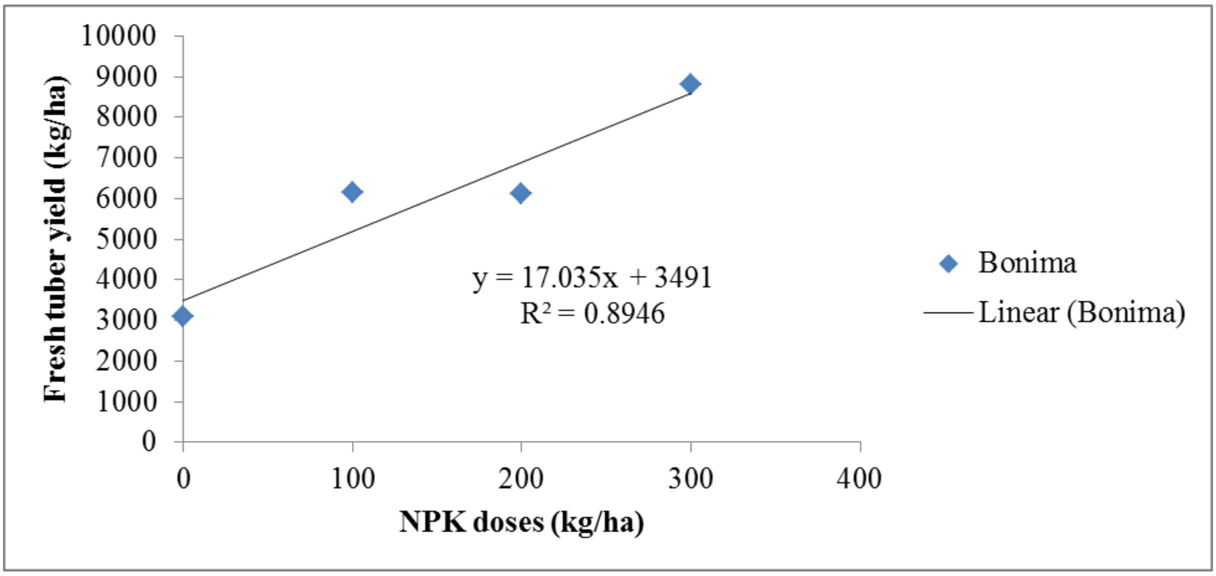

Figure 15: Regression of Bonima genotype mean yield and the four NPK doses in Loulouni site

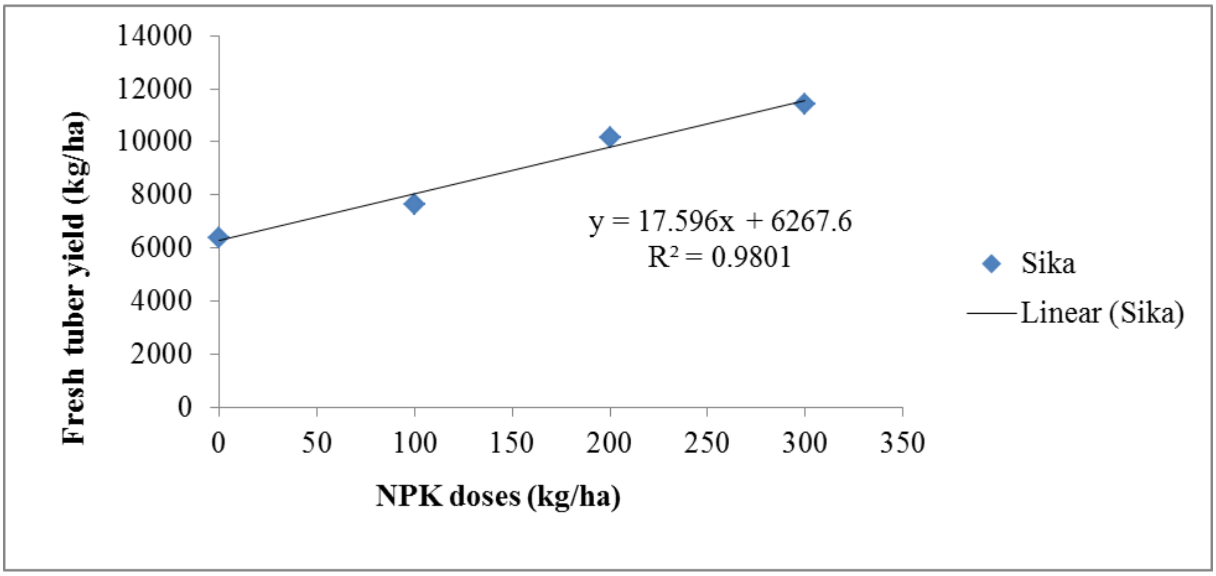

Figure 16: Regression of Sika genotype mean yield and the four NPK doses in Loulouni site

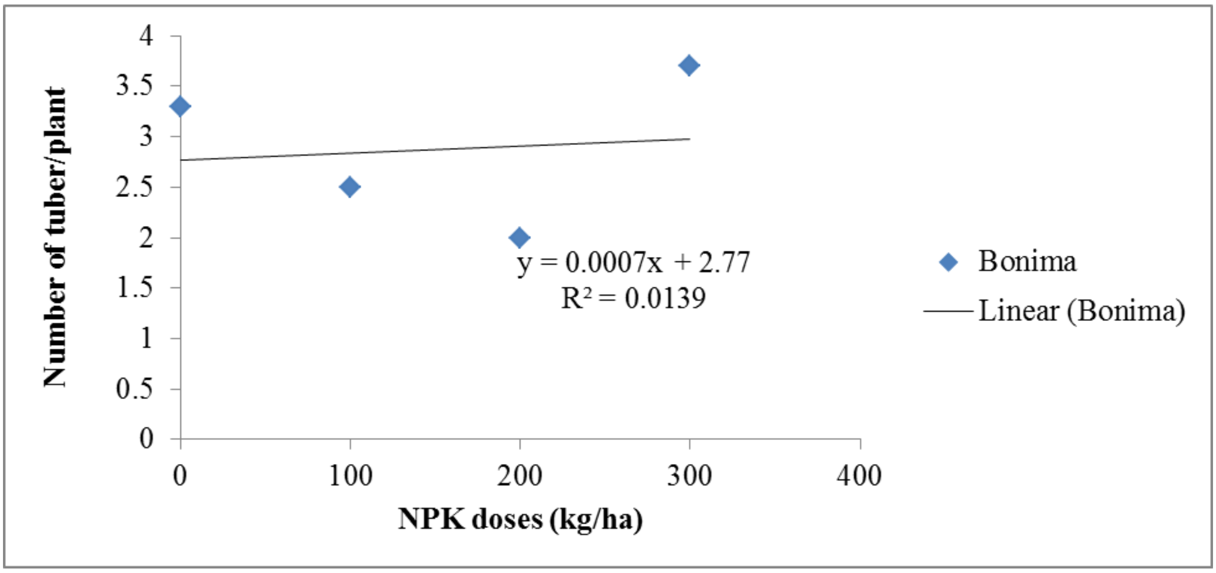

Figure 17: Regression of Bonima genotype mean number of tuber/plant and the four NPK doses in Loulouni site

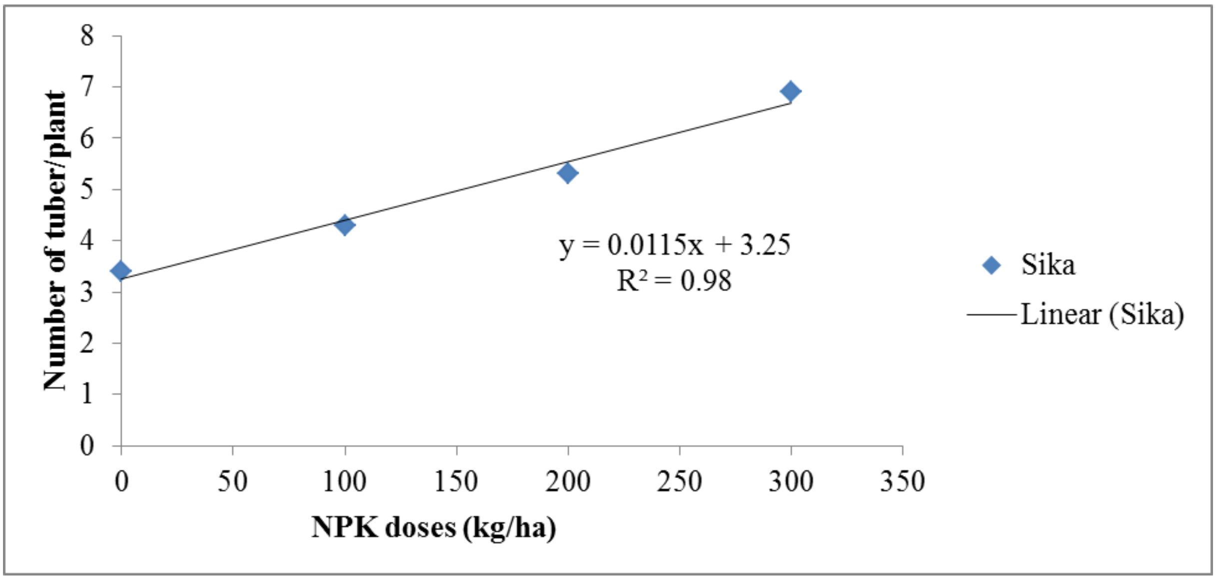

Figure 18: Regression of Sika genotype mean number of tuber/plant and the four NPK doses in Loulouni site

The regression analysis showed also in Finkolo that, cassava number of branches, number of tuber per plant and fresh tuber yield and of the two cassava genotypes increase as the NPK inorganic rate increase; with *Sika* genotype providing the higher coefficient of regression as presented in Figures (20, 22 and 24).

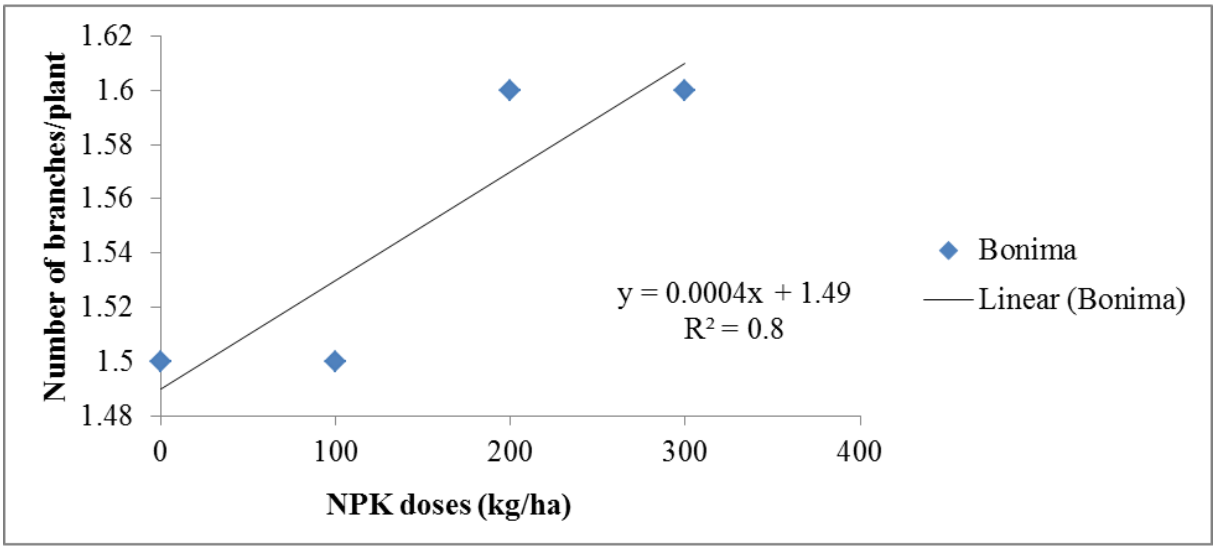

Figure 19: Regression of Bonima mean number of branches per plant and the four NPK doses in Finkolo site

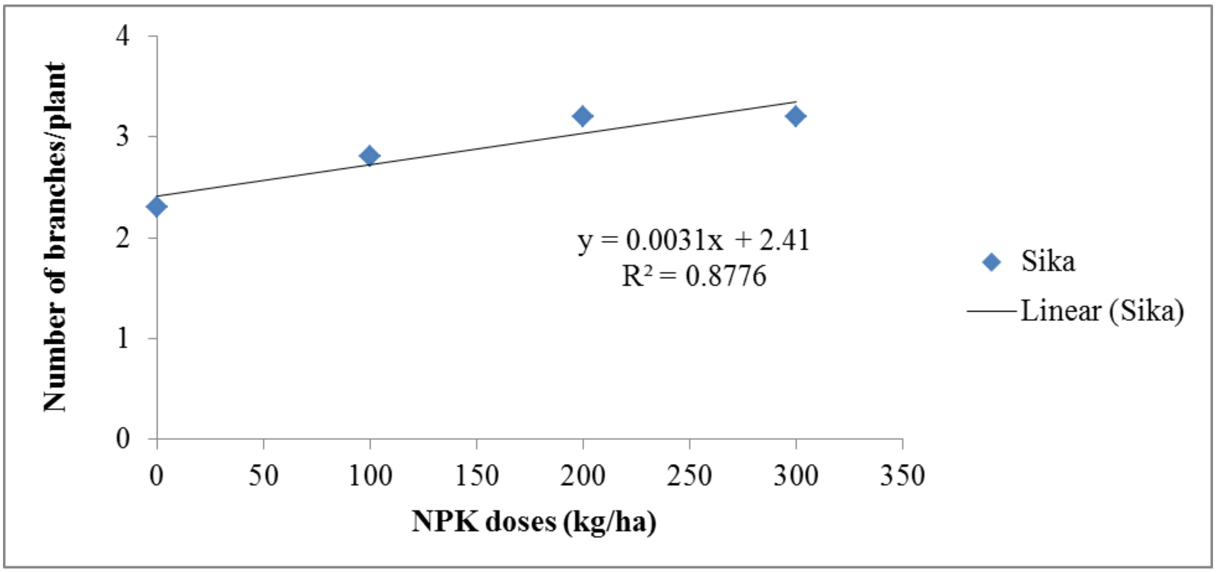

Figure 20: Regression of Sika mean number of branches per plant and the four NPK doses in Finkolo site

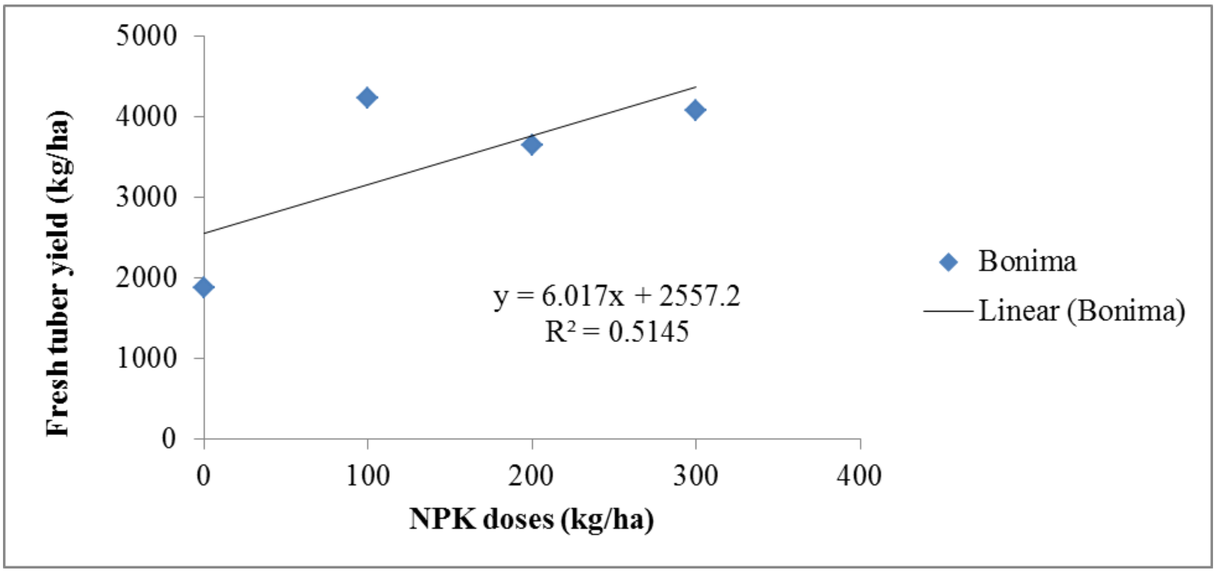

Figure 21: Regression of Bonima mean yield and the four NPK doses in Finkolo site

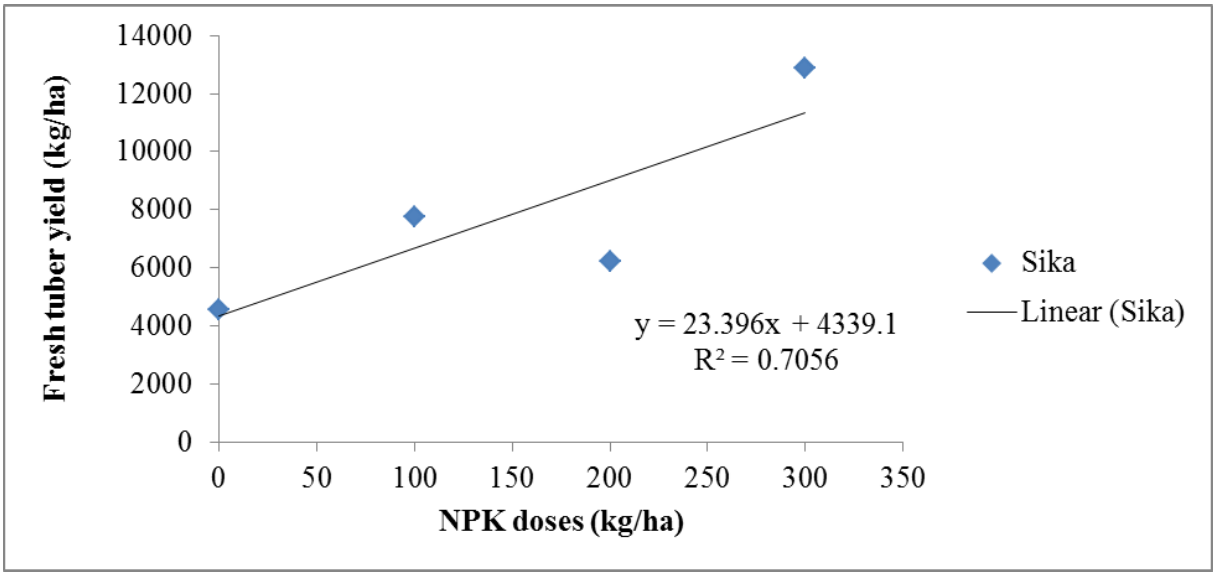

Figure 22: Regression of Sika mean yield and the four NPK doses in Finkolo site

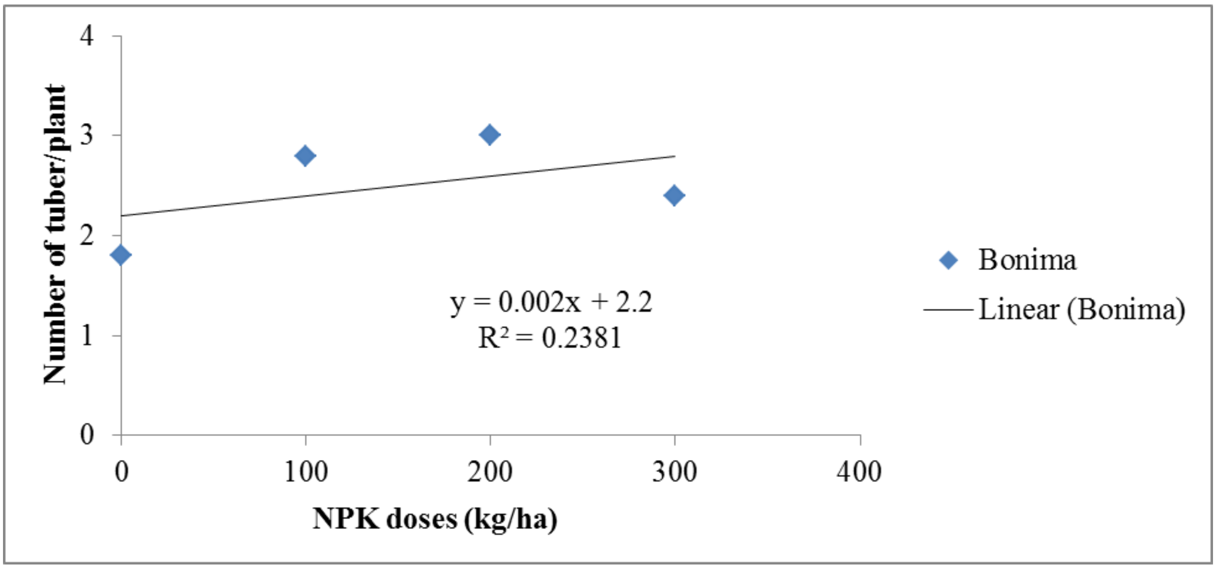

Figure 23: Regression of Bonima mean number of tuber/plant and the four NPK doses in Finkolo site

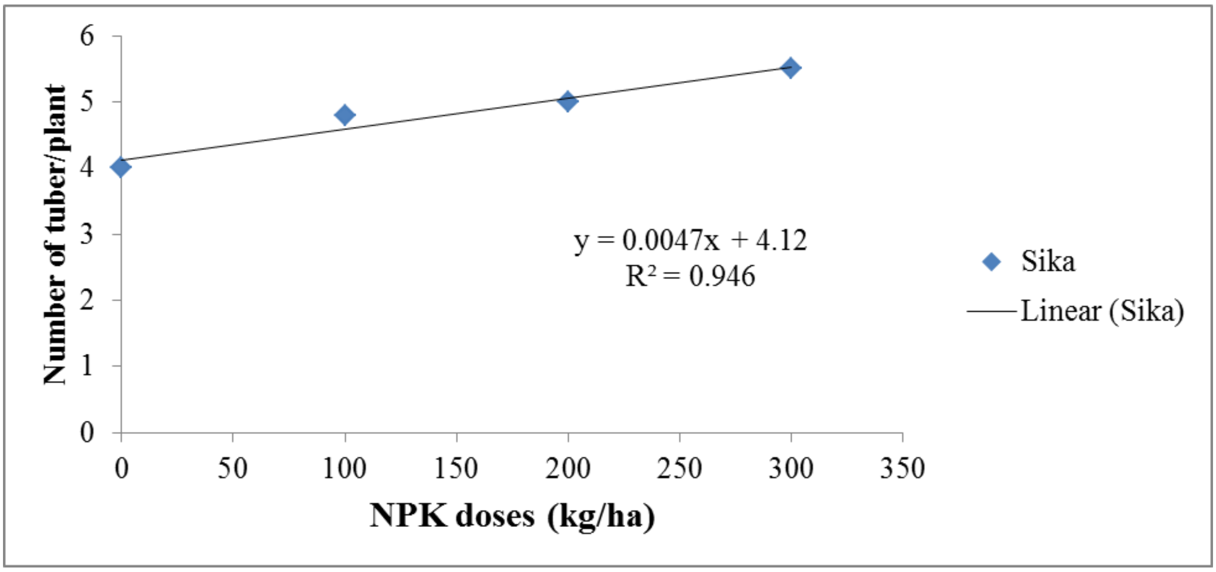

Figure 24: Regression of Sika mean number of tuber/plant and the four NPK doses in Finkolo site

4.6 Cassava agronomic nutrient use efficiency

The Analysis of Variance (ANOVA) revealed that only the treatments genotype, site and site by level of fertilizer interaction were found to be significant.

The genotype effect on cassava nutrient use efficiency (NUE) is presented in (Figure 25). The *Sika* genotype was found to have an NUE 3 times higher than the one of *Bonima* genotype. This finding is similar to study in which the NUE differences among genotypes groups were also significant with lowest values in the tall cultivars. It implies that short cassava cultivars are advantageous due to their higher nutrient use efficiency as compared to the tall ones (Mabrou *et al.,* 1998).

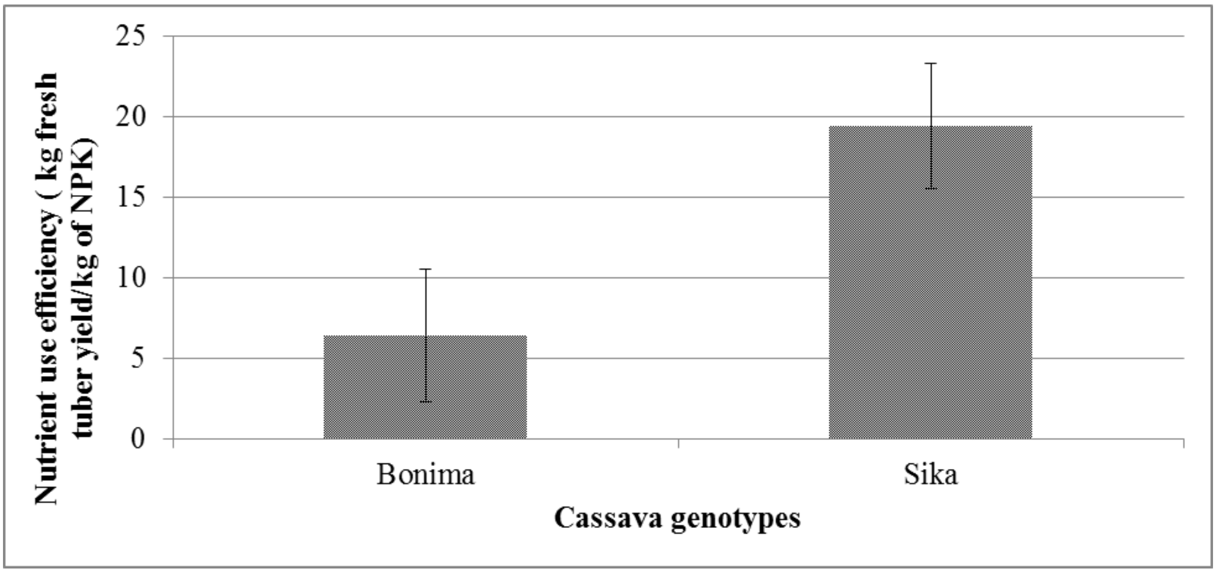

Figure 25: Effect of NPK doses on Bonima and Sika nutrient use efficiency

The site effect on cassava NUE is presented in Figure 26. The NUE in Finkolo was found to be 129 % higher than the one in Loulouni. This can be attributed to the faster nutrient use in Finkolo as the two site received irrigation during drought stress. But the irrigation in Loulouni stopped one and half month earlier than in Finkolo because of the lack of irrigation water availability in Loulouni. In Finkolo, cassava rooting systems benefited from good humidity and soil water shortages status for it to explore deeper soils and enhanced it NUE as demonstrated in a study by (Mabrouk, 2012).

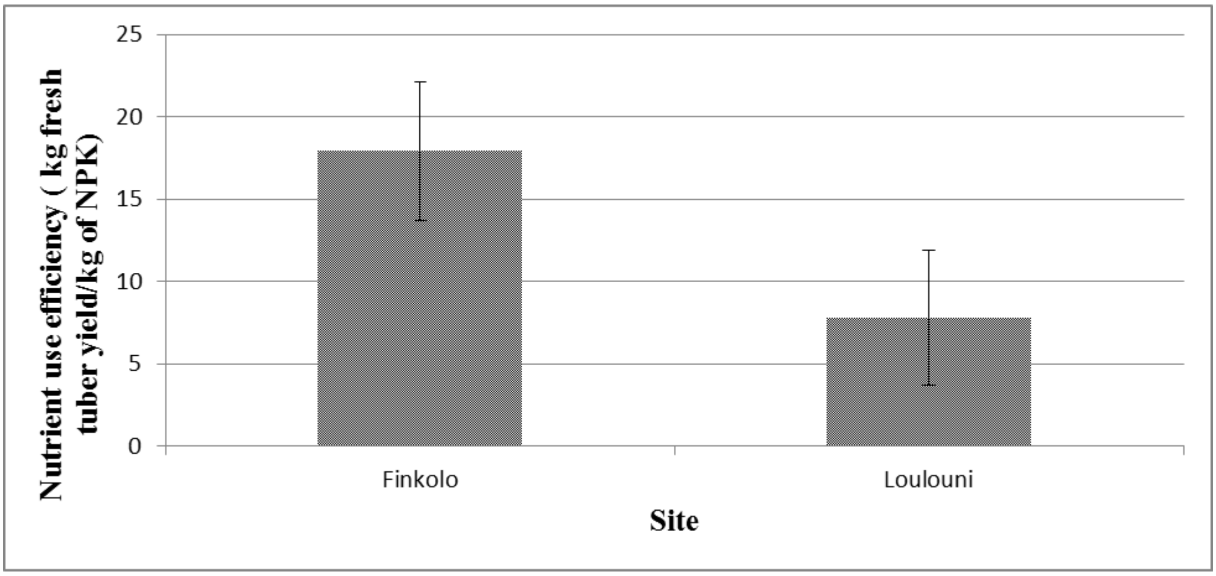

Figure 26: Effect of NPK doses on cassava nutrient use efficiency in Finkolo and Loulouni

Site by fertilizer level interaction effect on NUE is presented in Figure 27. In Finkolo the NUE of 100 and 300 kg ha^{-1} of inorganic NPK did not differ significantly from each other but were found to be from the application of 200 kg ha^{-1} of NPK. However, in Loulouni site, the NUE from the application of 200, 300 kg ha^{-1} were found to be not significantly different but the later was significantly different from the NUE of 100 kg ha^{-1} of NPK. Regardless of specified genotypes the NUE in Loulouni increases with the increase of inorganic NPK rates from -2.7, 11.8 to 14.4 kg of fresh tuber yield/kg of NPK respectively by the application of 100, 200 and 300 kg ha^{-1} of inorganic NPK. The NUE of 100 and 200 kg ha^{-1} were found to be similar in Loulouni. This finding is similar to study in Nigeria in which, cassava nutrient use efficiency (NUE) was found to increase with the increased dose of nitrogen up to 60 kg ha^{-1} (Umeh *et al.,* 2012).

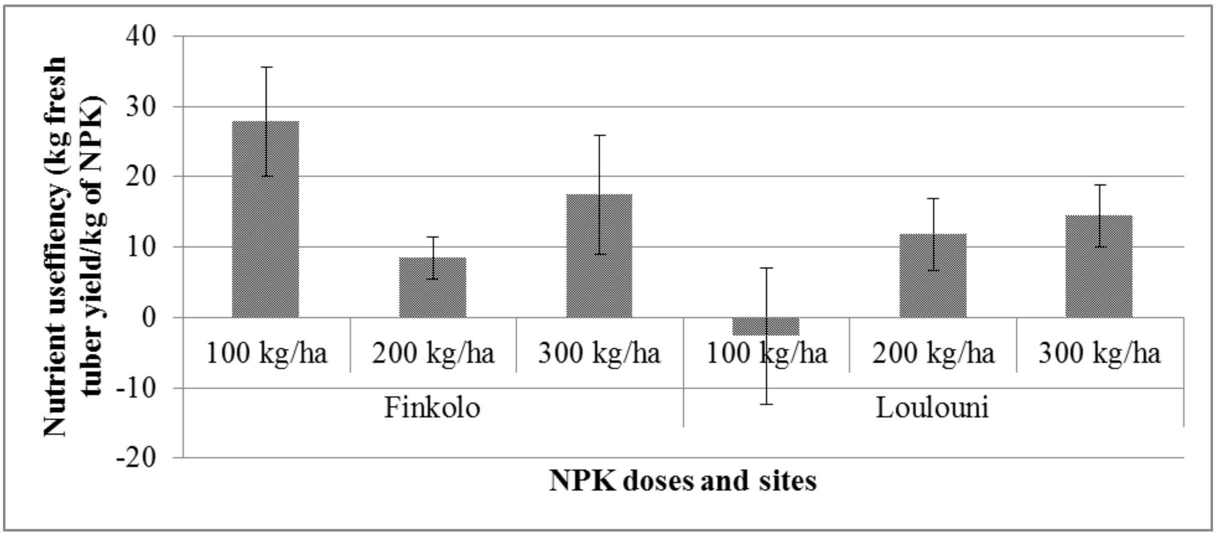

Figure 27: Effect of site by NPK doses on cassava nutrient use efficiency in Finkolo and Loulouni

4.7 NPK uptake in cassava plant leaves

In the study zone, ANOVA showed that the treatments site was significant at ($P<0.01$) on nitrogen uptake and significant at ($P<0.001$) on potassium uptake. The fertilizer level was found to be significant at ($P<0.001$) on the phosphorus uptake.

The effect of NPK fertilizer level on phosphorus uptake in cassava plant leaves is presented in (Figure 28). It was found that the phosphorus uptake from 300 kg ha^{-1} of NPK application which was 2.78 % was found to be significantly different from the phosphorus uptake through the application of 0, 100 and 200 kg ha^{-1} of NPK respectively. This implied that the application of the NPK increases the availability of phosphorus in the soil and had led to a significant uptake in the cassava plant leaves. This finding is similar to study in which the leaf phosphorus content was found to be positively affected by the time of assessment and nitrogen dosages in the soil and was explained by the greater development of absorbing roots stimulated by the larger availability of N in the soil, which in return increased the explored crop area and, consequently higher P uptake (Nádia *et al.*, 2014).

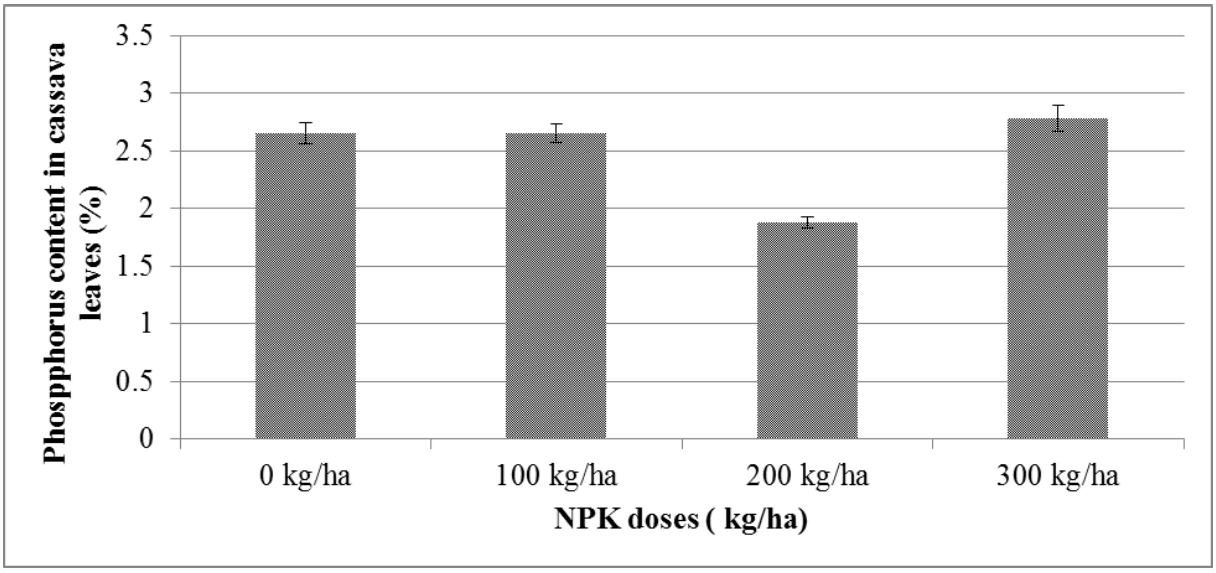

Figure 28: Effect of NPK fertilizer on the percent of phosphorus uptake in cassava leaves at 4 months after planting in the study area.

The site effect on nitrogen uptake in cassava leaves is presented in Figure 29. It was found that the nitrogen uptake in Finkolo which was 3.6% was 24 % higher than it uptake in Loulouni where it was 2.9%. This study is similar to finding in Puerto Rico in which the leaf nitrogen content of cassava plants grown at Corozal was significantly higher than that at Juana Díaz (Gustavo *et al.*, 2001).

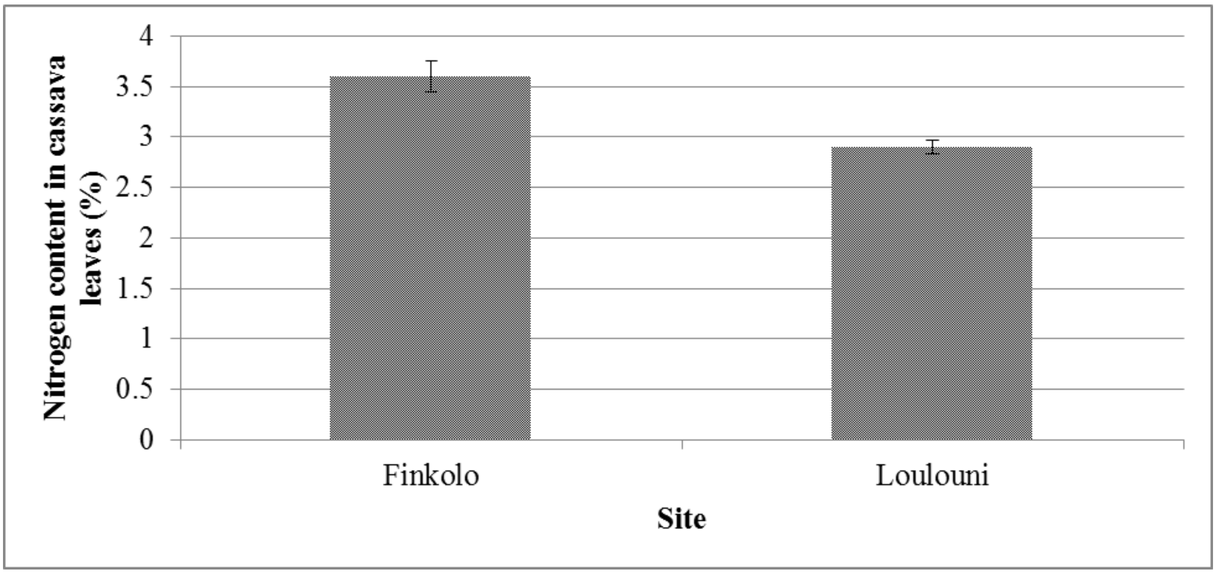

Figure 29: Effect of sites on the percent of nitrogen uptake in cassava leaves at 4 months after planting in the study area

In Figure 30 is presented the effect of site on potassium uptake in Finkolo and Loulouni. Like nitrogen, the potassium uptake in Finkolo was found to be 44 % higher than in Loulouni. The reason can be attributed to the fact cassava plant in Finkolo got favorable soil type and climatic conditions than in Loulouni for nutrient uptake in the leave at 4 MAP on the end of January month 2017. Irizarry *et al.* (1983) argued that the fertilizer needs vary depending on factors such as soil type, cultivar, and climatic conditions prevalent during the growing stages.

An adequate supply of K is important for starch synthesis and translocation, and it also increases yield and improves tuber quality (Mehdi *et al.*, 2007). From studies, it was stated that in West Africa (Ghana) cassava responded mainly to K, in Latin America (Brazil) to P and Asia (Indonesia and Thailand) to N (Hagens and Sittibusaya, 1990).

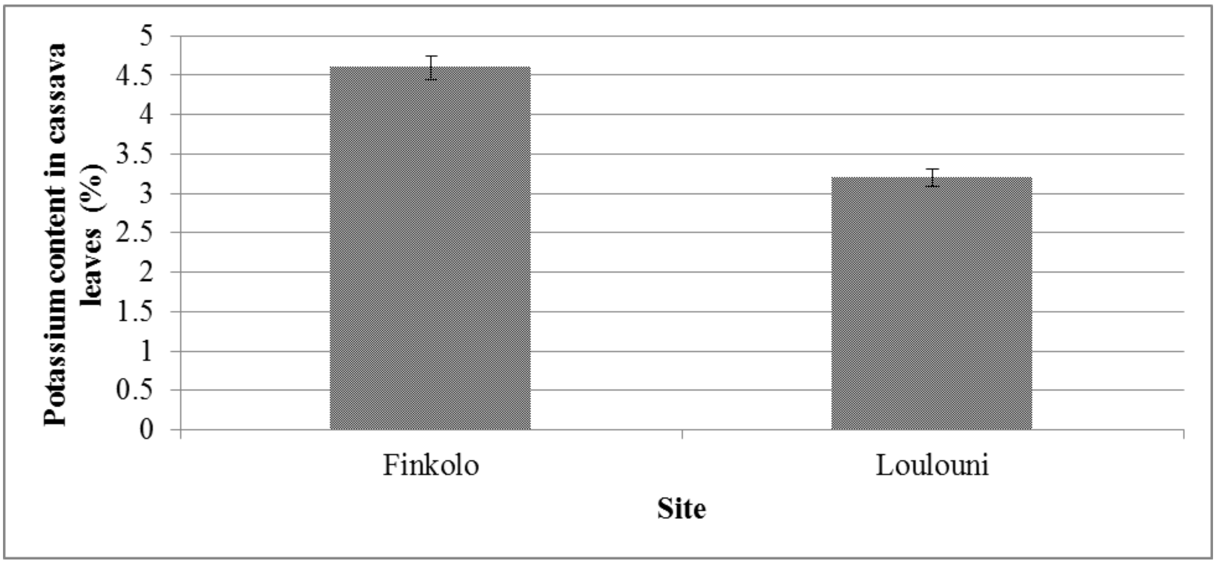

Figure 30: Effect of sites on the percent of potassium uptake in cassava leaves at 4 months after planting in the study area

4.8 Simple cost benefit analysis

The cost benefit was separately calculated for Loulouni and Finkolo.

4.8.1 Simple cost benefit analysis in Loulouni

The simple cost benefit analysis in Loulouni is presented in Table 14. In Loulouni the land preparation of one hectare of cassava is done per 5 men for 3 days with a cost of 96$. A bag of 50 kg of NPK fertilizer is sold at 20.83 $ in the market. The cuttings are not buying from the farmer. The weeding is done by 20 women for a cost of 33.33 $. Two men ensure the planting for 3.33 $. A group of men ensures the harvesting for 16.66 $. Cassava bag of 600 kg is transported at 2.5 $ from the field to the selling place. The prevailing market price of 0.16$ per kg of fresh cassava in July 2017 was realized.

Table 14: Cost benefit in Loulouni

NPK (kg/ha)	Yield(Kg/ha)	Gross margin (USD)	Input (USD)	Net benefit (USD)
000	4747	759.52	169.32	590.2
100	6906	1104. 96	219.75	885.21
200	8146	1303.36	266.58	1036.78
300	10106	1616. 96	316.40	1300.56

4.8.2 Simple cost benefit analysis in Finkolo

The simple cost benefit analysis in Finkolo as presented in Table 15. In Finkolo the land preparation and cuttings planting of one hectare of cassava are done per 20 men for 1 day with a cost of 45$. A bag of 50 kg of NPK fertilizer is sold at 20.83 $ in the market. The cuttings are not buying by the farmer. The weeding is done by 20 men for a cost of 47 $. A group of 16 men ensures the harvesting for 38.33 $. Cassava bag of 1000 kg is transported at 12.5 $ from the field to the selling place in Sikasso. A kilogram of cassava fresh tuber in Finkolo was sold at 0.10$

Table 15: Cost benefit in Finkolo

NPK (Kg/ha)	Yield(Kg/ha)	Gross margin (USD)	Input (USD)	Net benefit (USD)
000	3216	321.6	170.53	151
100	5997	599.7	246. 95	352.75
200	4928	492.8	275.25	217.55
300	8475	847.5	361.24	486.26

The cost-benefit analysis showed that on both sites the net benefit from cassava production increases with the increase rate of inorganic NPK (15-15-15). However, in Loulouni, the application of 300 kg ha^{-1} of inorganic NPK gave a net benefit of 1300.56 $ higher by 25%, 46% and 120 compared to the net benefit from 200, 100 kg ha^{-1} of inorganic NPK and the control plots respectively. While in Finkolo the highest NPK rate allowed a net benefit of 486.26 $ higher by 123%, 37%, and 222% compared to the net benefit obtained by the application of 200, 100 kg ha^{-1} of inorganic NPK and the control plots respectively. These finding showed that cassava production is a beneficial venture in the study areas. The finding is supported by a study done in Nigeria in which a gross margin of 141,850.00 Naira (401.84$) for one hectare of sole cassava was found and therefore declared that cassava farming is profitable in the area of Eket local government of Akwa Ibom State of Nigeria (Ebukiba and Elizabeth, 2010). In Nigeria, another study about cost benefit analysis showed that, with a cassava yield of 40 t ha^{-1} harvested between 15 and 24 months receiving 150 kg ha^{-1} of NPK (15-15-15) performed a gross margin of 68,662.50 Naira (194.50 $). The activity was also declared to be a profitable venture (Toluwase *et al.,* 2013).

In Bangladesh in Asia, Afreen *et al.* (2010) stated also that cassava production was a profitable activity in two different locations. They found an average gross margin for cassava of Bangladesh Taka (BDT) 61,880.36 (758 $) in Jhinaigati Upazila and BDT 105,885.10 (1,297 $) in Sreebardi Upazila respectively (Afreen *et al.,* 2010).

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The results of this study show that the application of the inorganic fertilizer NPK (15-15-15) improves both cassava growth and yield parameters confirmed by the regression analysis.

Sika genotype has higher yield use efficiency than *Bonima*. For NPK nutrient level in cassava leaves, the level was P increases through higher rate of inorganic NPK application while the level N and K are favorable in Finkolo site. The production of cassava qualifies as beneficial activity in the study area of Sikasso.

5.2 RECOMMENDATION

1. *Sika* genotype as a higher NUE than *Bonima*, resulting in more tubers per plant and fresh tuber yield in both study site and therefore is recommended.
2. The application of 300 kg ha^{-1} of NPK had a higher yield and net benefit than the other NPK rates and therefore recommended for cassava production in the study zone.
3. Another NPK (15-15-15) application study should be done at higher rates to establish the optimum rate.
4. A study of the use of NPK and organic manures on common cassava genotypes planted in the country should be done to make a recommendation on the reduced use of inorganic fertilizers.

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APPENDICES

Appendix 1: ANOVA on cassava plant height at 4, 6 and 8 MAP

Source of variation	Df	4 MAP	P Value	6 MAP	P Value	8 MAP	P Value
Levelfer	3	180.13194ns	0.803	468.96528ns	0.0736	2134.07639**	0.0064
site	1	28178.52083***	<.0001	19967.52083***	<.0001	5440.02083**	0.0013
Sie*levelfer	3	18.40972ns	0.8563	106.18750ns	0.6294	1008.90972ns	0.0891
geno	1	17671.68750***	<.0001	26273.52083***	<.0001	38025.02083***	<.0001
Site*geno	1	9157.68750***	<.0001	10710.18750***	<.0001	7726.68750**	0.0002
Geno*levelfer	3	87.35417ns	0.3231	124.74306ns	0.5670	588.68750ns	0.2630
Cv		14.48		17.80		18.88	
R2		0. 96		0. 92		0.85	

Ns: Not significant *: p<0.05 ** : <0.01 ***: p<0.001

Appendix 2: ANOVA on cassava stem number at 4, 6 and 8 MAP

Source of variation	Df	4 MAP	P Value	6 MAP	P Value	8 MAP	P Value
Levelfer	3	0.10290208ns	0.1239	0.03167222ns	0.8107	0.03167222ns	0.8107
site	1	1.94810208***	<.0001	0.83213333**	0.0073	0.83213333**	0.0073
Sie*levelfer	3	0.07785764ns	0.2912	0.16615000ns	0.1948	0.16615000ns	0.1948
geno	1	0.07785764ns	0.8373	0.03000000ns	0.5864	0.03000000ns	0.5864
Site*geno	1	0.74750208**	0.0014	1.29363333**	0.0012	1.29363333**	0.0012
Geno*levelfer	3	0.03458542ns	0.6317	0.1626611ns	0.2025	0.16266111ns	0.2025
Cv		14.62		18.04		18.04	
R2		0.76		0.64		0.64	

Ns: Not significant ***: p<0.05** **** : <0.01** *****: p<0.001**

Appendix 3: ANOVA on cassava number of branches per plant at 4, 6 and 8 MAP

Source of variation	Df	4 MAP	P Value	6 MAP	P Value	8 MAP	P Value
Levelfer	3	0.04092500ns	0.3450	0.97970000*	0.0161	0.99521875*	0.0120
site	1	4.16540833***	<.0001	0.08333333ns	0.5597	0.25085208ns	0.3014
Sie*levelfer	3	0.09014722ns	0.0771	0.65452222ns	0.0629	0.37617986ns	0.1981
geno	1	3.80813333***	<.0001	6.13470000***	<.0001	14.77410208***	<.0001
Site*geno	1	2.01720000***	<.0001	0.56333333ns	0.1363	0.39421875ns	0.1977
Geno*levelfer	3	0.04522778ns	0.3023	0.16575556ns	0.5639	0.08826319ns	0.7608
Cv		13.72		28.72		22.4	
R2		0. 91		0.66		0.77	

Ns: Not significant *: p<0.05 ** : <0.01 ***: p<0.001

Appendix 4: ANOVA on cassava stem diameter at 4, 6 and 8 MAP

Source of variation	Df	4 MAP	P Value	6 MAP	P Value	8 MAP	P Value
Levelfer	3	0.4773806ns	0.1425	1.38112500ns	0.0929	3.82205764*	0.0119
site	1	102.6090083***	<.0001	40.26003333***	<.0001	1.03546875ns	0.2840
Sie*levelfer	3	0.2123139ns	0.4661	0.86392778ns	0.2418	1.35259653ns	0.2217
geno	1	0.6533333ns	0.1123	1.91200833ns	0.0813	2.93535208ns	0.0767
Site*geno	1	0.1541333ns	0.4323	0.01763333ns	0.8632	0.03575208ns	0.8406
Geno*levelfer	3	0.3066167ns	0.3064	0.30018056ns	0.6756	0.50082431ns	0.6345
Cv		12.14		18.09		16. 97	
R2		0. 94		0.77		0.56	

Ns: Not significant ***: p<0.05** **** : <0.01** *****: p<0.001**

Appendix 5: ANOVA on cassava yield parameters

Source of variation	Df	Number of tuber/plant	P Value	Fresh tuber yield	P Value
Levelfer	3	5.01092986*	0.0231	56462661.2**	0.0004
Site	1	1.81351875ns	0.2608	39845318.5*	0.0246
Site*levelfer	3	1.68359097ns	0.3196	7005116.0 ns	0.7510
Geno	1	53.53075208***	<.0001	157676625.2***	<.0001
Site*geno	1	0.59630208ns	0.5163	7005116.0 ns	0.3307
Geno*levelfer	3	2.07575764ns	0.2331	6096503.6 ns	0.4774
R2		0.64		0.66	

Ns: Not significant   *: p<0.05   ** : <0.01   ***: p<0.001

Appendix 6: ANOVA on cassava nutrient use efficiency

Source of variation	Df	Mean square	P Value
site	1	912.644100*	0.0526
Site*geno	1	111.302500ns	0.4832
Site*levelfer	2	965.041058*	0.0236
Levelfer	2	100.055003ns	0.6392
Geno	1	1522.300278*	0.0145
Geno*levelfer	2	122.577519ns	0.5793
R^2		0.54	

Ns: Not significant   *: p<0.05   ** : <0.01   ***: p<0.001

Appendix 7: ANOVA on NPK uptake in cassava plant leaves at 4 MAP

Source of variation	Df	NUP	P Value	PUP	P Value	KUP	P Value
Levelfer	3	0.13675764ns	0.7696	2.01999097***	<.0001	0.19801667	0.6958
site	1	6.15616875**	0.0003	0.08085208ns	0.4474	23.82900833***	<.0001
Site*levelfer	3	0.05875764ns	0.9207	0.01706875ns	0.9442	0.68769167ns	0.1942
geno	1	0.54826875ns	0.2289	0.08416875ns	0.4383	0.89653333ns	0.1501
Site*geno	1	0.66976875ns	0.1849	0.17400208ns	0.2679	0.62107500ns	0.2283
Geno*levelfer	3	0.12131319ns	0.7999	0.01477431ns	0.9543	0.19741667ns	0.6968
Cv		18.42		14.7		16.52	
R2		0.52		0.69		0.74	

Ns: Not significant *: p<0.05 ** : <0.01 ***: p<0.001