YIELD RESPONSE OF NEWLY RELEASED CASSAVA GENOTYPES AND HYBRID MAIZE TO INTERCROPPING AND INORGANIC FERTILIZERS IN UGANDA

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DECLARATION

I **Ekwaro Benson** declare that the work presented in this dissertation is my original work and has not been presented for any award in any other university or institution of higher learning.

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APPROVAL

This dissertation has been submitted for examination with our approval as university supervisors.

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DEDICATION

This work is dedicated to my dear parents: Mr. Abili James and the Late Auma Hellen, my lovely wife Molly Ekwaro and my children Anek Peace, Abili Timothy, Gole Jordan and Ekwaro Savior, all my brothers and sisters, and the entire Okum Clan.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
COSCA	Collaborative Study for Cassava in Africa
DM	Dry Matter
FAO	Food Agriculture Organization
FAOSTAT	Food and Agriculture Organization Statistics
IITA	International Institute of Tropical Agriculture
LAI	Leaf Area Index
LSD	Least Significant Difference
MAP	Months After Planting
NARO	National Agricultural Research Organization
RCBD	Randomized Complete Block Design

ABSTRACT

This study determined the effect of intercropping the newly developed cassava (*Manihot esculenta* Crantz) genotypes with hybrid maize (Longe 6H) and NPK fertilizer application on the growth and yield of the component crops. The specific objectives were to determine the effect of maize planting density in the cassava/maize intercrop on the growth and yield of the component crops, and to determine the effect of NPK fertilizer on the growth and yield of the newly released cassava genotypes.

In experiment one, two newly released cassava genotypes NAROCASS 1 and NASE 14 intercropped with Longe 6H maize were evaluated in different combinations including sole maize (SM), sole cassava (SC), one row of maize and cassava (1C:1M), and two rows of maize and cassava (1C:2M). Intercropping significantly influenced maize plant heights; cob length, the number of rows per cob and the maize grain weight when compared with sole cropping. The cob length and the number of rows per cob decreased in the order SM>1C:1M>1C:2M indicating that as the plant population density increases, the cob length and the number of rows per cob gradually decrease. In both NAROCASS I /Maize and NASE 14 /Maize intercrops, maize grain yield under the low plant density (1C:1M) was comparable to sole cropping than those at the higher plant density (1C:2M). Thus indicating that increasing maize plant population density (1C:2M) significantly reduced grain yields compared to grain yields at low plant population density (1C:1M). Similarly, cassava root yield decrease in the same order (SM>1C:1M>1C:2M) indicating that increased in population gradually reduced root yield. The land equivalent ratio (LER) values for intercrops were greater than one, indicating yield advantage of intercropping over sole cropping.

In experiment two, the effects of NPK fertilizer on the growth and yield of the newly released cassava genotypes were assessed at three levels of 200, 400 and 600 kg/ha. Fertilizer application up to 400 kg/ha significantly ($P<0.05$) influenced the cassava root length, fresh

root tuber yield and number of cassava root tubers per plant when compared with the control treatment plots. Interestingly, the incremental addition of NPK did not significantly ($P>0.05$) affect the tuber girth of NAROCASS 1. However, the increase in NPK application up to 400 kg/ha significantly ($P<0.05$) increased the tuber girth in NASE 14.

Based on the results, it was concluded that (i) intercropping newly developed maize and cassava genotypes in the ratio of 1:1 is a feasible cropping system which increases total land productivity, and (ii) application of NPK fertilizer significantly improves the yield potential of cassava.

Based on the above conclusions, it was recommended that small scale farmers should intercrop the newly developed maize and cassava genotypes in the ratio of 1:1 in order to increase the total land productivity and yield potentials of cassava/maize intercrops. Those who can afford should apply NPK fertilizer up to 400 kg/ha to improve the root yield of cassava. In addition, further research is required to scale up the study to include more maize and cassava genotypes, and be carried out in different agro-ecological zones of Uganda. Furthermore, there is need to determine the agronomic and economic use efficiencies of NPK fertilizer in the cassava/maize intercropping systems.

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Cassava (*Manihot esculenta* Crantz) is a shrubby perennial plant that grows to the height ranging between one and four metres with leaves varying in size and shape. It is a tuberous crop that produces long and tapered storage roots that are a major source of carbohydrates for humans. Depending on the cultivar and growing conditions, these large storage roots are harvested between six and 24 months after planting [MAP] (Alves, 2002). According, to Nweke *et al.* (1999) the roots can remain in the soil for one to two years without rotting, particularly under drought conditions

During its growth, cassava develops alternating periods of vegetative growth and carbohydrate storage in its roots (Alves, 2002). The fibrous roots can absorb water and nutrients in the soil at one MAP and become storage roots from two to six MAP (Howeler, 2002). The storage and translocation of carbohydrates from leaves to the roots may occur within six to ten MAP. To get maximum crop productivity, the number of storage roots and their mean weight is crucial for the cassava crop (Alves, 2002).

Cassava is believed to have originated from America but today it is cultivated in the tropical Africa, Asia and America where 38, 36 and 26%, respectively of the world production occurs (Ayoola *et al.*, 2007b). Cassava is the third most important energy staple crop of the tropics, providing food and income to about 750 million people (FAOSTAT, 2010). The total estimated world fresh-root production reached 122 million metric tons (MT) in 1980. According to FAOSTAT, 2010), in the last five decades, total cassava production in Africa has increased from 31 to 118 million MT per year. In fact, most of the increased production in Africa is due to increase in land under production rather than increase in yield per hectare (Howeler, 2002).

However, in the humid and sub-humid tropical regions, cassava is extensively grown and the maximum root production is expected to occur in the tropical lowlands below 150 meters above sea level (FAO, 2012). Cassava can be grown in a wide range of altitudes up to 2300 – 3000 meters above sea level and annual rainfall conditions from less than 600 mm in unimodal rainfall areas to above 2000 mm in bimodal rainfall zones (Alves, 2002). Cassava is adapted to a wide range of ecological conditions and is known to tolerate low soil fertility, drought and pests than any other crop. Recent estimates indicate that 40 and 50% of the cassava grown in America and Africa is intercropped, whereas in Asia, this percentage is likely to be lower (Fonseca, 1981). Each continent and region has developed its own characteristic crop combinations and sequences, the position of cassava often being at the end of relay intercropping systems.

However, the greatest complexity of cassava intercropping systems is probably found in Africa, close to homestead gardens of rural farm families (Ayoola and Makinde, 2007a). When smallholder farmers adopt intercropping as the production system, a relatively small plot is sufficient to provide the family with the basic dietary elements. In Uganda, cassava production is characterized by intercropping with several short duration crops, such as maize, beans, sorghum and many others (Willy and Osiru, 1972). According to Osiru and Ezumah (1991), cassava/maize intercrop is the most common and compatible combination.

Cassava is grown by smallholder farmers in marginal areas as it has the capacity to produce reasonable yields on degraded soils where other crops do not produce well. Besides, it is well adapted to acidic soils with high levels of exchangeable aluminum (Howeler, 2002). Additionally, it can withstand low concentration of phosphorus (P) in the soil due to its association with mychorrhiza fungi that can increase the transportation of **P** to the roots (Howeler, 2002). According to El-Sharkawy and Cock (1986), unlike other crops cassava has greater water use efficiency and can tolerate water shortage.

Declining land productivity is a major problem facing the smallholder farmers in sub-Saharan Africa (SSA) due to low soil fertility, limited available resources to farmers and nutrient mining (Chukwuka and Omotayo, 2009). According to Bationo *et al.* (2006), fertility of Africa's soil is inherently low since African soils are very old and lack volcanic rejuvenation with nitrogen (N) commonly deficient in these soils. In fact, the population pressure coupled with limited land has forced the farmers not to practice crop rotation, hence over-burdening the soils leading to depletion of soil nutrients (FAO, 2000). Also, intensified cropping activities on the available cropland resources have resulted in alteration of the natural physical and chemical properties and an overall decline in fertility (Omotayo and Chukwuka, 2009). Continuous cropping without external nutrient input such as mineral fertilizers depletes the soil nutrient pool, and this unavoidably results into low crop yields. While already farmers consider cassava as a major staple crop, it has the potential to be an important part of the solution to improving food security in times of climate change, hunger and suited for poor soils (El-Sharkawy and Cadavid, 2003).

However, the major limitations associated with cassava production in Uganda include low inherent yielding varieties, soil infertility, erratic and unpredictable climatic conditions, pests and diseases notably cassava mosaic disease (CMD) and cassava brown streak disease (CBSD) (Fermont *et al.*, 2008; Pypers *et al.*, 2011). As a result of the limited use of fertilizer inputs, soil fertility is the main cause of decreasing cassava production in East and Central Africa (CIALCA, 2006). Because arable land under agricultural production in Uganda has been severely mined of nutrients over time, inorganic fertilizers provide an option for reversing the negative agricultural productivity trends. Fertilizer application has been and continues to be a key ingredient in intensified agricultural systems globally (Fermont, 2008). Increasing pressures on agriculture have resulted in much higher nutrient outflows and the subsequent breakdown of many traditional soil fertility maintenance strategies. However, sustainable cassava production depends on the use of genotypes adapted to the environment (Zinsou *et al.*, 2004) together with cultural practices like intercropping and fertilizer application. On the other hand, agronomic practices like plant densities, crop arrangement and relative planting times can increase productivity in cassava/maize intercropping systems (Pypers *et al.*, 2011).

The agricultural sector is under enormous pressure, to meet food demand of a projected population of 9.2 billion in 2050, particularly meeting this demand together with increased challenges from climate change, competition from bio-energy, and land degradation (FAO, 2008). Worldwide, 850 million people suffer from undernourishment (FAO, 2000). Yet, there is a great potential for increasing crop yields in most parts of Uganda, and it is possible to reduce and even erase the gap between the actual yield and the potential yield (Sanchez *et al.*, 2002). Meeting an increasing demand for cassava in an emerging cassava industrial sector will require availability of basic agronomic information on fertilizer requirements and proper fertilizer recommendations for higher tuber yield and quality (NaCRRI, 2017).

1.2 Problem statement

Cassava accounts for a third of the total food production in the SSA (Hillocks, 2002). In Uganda, cassava is currently one of the most important food crops, and is ranked second to bananas, providing around 13% of the daily caloric intake (Bua *et al.*, 2012). Despite its importance, cassava yields per unit area in Uganda are relatively low; averaging to 12.6 MT/ha compared to the yield potential of 25.5 MT/ha (Fermont *et al.*, 2009). The reasons for this wide yield gap include low inherent yielding varieties, soil infertility, and persistent and low use of inputs such as mineral fertilizers, pests and diseases, unpredictable climatic conditions such as floods and droughts, and lack of national cassava industrialization strategy (MAAIF/FAO, 2011).

Therefore, in order to meet the ever growing demand for cassava in Uganda, more improved cassava varieties have been developed and released (NARO, 2016). In spite, of availability of improved varieties, yields are still below the achievable yields. Accordingly, numerous alternatives have been proposed to improve and sustain cassava production. Amongst these are the use of inorganic fertilizers (FAO, 2013) and carefully designed cropping systems (Okalebo *et al.*, 2006). In fact, intercropping is the principle means of intensifying crop production as well as improving returns from limited land holdings.

Intercropping may lessen intra-specific competition which consequently may improve nutrient utilization by the intercropped plants (Nguyen *et al.*, 2002). In fact, intercropping reduces weed growth, improves yield stability and promotes efficient use of resources thereby reducing input costs. However, there is limited information on the performance of newly released cassava varieties when intercropped with hybrid maize. Also, the effect of inorganic fertilizer application on the performance of these newly released cassava varieties is very limited and scanty, although fertilizer use in cassava production elsewhere has been reported to significantly increase cassava yields (Howeler, 2002). In addition, the declining land productivity is an issue which must be confronted head on, hence requiring the fertilizer usage to be addressed. This study, therefore, aimed at evaluating the yield performance of newly developed cassava genotypes when intercropped with hybrid maize, and when inorganic fertilizers are applied.

1.3 Justification of the study

The demand for food is rising rapidly and will continue to rise due to rapid population growth and reduction in arable land. In Africa, cassava has been a major food security crop in times of famine due to its adaptability to marginal areas. As a result, it has been widely grown in the tropical and sub-tropical areas. However, the role of cassava as a food security crop especially to the poor households is under threat due to an increase in both biotic and abiotic constraints that limit the attainment of optimal yields. Poor farming practices and soil miming as a result of harvest and failure to apply fertilizers are causing degradation in soil fertility. In order to obtain optimum yields, cassava growers will have to go a step ahead by applying inorganic fertilizers, practicing intercropping, growing improved cassava varieties that are high yielding and tolerant to diseases, and adopting best agronomic practices.

To achieve the yield potential of cassava, maintaining soil fertility through adequate fertilization is essential (Agbaje and Akinlosotu, 2004). Intercropping is practiced by many farmers to increase total yields per unit area of land per unit time, avoid total crop failure and ensure efficient utilization of labour, among others. However, despite the associated advantages there is no cassava breeding program that has been carried out to identify varieties specifically for intercropping. Therefore, the need for such varieties arises from the fact that varieties selected on the basis of monoculture performance may not necessarily perform the same way as under intercropping system (Osiru and Ezumah, 1991).

The introduction of improved varieties is one of the most effective and cost-effective means of enhancing crop productivity and household incomes (Kueneman, 2002). But ensuring sustainability of production of improved cultivars requires agronomic packages based on sound scientific principles. The high yielding cassava varieties with high demand for nutrients and other growth habits like branching and leafiness will probably aggravate the soil fertility problems and competitive abilities under intercropping (Adeniyan *et al.*, 2014).

In Uganda, very few studies have been conducted to evaluate the newly developed and released varieties for their yield potential under intercropping system and response to mineral fertilization. Yet, fertilizer usage plays a major role in the universal need to increase food production to meet the demand of the growing world population. Thus, this study determined whether these newly released cassava varieties selected on the basis of monocrop performance performed equally well when intercropped with hybrid maize varieties and when supplied with inorganic fertilizers.

1.4 Objectives of the study

1.4.1 General objective

To improve the productivity of newly developed cassava varieties when intercropped with hybrid maize varieties and supplied with inorganic fertilizers.

1.4.2 Specific objectives

1. To determine the effect of maize planting density in the cassava/maize intercrop on the growth and yield of the component crops.
2. To determine the effect of NPK fertilizer application on the growth and yield of the newly released cassava varieties.

1.5 Hypotheses

1. Maize planting density in the cassava/maize intercrop significantly influences the growth and yield of the component crops.
2. The application of NPK fertilizer in the cassava/maize intercrops significantly influences the growth and yield of newly developed cassava varieties.

CHAPTER TWO

LITERATURE REVIEW

2.1 Origin of cassava and maize

Cassava appears to have originated in Brazil and Paraguay, but has spread throughout tropical areas of the South and Central America long before the arrival of Columbus (Mim, 2003). According, to Olsen and Schaal, (1999) one school of thought wild populations of *M. esculenta* sub-species *flabellifolia*, is believed to be the progenitor of domesticated cassava and centered in Brazil, where it was likely first domesticated more than 10,000 years. In mythology it is portrayed as a savior that protects against starvation. By 6600 BC, manioc pollen appeared in the Gulf of Mexico lowlands, at the San Andrés archaeological site. Mimura, (1999), reported that, the oldest direct evidence of cassava cultivation comes from 1,400-year-old Maya site, Joya de Cerén, in El Salvador (University of Colorado, 2007) and the species *Manihot esculenta* likely originated further south in Brazil, Paraguay and Argentina. Cassava is now one of the most important food crops in tropical countries throughout the world and ranks as the 6th most important food crop worldwide, even though in western countries it is little known (Aminu, 2000). With its high food potential, it has become a staple food of the native populations of northern South America, southern Mesoamerica, and the Caribbean by the time of the Spanish conquest (Mimura, 1999). Cassava cultivation was continued by the colonial Portuguese and Spanish. Forms of the modern domesticated species can be found growing in the wild in the south of Brazil. While several *Manihot* species are wild, all varieties of *M. esculenta* are cultigens (Mishra *et al.*, 1993). Cassava was a staple food for pre-Columbian people in the America's and is often portrayed in indigenous art (Berrien *et al.*, 2010) since being introduced by Portuguese traders from Brazil in the 16th century, maize and cassava has replaced traditional African crops as the continent's most important staple food crops (FAO, 2000).

Maize originated in the Andean region of Central America and is one of the most important cereals both for human and animal consumption and is grown for grain and forage. Present world production estimate at 594 million MT from about 139 million hectare (FAO, 2000). Maize is an important staple cereal crop produced in all agro-ecologies of West and East Africa, with a demonstrated high yield potential in the savanna zones (FAO, 2000). In sub-Saharan Africa, maize is mostly grown by small-scale farmers, generally for subsistence as part of mixed agricultural systems (FAO, 2000). Many researchers believe the introduction of maize to Africa is very recent compared to Europe and Latin America (Ristanovic, 2001).

2.2 Botany of cassava and maize

Cassava is a shrubby perennial plant of height ranging between one and four metres with leaves varying in size and shape. Cassava is a tuberous crop that produces long and tapered storage roots that are a major source of energy and carbohydrates. Depending on the cultivars and growing conditions, these large storage roots are harvested 6 to 24 months after planting [MAP] (Alves, 2002) and can remain in the soil for 1 to 2 years without rotting particularly under drought conditions (Nweke *et al.*, 2002). During its growth, the cassava develops alternating periods of vegetative growth and carbohydrate storage in its roots (Alves, 2002). Under favorable conditions, the photosynthetic process occurs in plant growth after the true leaf appears at about 1 MAP. Most of the leaves and stems develop during 3 to 6 MAP. Since the leaves can intercept most of light incidence during the first 3 MAP, maximum canopy size may reach at 6 MAP (Hillocks, 2002).

The fibrous roots can absorb water and nutrients in the soil at 1 MAP and storage roots may initiate when few fibrous root become storage roots from 2 to 6 MAP (Howeler, 2002). The storage of carbohydrate from leaves to roots may occur within 6 to 10 MAP. In humid and sub-humid tropical regions cassava is extensively grown and the maximum root production is expected to occur in the tropical lowlands below 150 meter altitude (FAO, 1999).

Cassava can be grown in a wide range of altitude (sea level to 2300 metre altitude) and rainfall conditions from less than 600 mm in unimodal rainfall areas to above 2000 mm in bimodal rainfall zones (Alves, 2002). In general, cassava is grown by smallholder farmers in marginal areas and has a capacity to produce reasonable yields on poor or degraded soils where other crops do not produce well (Howeler, 2002). According to El-Sharkawy and Cock (1986), unlike other crops cassava has greater water use efficiency and can tolerate water shortage. Cassava is well adapted to acid soils (low pH) and high level of exchangeable Aluminum. In fact, it can withstand low concentration of **P** in the soil due to the association with mychorrhiza fungi that can increase the uptake and transportation of **P** to the roots and increase the explored soil volume (Howeler, 2002).

Maize is a plant that stores varied materials, such as starch, protein, fat and other foodstuffs. The crop has a wider range of uses including human food, industrial products like starch and forage to feed animals (Amin, 2011). As a crop, maize can be grown on most Ugandan soils but does best on soils that are well drained. In the recent past however, due to changes in climate (Dalipagic and Elepu, 2014). It is therefore not easy any more to tell when rain is expected. Most households in Uganda grow maize as smallholder farmers for food security and household income with an average yield of 2.4 MT/ha in 2009/10. In Uganda, maize is grown in nearly all parts of Uganda though Busoga region has the largest acreage of maize fields. Also, there is considerate production in Bunyoro and Bugisu regions (MAAIF, 2002).

According to NARO (2010), the optimum temperature for plant growth and development range is 30-34 °C. The cool conditions at high altitude lengthen the cycle or growing period. Temperatures below 5 °C and above 45 °C result in poor growth and death of the maize plant. In general, temperatures in Uganda are favorable for maize production as long as appropriate varieties are grown in areas for which they were bred. For example, highland maize is suitable for highland areas (MAAIF, 2002).

Evidence shows that Uganda's maize agro-ecology can be categorized as largely mid-altitude and highland. The bulk of maize is grown in the mid-altitude that occupies about 85% of the total maize and the highland ecology occupies 15%. However, the highland agro-ecology, particularly the Mt. Elgon region, is a major growing area, accounting for about 30% of the total production. Regionally, the largest production is in eastern region (38%), followed by northern region (24%), central region (19%), and western region (19%). MAAIF (2010) reported that maize is one of the top priority food crops in Uganda. Maize is the cereal crop that provides calorie requirement in the traditional Ugandan diet. Apart from use as a diet, maize leaves and its stalk are fed to animals. In addition to the highest total production per annum and the highest per-hectare yield, maize is also the single most important crop in terms of number of farmers engaged in cultivation in Uganda (NARO, 2010).

2.3 Importance of cassava

Cassava production and consumption continues to grow at a high rate in Africa, Asia and South America. Cassava is the second most important root crop in the world after potatoes (*Solanum tuberosum*) and second most important staple crop in Africa after maize (FAO, 2009a). According to Nyembe and Kambewa (2008), the world annual production of cassava is over 158 billion MT. Aminu (2000) also confirmed that amount is used for various uses including human consumption (58%), animal feed (22%), and other uses (20%).

2.3.1 Used as human food

Cassava is grown on an estimated 80 million hectares in 34 African countries. It is an important crop in subsistence farming, as it requires few production skills and inputs. It is a major and the cheapest source of carbohydrates to over 800 million people worldwide contributing over 500 KCal/day (FAO, 2009b). The tubers of cassava are rich in starch, and are the richest source of starch than any food plant and contains up to 10 times as much starch as corn and twice as much as sweet potato (Duke, 2013). Cassava leaves contain high amounts of vitamins (A and C), minerals (iron, zinc, calcium, potassium) and proteins, and are consumed as vegetable in many areas (FAO, 2012). The cassava root flour is also used to make cassava bread (Diziedzoave *et al.,* 2008). The flour is also made into a paste and fermented before boiling after wrapping in banana leaves. This last form has a long shelf life and is a preferred food to take on long trips where refrigeration is not possible (Yusif, 2013).

2.3.2 Used as animal feed

Both the roots and leaves of the cassava plant can be used as on-farm animal feed or as an ingredient in commercial animal feed (Howler, 2012). Because of their high cyanide content, however, fresh roots or leaves can be fed to animals only in very small quantities. Cassava roots are chipped or sliced, while leaves are chopped into small pieces. The chopped pieces of roots and leaves can be sun dried or packed tightly in plastic bags or air-tight containers and fermented to make silage (Howler, 2005). Both sun-drying and ensiling will release most of the cyanide, making those products safe as feed for pigs, cattle, and chickens.

2.3.3 Source of biofuel

In many countries, significant research has begun to evaluate the use of cassava as an ethanol biofuel feedstock (Graham *et al.,* 2000). For example, Nigeria has gone a step forward by producing ethanol biofuel from cassava. This means that cassava is not only a food security crop but also a raw material for many industries and therefore contributing to economic development.

2.3.4 Medicinal uses

Cassava is not commonly used in herbal medicine, but indigenous people do use it for various healing purposes. The leaves can be used as a styptic, while the starch mixed with rum has been used for skin problems, especially for children (Rudrappa, 2014).

The leaves of bitter varieties are used to treat hypertension, headache, and pain (Anderson and Ingram, 1993). As cassava is a gluten-free, natural starch, it's use in western cuisine as a wheat alternative for sufferers of celiac disease is becoming common (Dziedzoave, 2006).

2.4 Importance of maize

Maize is an important grain crop of the world and it ranks second, after wheat in hectare (177,379,567 ha) and first in total production (872,066,770 MT) and productivity (4.9 MT/ha) (FAOSTAT, 2012). According to USDA-FAS (2013) United States is the largest global producer of corn accounting for approximately 35% and 32% of global production during the 2011 and 2012 growing seasons, respectively.

In Uganda, maize is one of the most important cereal crops (Isabirye and Rwomushana, 2016). Evidence from research shows that maize is one of the most important food security crops in Uganda (Isabirye and Rwomushana, 2016). It is the third most-cultivated crop after banana and beans (FAO, 2012). In some regions of the country, the crop has now become a staple food, replacing crops like sorghum, millet, cassava and banana (Agona *et al.*, 2001; Doss *et al.*, 2003). It provides over 40% of the calories consumed both in rural and urban areas. Over 90% of Uganda's maize is produced by smallholders, of which about 60% of the annual maize output is consumed on the farm.

2.5 Cassava production in the world

Africa is the leading producer of cassava in the world, and the major producing countries are Nigeria, Democratic Republic of Congo (DRC), Angola, Ghana and Mozambique (Table 1). Asia (mainly Thailand and Indonesia) comes second in cassava production followed by Brazil. In Asia, the crop is grown mainly for export for animal feeds in European countries. In Africa, cassava is mainly a food crop and provides livelihood to millions of smallholders living in humid, sub-humid and marginal lands in the continent (IFAD, 2005). In Eastern and Central Africa countries, cassava provides livelihood to about 80% of the population in the region. In majority of the countries the share of sales out of the total production rarely exceeds 15%. This means the crop is largely grown for food security reasons (Ntawuruhunga and Okidi, 2010).

The potential for cassava to contribute to food security in the region is enormous as most of the countries continue to register food deficits and reliance on food relief from international agencies. Opportunities exist to expand production through increase in acreage and improvement in yields. Within the region cassava is primarily a food crop, being the main staple in DRC, second important food staple in Uganda and Madagascar and third important staple in Rwanda and Burundi. Cassava yield in Africa could be increased markedly if farmers had access to fertilizers.

Table 1: Global cassava Production in the world metric tons(MT)

Country	Production Quantity (in MT)
Nigeria	53,000,000
Thailand	30,228,000
Indonesia	23,936,921
Brazil	21,484,218
Democratic Republic of Congo	16,500,000
Angola	16,411,674
Ghana	15,989,940
Mozambique	10,000,000
Vietnam	9,757,681
Cambodia	8,000,000
India	7,228,000
Uganda	5,228,000

Source: FAOSTAT, 2010

With increasing demand for cassava following population growth, changes in food preferences and increase in industrial needs in the continent, sub-sector operators will be confronted with the challenge of increasing production, improving access to good quality cassava products and expanding markets, which will contribute to local, national, and regional food security and socio-economic growth.

2.6 Response of cassava to inorganic fertilizers

Soil fertility depletion in smallholder farms is the main reason for declining per capita food production in (SSA) (Drechsel and Quansah, 2001). Gregory and Bump (2006) reported that during the last 30 years an average of 660 kg N ha^{-1}, 75 kg P ha^{-1} and 450 kg K ha^{-1} have been depleted from about 200 million hectares of cultivated land in 37 African countries. Traditional soil fertility maintenance strategies practiced in SSA and Uganda in particular, such as fallowing land, cereal-legume intercropping and mixed crop-livestock farming were no longer capable of adjusting quickly enough to rapid population growth combined with reducing farm size and soil fertility (Bationo *et al.*, 2006). Thus, soil fertility replenishment in smallholder farms should be considered as an investment in SSA (Sanchez *et al.*, 2002).

Cassava is a crop that is suited for poor soils because it has a potential to produce reasonable good yields on eroded and degraded soils (Howeler, 2002). This has led to many to believe that soil fertility is not important in cassava production. However, like other crops it shows response to inorganic fertilizer application (Pypers *et al.*, 2011; 2012; Uwah *et al.*, 2013). Pypers, *et al.* (2012) found that cassava yields were increased by 42 to 212% with the application of NPK fertilizer in western DRC. Uwah *et al.* (2013) reported that **N** fertilizer application at the rate of 120 kg N ha^{-1} increased the tuber weight and yield of cassava by 48 and 36%, respectively.

Similarly, Fermont (2009) found the response of cassava to applied **P** fertilizer in Uganda and Western Kenya and also reported that average yield response to **P** was 45 to 106 kg of fresh root of cassava per kg of applied **P** fertilizer. The response to **P** application may depend on soil mycorrhiza potential and available **P** supply in the soil (El-Sharkawy, 2007). When planted in natural soil, the cassava roots soon become infected with native soil mychorrhiza. The resulting hyphae grow into the surrounding soil and help in the uptake and transportation of **P** to the cassava roots. Through this highly effective symbiosis, cassava is able to absorb **P** from soils with low levels of available **P**. But with a less-efficient mychorrhiza population, cassava responded very markedly to **P** applications.

Adequate **K** levels in soil stimulate the response to **N** fertilizers but excess amount of both N and K nutrients leads to luxuriant growth at the expense of tuber formation (Wilson and Ovid, 1994). Potassium stimulates net photosynthetic activity of a given leaf area and increases the translocation of photosynthates to the tuberous roots. This results in low carbohydrate levels in the leaves, further increasing photosynthetic activity. Howeler (1998) reported that **K** application not only increased root yields but also their starch content. In fact earlier, Kabeerathumma and Mohankumar (1990) reported that **K** application also decreased the HCN content of roots.

To maintain high yields when cassava is grown on an area continuously, NPK fertilization is essential. According to Vanlauwe (2012), cassava yield increased from 12 to 25 MT/ha when moderate level of NPK was applied to the crop, and yield increased more than 40 MT/ha when higher rates of NPK were applied. FAO (2013) recommended that cassava should be fertilized initially with equal amounts of N, P and K at a rate between 500 to 800 kg/ha of a compound fertilizer such as 15:15:15 or 17:17:17. However, the NPK levels need to be modified to compensate for the nutrient loss through root harvest when the crop is grown continuously on that same land. Agbaje and Akinlosotu (2004) reported significant reduction in root yield of cassava when fertilized with 600 – 800 kg/ha of NPK, and that root lengths were not influenced by NPK application. Lebot (2009) recommended that 400 kg/ha of NPK or 40 g/plant be applied to the crop and that the application be split with first application done 30 days after planting (DAP), and second application at 60 DAP.

FAO (2009) reported that NPK (17:17:17) should be applied at 200 kg/ha or 20 g per plant but be split at one month after planting and four months after planting respectively . However, Howeler and Cadavid (1990) reported no significant differences between a single applications at 30 DAP and split application at 30 and 60 or at 30, 60 and 90 DAP. In Africa few fertilizer trials have been conducted, because few cassava farmers apply fertilizers.

Uganda farmers can harvest an average of between 7 and 10 MT/ha using farmers' practices. However, this is far below the optimum (35 MT/ha) that was observed during a two year trial on farms in Iganga District, Eastern Uganda and this clearly showed the potential for improving cassava yield. About 30% of the cassava yield increase was attributed to improved cassava genotypes, while 60% was as a result of fertilizer use.

2.7 Effect of nutrient requirements in maize production

Major nutrients required by maize for optimum growth and yield include, nitrogen (N) which is required for obtaining maximum yield and quality (Nuttall, 2012), Phosphorus required particularly by the growing tips of the plant for root growth and development, potassium (K) is required in the greatest amount by maize. The assimilation of N, P and K reaches a peak during tasseling (Du Plessis, 2003). Maize also requires Sulphur (S) which is a constituent of protein together with nitrogen and magnesium (Mg) an essential element in chlorophyll used for photosynthesis (Anem *et al.*, 2011). Maize is not very sensitive to trace element deficiencies. However, boron, copper, zinc, manganese and iron may occasionally be deficient in soils which may also affect the production.

2.8 Concept of intercropping

Intercropping is the growing of two or more crops on the same piece of land within the same year to promote their interaction and also maximizes chances of productivity by avoiding dependence on only one crop (Sullivan, 2003). Various intercropping patterns of legumes and non-legumes have been a central feature of many agricultural systems in the tropics (CIAT, 2009). Ezumah and Ikeorgu (1993) proposed that intercropping be divided into three categories; full, relay and sequential intercropping and that preference depend on the extent of physical association between the crops.

According to Ofori and Stern, (1987), there are several socio-economic factors, biological as well as ecological advantages of intercropping relative to sole cropping for smallholder farmers. Intercropping is a principal means of intensifying crop production and to improve returns from limited land holdings (Storck *et al.*, 1991).In the tropics, maize and cassava are often intercropped (Van Kessel and Roskoski, 1988). Suitable land area for agricultural production remains fixed or is diminishing, yet farmers are faced with the task of increasing production. Raising productivity, through adequate use of available natural resources, for example, light and nutrients, is possible through intercropping provided the demands for component crops are well understood (Midmore, 1993).

Intercropping is known to influence yield variables of the component crops, such as harvest index, hundred seed weight, number of reproductive organs and number of seeds, within each reproductive unit (Carruthers *et al.,* 2000). Intercropping reduces weed growth (Tripathi and Singh, 1983; Weil and McFadden, 1991; Carruthers *et al.,* 1998), thereby causing reductions in herbicide use. Intercropping also produces crops that can be harvested at different times during the year, increases total net income per unit area of land and reduces the risk of total crop failure (FAO, 2013).

Developmental changes in crop can be examined by investigating the manner in which yield components are being affected by alterations in the cropping pattern. For example, the harvest index indicates the amount of plant biomass that is allocated to grain, thus providing an indication of the ability with which the plant partitions resources between vegetative and reproductive structures. Fukai and Midmore (1993) also reported that intercropping may improve stability in cassava yield, allowing more consistent yields. The efficient use of the resources under intercropping also reduces input costs (Ofori and Stern, 1987).

2.9 Effect of plant population density and intercropping on yield performance

Plant populations are important in determining yield and competition for the available resources. Some crop varieties, however, have a high degree of plasticity and such varieties give fairly stable yield over a wide range of populations and on intercropping such varieties, the population effect on yield is low compared to its sole stand Carsky and Toukourou (2005) reported that two plants no matter how close do not compete with each other as long as the water content, the nutrient material, light and space are in excess of the needs of both. In addition, Quansah *et al.* (1998) reported that the level of competition depended on the level of supply of resources, the nature of the plant community in particular the resource requirements of the individual plants, the number of plants per unit area (plant population) and the spatial arrangements. Carsky and Toukourou (2005) suggested that as population of monocultures are increased, competition is likely to begin earlier than for different species because in a monoculture all the plants require the same resources at the same time. Willey and Osiru (1972) suggested that intercrops required different resources and competition was less likely, and optimum population for intercrops was higher since the intercrops had the ability to make better use of environmental resources. This was further supported by the research of Adeniyan *et al.* (2010) who pointed out that maize in pure stand yielded best at 75 x 50 cm spacing, but under intercropping, the best yield was obtained at 75 x 30 cm spacing in a cassava/maize intercrop. It therefore follows that the extent to which the population must be increased should be related to the magnitude of the yield advantages (Ayoola *et al.*, 2007b).

2.10 Land Equivalent Ratio

Land Equivalent Ratio (LER) defined as the total land area required under sole cropping to yields obtained in the intercropping (Mead and Willey, 1980). Land equivalent ratio shows the efficiency of intercropping for using the environmental resources compared with mono cropping with the value of unity to be the critical. When the LER is greater than one (unity) the intercropping favors the growth and yield of the species, whereas when the LER is lower than one the intercropping negatively affects the growth and yield of the plants grown in mixtures (Willey, 1979; Willey and Natarajan, 1980). Asynchrony in resource demand ensures that the late maturing crop can recover from possible damage caused by a quick-maturing crop component and the available resources, e.g. radiation capture over time, are used thoroughly until the end of the growing season (Keating and Carberry, 1993).

Land equivalent ratio is one of the most important reasons for growing two or more crops simultaneously is to ensure that an increased and diverse productivity per unit area is obtained compared to sole cropping. An assessment of land return is made from the yield of pure stands and from each separate crop within the mixture. The calculated figure is called the LER, where intercrop yields are divided by the pure stand yields for each crop in the intercropping system and the two figures added together (Sullivan, 2003).

Yield advantages from intercropping as compared to sole cropping, are often attributed to mutual complementary effects of component crops, such as better and total use of available resources (Ayola and Makinde, 2007a). Generally, sole maize has higher yields compared to yields in an intercropping system. However, in most cases, land productivity measured by LER clearly shows the advantage of mixed cropping of cereals and cassava (Yunusa, 1989). The land use efficiency measured by relative yields increased with increasing maize population. Planting cassava and maize in the same row, inter-row and alternate row arrangements had no significant effect on maize grain or on cassava root yields, the earliness of maize maturity notwithstanding (Ayola and Makinde, 2007b).

Due to a compensatory relationship in the yields of cassava and maize intercropping systems, the choice of an appropriate maize variety and maize population in cassava and maize intercrop system will depend on the relative importance to a farmer of the two crops (Ezumah *et al.*, 1988). Muoneke *et al.* (2007) found that the productivity of the intercropping system indicated yield advantage of 2.63% as depicted by the LER of 1.02-1.63 showing efficient utilization of land resource by growing the crops together. Land equivalent ratio gives an indication of magnitude of sole cropping required to produce the same yield on a unit of intercropped land and research results indicate that response of **N** to intercropping generally results in reduced LER values. However, when two intercrops are using the same growth resource, a decrease in yield of one crop could be expected especially when one crop is more competitive than the other. Limitations to the use of the LER concept should also be realized, particularly when used to compare the productivity of an intercrop and sole crop. Willey (1979) stated that one major problem is that the computation of LER needs maximum yields of sole crops obtained at optimum plant densities. When yields of sole crops at recommended densities are compared with those of intercrops, it will be likely that the advantage of intercropping is overestimated since density may be altered as an experimental variable to determine the optimum density overestimated (Hamid and Haque, 2001).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Experimental site

Two experiments were conducted in the two rainy seasons of 2016 and 2017 and were repeated to cover each of the specific objective of the study. The experiments were conducted in the field at Kyambogo University farm which is located on the eastern side of the university main campus at an altitude of 1189 meters above sea level. The coordinates of University are: 0°20'54" N and 32°37'49" E (Latitude 0.348334 and Longitude 32.630275). (https://en.wikipedia.org/wiki/Kyambogo). Six soil samples were randomly collected from the trial site at the depths of 0 – 15 cm for topsoil analysis prior to planting. Samples were combined and sub-samples used to determine soil chemical and physical properties according to Okalebo *et al.* (2002).

Table 2: Physical and chemical properties of soil on the experimental site

Soil Property	0 – 15 cm
Organic Carbon (%)	2.27
Total Nitrogen (%)	0.12
Potassium (Cmol/kg)	0.38
Available Phosphorus (mg/kg)	4.96
Soil pH	6.8
Clay (%)	19
Silt (%)	12
Sand (%)	71
Soil textural class	Sandy loam
Soil structural class	Sub-angular blocky

3.2 Planting materials

Planting materials (stakes) were obtained from National Crop Resources Research Institute (NaCRRI), Namulonge and were 13 months old). Cuttings were taken from middle part of the cassava stems. The cuttings/stakes for the respective varieties were sourced from low cassava mosaic (CMD) and cassava brown streak disease (CBSD) pressure area of Namulonge and were then visually assessed for the absence or presence of the two diseases. The varieties used were among the newly developed and released varieties; NASE 14 and NAROCASS 1 and can be harvested at eight months onwards. They both have yield potential of 20 MT/ha-1 and above (Bua et al., (2012).

Cassava cuttings of 25 cm length were planted at a spacing of 1m x 1m between plants and between rows making a total plant population of 10,000 plants/ha. Each plot had 4 x 3 rows with a total of 12 plants per sub-plot. Refilling was done two weeks after planting to maintain the plant population. Maize variety Longe 6H was obtained from NASECO seed supplier. It is a medium duration variety and has a potential yield of 3200 – 4100 kg/ha and maturity period of 120 days.

3.3 Land preparation, planting and field management

The experimental land was ploughed twice. First and second land preparation was done at two weeks' interval to improve soil structure, reduce weeds, facilitate organic matter decomposition and enhance the circulation of soil air so as to optimize plant growth. The experimental plot was then divided into blocks and plots.

Cassava cuttings which were 25 – 30 cm long with an average of 5 – 9 buds were planted horizontally in rectangular holes spaced 1 x 1 m. Each plot of cassava had 4 x 3 rows with a total of 12 cassava plants, while each block had 8 plots which were separated from each other by an alley of 2 metres.

Maize planting was done at the rate of 2 seeds per hole and at a spacing of 75 x 30 cm (standard for sole maize) and 37 x 30 cm (higher density) and both were later thinned to one plant per hill at 2 weeks after planting (MAAIF, 2013). Four rounds of weeding were done to control weed infestation. Weeding was done by hand pulling to avoid cutting cassava roots.

3.4 Experiment 1: Determining the effect of maize planting density in the cassava/maize intercrop on the growth characteristics and yield performance of the component crops

3.4.1 Experimental design and treatments

The experimental design was Randomized Complete Block Design (RCBD) arranged as factorial with three replications. The treatments comprised: (T1) sole maize (SM) and sole cassava (SC), (T2) intercrop of one row of cassava (NASE 14 / NAROCASS 1) to one row of maize (1C:1M) and (T3) intercrop of one row of cassava (NASE 14 / NAROCASS 1) to two rows of maize (1C:2M) (Table 3). Newly developed cassava genotypes NASE 14 and NAROCASS 1 formed the main plots and the cropping system formed sub-plots. Sub-plot size was 4 x 5 m. The field was marked into blocks and plots with one meter width alleys in between to enhance easy movement of materials and agronomic operations.

Table 3: Description of treatments for experiment 1

Treatment	Treatment description
T1 .	Sole maize (SM) at 75 x 30 cm / Sole cassava (SC) of NASE 14 / NAROCASS 1 variety
T2	Intercrop of one row of NASE 14 / NAROCASS 1 and one row of maize at 75 × 30 cm (1C:1M)
T3	Intercrop of one row of NASE 14 / NAROCASS 1 and two rows of maize at 37 × 30 cm (1C:2M)

3.4.2 Data collection

Parameters that were measured on maize were plant height, number of rows per cob, cob length, maize grain weight and grain yield. For cassava, parameters that were measured were, plant height, number of cassava tubers per plant, tuber diameter/girth, fresh tuber weight, length of fresh tubers and total tuber yield per hectare.

Heights of maize plant height were measured from the base of plant to the upper top most leaves at 2 MAP, 3 MAP, at tasseling and at harvest using a flexible measuring tape in centimeter.

Cob length was measured from six dehusked randomly selected cob using a thread measurement and later transferred to a meter ruler to determine the length of the cob. The reading at the end of the cob tip was recorded and the average calculated for each treatment.

Grain yield was obtained from sun-dried maize cob sample that was threshed manually. The moisture content of sample was adjusted to 15% and then weight of sample measured and converted to grain yield per hectare. Number of rows per cob of the six randomly dehusked sampled maize was taken at harvest and the mean recorded and average taken. Maize grain weight was obtained from threshed grains per plot weighed, using weighting balance and then converted to grain yield in grams per square meter (g/m^2).

Height of cassava plants from four randomly sampled plants in the net plot were measured from the base of plant to the newly emerging leaf using a measuring tape, the average height of the four plants per plot was computed and recorded. Number of cassava root per plant, four randomly selected cassava plants from the middle rows were harvested from each plot. The numbers of root per plant was determined by visually counting the root tubers that were big enough to be consumed.

For the case of root tuber girth/diameter, the circumference of root tubers from four randomly harvested plants from each plot were measured from the mid region of the root tuber using thread and later transferred to a ruler for measurement. The length of root tubers were taken from the base to the end point of the fresh root tuber using a carpenter's steel measuring tape. Fresh root tuber weight was determined from four plants in the two middle rows in each plot by weighing the root tubers using a weighing scale in kilograms. Total root tuber yield per hectare for the entire cassava plot were weighed and then converted to MT/ha.

$$\text{Total fresh root tuber yield (MT/ha)} = \frac{10000\ m^2 \times \text{weight of tubers harvested in kg}}{\text{Number of plants harvested in net plot}}$$

3.4.3 Data analysis

Data collected were subjected to analysis of variance (ANOVA) using Genstat Statistical Package (Version 12). Treatment means were compared using the Least Significant Difference (LSD) at 5% level of significance. Mean comparisons were made by Duncan Multiple Range Test (Gomez and Gomez, 1984).

Land Equivalent Ratios for the intercrops were computed as follows:

$$\textbf{LER} = \frac{Y^*Ci}{Y^*Cm} + \frac{Y^*Mi}{Y^*Mm}$$

Willey (1985) and Willey and Rao (1980)

Where: Y*Ci = yield of cassava in the intercrop, Y*Cm = yield of cassava in the monocrop, Y*Mi = yield of maize in the intercrop and Y*Mm = yield of maize in the monocrop.

3.5 Experiment 2: Determining the effect of NPK fertilizer (17:17:17) on the growth characteristics and yield components of newly developed cassava varieties

3.5.1 Experimental design and treatments

The experimental design was RCBD arranged as a split-plot arrangement with three replications. The sub-plot size was 4 × 5 m with a total of 12 cassava plants per plot, there were two metre paths between replicates and one metre paths between sub-plots. Cassava varieties NAROCASS 1 and NASE 14 formed the main plots and the NPK fertilizer rates formed the sub-plot treatments (Table 4).

Table 4: Description of treatments for different levels of NPK on NASE 14 and NAROCASS 1 cassava varieties

Treatment	Treatment description
T1	NASE 14 /NAROCASS 1 + Zero NPK (No fertilizer applied)
T2	NASE 14/ NAROCASS 1 + 200 kg/ha of NPK fertilizer
T3	NASE 14/ NAROCASS 1 + 400 kg/ha of NPK fertilizer
T4	NASE 14/ NAROCASS 1 + 600 kg/ha of NPK fertilizer

The treatments consisted of four levels of NPK fertilizer and these were zero or no fertilizer added (the control), 200, 400 and 600 kg/ha. Fertilizers were applied in a split application at planting and at 16 weeks after planting (Anneke *et al.*, 2009). The quantity of fertilizer applied per plant was calculated using the following formula:

$$\text{Quantity applied per plant} = \frac{\text{Plot size (area) x Rate of fertilizer per hectare}}{\text{Area in hectares x Number of plant per plot}}$$

By calculation, each plant received 0, 10, 20 and 30 g of NPK per treatment, respectively. The fertilizer was placed at a distance of 10-15 cm from the stem in the drill holes to reduce fertilizer loss through run-off. During second application, fertilizer was placed in half-moon shaped furrow about 3-5 cm deep and 20 cm away from the base of the plant and covered.

Weeding was done four times by hand pulling to avoid cutting of cassava roots and interfering with mineral fertilizer uptake and turning of soil with nutrients. Herbicide was applied to control weeds around the experimental boundary.

3.5.2 Data collection

Parameters that were measured included cassava height at first branching and numbers of cassava stems per plant. At harvest, number of roots per plant, root diameter/girth, fresh root weight, lengths of fresh root and total root yield were recorded including cassava height at harvest.

Height at first branching was taken from four plants from the middle rows of each plot randomly selected. Measurements were taken from the base of the plant to the point of the first branch on each plant with a flexible measuring tape. Plant height at harvest was taken at 11 months after planting (MAP). Four plants from the two middle rows of each sub-plot were randomly selected, and the height of each plant was taken with flexible measuring tape from the base of the plant at soil level to the tip of the terminal bud.

The number of root per plant was obtained from four randomly selected plants from the middle rows of from each plot. The numbers of roots per plant were determined by counting the tubers big enough to be consumed and marketed. Root diameter/girth was then determined by measuring diameter of roots from four randomly harvested plants from each plot. Measurement was taken from the mid region of each tuber using thread and later confirmed with a metre ruler in centimetre. Measurement of the length of each root was taken from the point of attachment of root to the stem up to the end point of the tuber using a flexible measuring tape. Fresh tuber weight was determined from four harvested plants from the two middle rows in each plot by weighing tubers using a weighing scale.

The total root tuber yield, all the root tubers for each plot were weighed and converted into metric ton/hectare (MT/ha) for each plot.

$$\text{Fresh root yield (MT/ha)} = \frac{10000\ \text{m}^2 \times \text{Weight of root harvested in kg.}}{\text{Number of plants harvested in net plot.}}$$

3.5.3 Data analysis

All data collected were subjected to analysis of variance (ANOVA) using Genstat Statistical package (version 12) at 5% level of probability and significance treatment mean values were separated using Duncan Multiple Range Test (Gomez and Gomez, 1984).

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Effect of maize planting density in the cassava/maize intercrop on the growth characteristics and yield performance of the component crops

4.1.1 Maize planting density in the cassava/maize intercrop on the growth characteristics and yield of maize

4.1.1.1 Maize plant heights

Results indicate that there were significant differences ($P<0.05$) in plant heights among the treatments at all stages of maize growth except at three months after planting (Table 5). However, the interaction effect between cassava genotypes and plant population densities on maize heights was not significant ($P>0.05$) (Appendix 1).

In fact, maize plant heights at 2 MAP (MH_2), at tasseling (MHT) and at harvest (MHH) under the intercropping system 1C:2M were significantly ($P<0.05$) higher than those of maize plants under sole maize cropping as well as in the 1C:1M intercropping system (Table 5). The same trend was observed in the NASE 14/Maize intercrops, although there was no difference ($P>0.05$) between 1C:1M and 1C:2M respectively.

Table 5: Mean effect of cassava/maize intercrop on maize plant height at Kyambogo, 2016/2017

	NAROCASS I / Maize intercrop				NASE 14 / Maize intercrop			
Treatments	MH_2	MH_3	MHT	MHH	MH_2	MH_3	MHT	MHH
1C:1M	35.73^{ab}	135.0	171.87^{b}	273.60^{a}	35.18^{ab}	126.0	165.80^{ab}	259.20^{b}
1C:2M	38.40^{b}	158.0	128.70^{a}	327.80^{b}	37.27^{b}	155.0	172.10^{b}	303.20^{b}
SM	29.50^{a}	156.0	192.20^{b}	250.30^{a}	29.67^{a}	137.0	182.40^{a}	277.50^{a}
F-Prob.	**0.002**	**0.618**	**0.004**	**<.001**				
Mean	**34.29**	**142.0**	**160.7**	**265.3**				
$LSD_{(0.05)}$	**6.28**	**75.8 NS**	**48.95**	**48.83**				

^{abc}=Means within the same column having different superscripts are significantly ($P \leq 0.05$) different from each other. **MH_2**= Maize height at 2 MAP, **MH_3**= Maize height at 3 MAP, **MHT**= Maize height at tasseling, **MHH**= Maize height at harvest, **1C:1M**= Intercropping one row of cassava to one row of maize, **1C:2M**= Intercropping one row of cassava to two rows of maize, **SM** = Sole maize, **$LSD_{(0.05)}$** = Least Significant Difference at 5% level of significance.

Intercropping significantly increased the maize plant heights in the 1C:2M intercropping system than in sole maize for both the NAROCASS 1/Maize and NASE 14 /Maize intercrops. This increase in the maize heights could be due to competition among the plants for light which made the maize plants in the intercrops to direct the assimilates to stem growth. Similar observations were reported by Adeniyan *et al.* (2014), Sangakara *et al.* (2004) and Kaizzi (2002). Zamir *et al.* (2011) also reported an increase in plant height following the increase in plant density and they related this to the increase in inter-plant competition for light and the disruption of the balance of growth regulators. Under these conditions, plant height increases if other environmental factors, such as moisture and soil fertility are not limiting.

4.1.1.2 Maize cob length

There were significant differences ($P<0.05$) in maize cob length for both cassava/Maize intercrops (Table 6). Similarly, the interaction between plant density and cassava varieties was significant ($P<0.05$) for maize cob length (Appendix 2). The lengths of cobs from sole maize cropping were higher ($P<0.05$) than those of cobs obtained from the 1C:2M intercropping (Table 6).

The higher cob length at lower plant population densities of sole maize (SM) could be attributed to lower competition for growth resources particularly nutrients, water and light. Lower competition allowed maize plants to accumulate biomass with higher capacity to make photosynthates for depositing into the sinks resulting in longer cobs. These results are in conformity with those reported by Moges (2015) and Al-Naggar *et al.* (2015).

Table 6: Effect of cassava/maize intercrop on the yield components of maize at Kyambogo, 2016/2017

	NAROCASS I / Maize intercrop				NASE 14 / Maize intercrop			
Treatments	MCL	MRPC	MGW	MGY	MCL	MRPC	MGW	MGY
1C:1M	24.80^{b}	14.80^{b}	2049.0^{a}	1922.0^{c}	23.73^{ab}	14.90^{b}	2050.0^{a}	2215.0^{c}
1C:2M	23.77^{a}	10.50^{a}	2025.0^{a}	1011.0^{a}	22.50^{a}	11.67^{a}	2028.0^{a}	1077.0^{a}
SM	24.03^{b}	16.15^{c}	2899.0^{b}	1310.0^{b}	28.15^{b}	15.98^{b}	2737.0^{b}	1686.0^{b}
F-Prob.	**<.007**	**<.001**	**<.001**	**<.001**				
Mean	**23.83**	**13.82**	**2298.0**	**1537.0**				
$LSD_{(0.05)}$	**4.69(NS)**	**1.20**	**282.8**	**206.6**				

^{abc}=Means within the same column having different superscripts are significantly ($P \leq 0.05$) different from each other, **MCL** = Maize cob length, **MRPC** = Number of rows per cob, **MGY** = Maize grain yield (kg/ha), **MGW** = Maize Grain weight (g/m^2), **SM** = Sole maize, NS = non-significant.

4.1.1.3 Number of rows per cob

The number of rows per cob was significantly ($P<0.05$) influenced by plant population densities (Table 6). Also, the interaction between plant density and cassava genotypes was significantly ($P<0.05$) different (Appendix 2). Apart from the 1C:1M intercropping under the NASE 14/Maize intercrop, the number of rows per cob from sole maize cropping were higher ($P<0.05$) than those of cobs from the NAROCASS 1/Maize and NASE 14/Maize intercrops (Table 6). In general, the number of rows per cob decreased in the order SM > 1C:1M > 1C:2M indicating that as the plant population density increased, the number of rows per cob also decreased. The decrease in the number of rows per cob followed the same trend as the cob length, which shows that both growth traits are equally affected by growth conditions. The higher the plant population density, the higher the competition for growth resources that results in smaller cobs with lower numbers of rows of grain (Zamir *et al.*, 2011; Al-Naggar *et al.,* 2015).

4.1.1.4 Maize grain weight

Intercropping maize with cassava (NAROCASS 1 and NASE 14) significantly ($P<0.05$) reduced the maize grain weight (g/m^2) (Table 6). The interaction effect of plant density and cassava genotypes was non-significant ($P>0.05$) for maize grain weight (Appendix 2). The reduction in grain weight is attributed to competition for growth resources, particularly sunlight. Maize is a warm season plant that requires high light intensity for optimal grain production, hence shading severely affects grain yield. Zamir *et al.* (2011) reported that the number of ears per plant increased with decreased plant population density. High plant population establishment creates competition for light, aeration, nutrients and consequently compelling the plants to undergo less reproductive growth.

4.1.1.5 Maize grain yield per hectare

Intercropping and plant population densities significantly ($P<0.05$) affected maize grain yield per hectare (Table 6). However, the interaction between plant density and cassava genotypes was non-significant ($P>0.05$) (Appendix 2). For the intercrops, maize grain yield was significantly higher at the lower plant densities of 1C:1M and sole maize cropping (SM) than for the intercrop of 1C:2M (Table 6). Thus, increasing the maize population density to 1C:2M significantly reduced the grain yields when compared with the grain yields obtained at the lower plant population density (1C:1M), as well as in the sole maize cropping.

This trend of response was also observed by Singh and Ajeigbe (2002) and Abuzar *et al.* (2011). The fact that higher grain yields were obtained when maize was intercropped with cassava at the same maize planting densities (1C:1M) as in sole maize cropping suggest that same maize populations could be used in a cassava/maize intercrop to increase the overall yields (Tollenaar and Wu, 1999). The decline in grain yield at high maize plant density of 1C:2M was attributed to competition for light, moisture and soil nutrients. Reduction in maize yield when intercropped at high density with cassava was also reported by Amanullah *et al.* (2006).

4.1.2 Maize planting density in the cassava/maize intercrop on the growth characteristics and yield of cassava

4.1.2.1 Heights of cassava plants at 2 MAP, at branching and at harvest

There were significant differences ($P<0.05$) in cassava plant heights at 2 MAP, branching and harvest (Table 7). The interaction effect due to cassava varieties and plant population densities on cassava plant height at branching was significant ($P<0.05$) (Appendix 3). In the NAROCASS I / Maize intercrop, cassava heights at 2 MAP and branching were in the order

SC < 1C:1M < 1C:2M indicating that as plant population density increased, the cassava plant height also increased (Table 7). In fact, at the time of harvest, the height of cassava plants under intercropping system (1C:1M and 1C:2M) were similar but significantly ($P<0.05$) shorter than the heights of cassava plants from sole cassava cropping for both intercrops.

Table 7: Effect of cassava/maize intercrop on cassava plant height at different stages of growth at Kyambogo, 2016/2017

	NAROCASS I / Maize intercrop			**NASE 14 / Maize intercrop**		
Treatments	CH_2	CHB	CHH	CH_2	CHB	CHH
1C:1M	21.33^b	94.20^b	184.20^a	20.63^b	97.40^a	175.50^a
1C:2M	27.63^c	149.10^c	150.20^a	25.40^c	115.10^b	149.10^a
SC	18.38^a	77.40^a	232.60^b	17.93^a	85.60^a	223.80^b
F-Prob.	**<.001**	**<.001**	**<.001**			
Mean	**21.89**	**103.1**	**185.90**			
$LSD_{(0.05)}$	**1.93**	**15.72**	**34.87**			

abc=Means within the same column having different superscripts are significantly ($P\leq0.05$) different from each other; **CH_2** = Cassava height at 2 MAP; **CHB** = Cassava height at branching and **CHH** = Cassava plant height at harvest, **SC** = Sole cassava.

For the case of NASE 14/Maize intercrop, the cassava heights at 2 MAP followed the same trend as in the NAROCASS 1 /Maize intercrop (Table 7). At branching, cassava plants in the 1C:2M intercrops were significantly taller than those under the 1C:1M intercropping and sole cassava cropping. However, at the time of harvest, the trend was similar to that in the NAROCASS 1 /Maize intercrop (Table 7).

Overall, increasing the plant population density significantly increases cassava plant height when still young (at 2 MAP and at branching). Therefore, the tallest cassava plants were in the cassava/maize intercrops of 1C:2M. This is most likely due to intensive competition for growth resources, especially light between maize and cassava plants. Shivananda (2005) reported that cassava has a wide range of growth habits which may influence the amount of solar radiation interception during growth. Adeniyan *et al.* (2014) also observed similar growth trends in cassava and attributed them to the competition for resources in the intercrop. The crop plants channeled more assimilates to elongation of stems of the component crops. Quansah *et al.* (1998) also observed intense competition for space in rapidly growing crops. Moreover, increasing the plant population increased the competition among plants for soil moisture, nutrient, light and carbon dioxide. However, in the sole cassava plants where the plant population density was low, cassava plants grew as isolated units for most of their early life and interfered less with each other than at higher densities. This explains why the sole cassava plants ended up being shorter by the time of harvest.

4.1.2.2 Number of cassava roots per plant

Increased maize plant population density significantly ($P<0.05$) affected the number of cassava root tubers per plant (Table 8). The number of cassava root tubers per plant from sole cropping was significantly ($P<0.05$) higher than those in the intercrops (1C:1M and 1C:2M). The higher plant population (1C:2M) recorded the lowest ($P<0.05$) number of tubers per plant for both intercrops. However, the interaction effect of plant density and cassava varieties was not significant ($P>0.05$) (Appendix 4).

Table 8: Effect of cassava/maize intercrop on the yield components of cassava at Kyambogo 2016/2017

	NAROCASS I / maize intercrop					**NASE 14 / maize intercrop**				
Treatments	TN	RG (cm)	RL (cm)	RW (kg)	RY (MT/ha)	TN	RG (cm)	RL (cm)	RW (kg)	RY (MT/ha)
1C:1M	20.53^{b}	20.67^{a}	48.27^{c}	11.52^{b}	28.79^{b}	16.60^{b}	20.93^{a}	40.70^{c}	10.97^{ab}	25.42^{a}
1C:2M	11.90^{a}	17.75^{a}	27.03^{a}	9.45^{a}	23.63^{a}	11.00^{a}	17.92^{a}	24.68^{a}	9.60^{a}	23.00^{a}
SC	29.20^{c}	26.83^{b}	38.70^{b}	14.95^{c}	37.38^{c}	28.23^{c}	40.00^{b}	30.80^{b}	13.93^{c}	34.83^{b}
F-Prob.	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**					
Mean	**19.58**	**24.02**	**35.03**	**11.74**	**29.34**					
$LSD_{(0.05)}$	**4.44**	**5.45**	**4.98**	**1.57**	**3392**					

^{abc}=Means within the same column having different superscripts are significantly ($P\leq0.05$) different from each other, **TN** = Number of root tubers per plant, **RG** = Cassava root tuber girth, **RL** = Cassava root tuber length, **RW** = Root tuber weight, **RY** = Cassava root tuber yield, SC = Sole cassava, NS = non-significant.

The decrease in the number of cassava tubers per plant when cassava is intercropped with maize could be attributed to competition for the available growth resources. This means that the peak demand for growth resources of the two crop species (maize and cassava) could have coincided, hence resulting in competition that led to significant reduction in the number of cassava tubers. Marer (2007) noted that yield advantage in intercropping systems occurred where the component crops differed in their use of growth resources. Similar observations were reported earlier by IITA (2000).

4.1.2.3 Cassava root girth

Cassava root tuber girth significantly ($P<0.05$) decreased under intercropping compared to sole cassava cropping for both intercrops (Table 8). However, the interaction effect of plant density and cassava varieties was not significant ($P>0.05$) (Appendix 4). Root tuber girth at higher intercrop (1C:2M) did not differ ($P>0.05$) from that of the lower intercrop (1C:1M).

The reduction in cassava tuber girth when cassava was intercropped with maize could be due to competition for growth resources, especially solar radiation which could have led to lower assimilates being produced and channeled to the tubers for bulking. Cassava plants under sole cropping, had a lot of space available to them with less shading which enabled them to photosynthesize at higher levels producing a lot of assimilates that were channeled to the tubers, hence leading to the development of tubers with larger girths. Also, more assimilates were channeled to the cassava stems which ended up being significantly taller than those of sole cassava plants. Obiero (2004) reported that high maize plant population in cassava/maize intercrop led to diversion of assimilates from cassava roots to the stem, and as a result there was a decrease in yield of commercially acceptable tubers. The results of this study are in conformity with those of Adjei-Nsiah (2010) who observed that total fresh tuber weight and girth were greater ($P<0.05$) at lower plant populations than at high plant populations.

4.1.2.4 Cassava root length

Cassava tuber lengths were significantly ($P<0.05$) affected by intercropping for both cassava varieties (Table 8). Similarly, the interaction between the plant population density and the cassava varieties was significant ($P<0.05$) (Appendix 4). Cassava tubers from the low intercrop density (1C:1M) were longer ($P<0.05$) than those obtained at the higher intercrop density (1C:2M) or sole cropping (Table 8). In other words, cassava tuber length significantly ($P<0.05$) increased when cassava and maize were intercropped in the ratio of one to one (1C:1M) for both cassava varieties, but significantly ($P<0.05$) decreased when the ratio of cassava to maize was changed to 1C:2M. Similar factors that were mentioned in the previous discussion could be regarded as the ones responsible for these variations (Adjei-Nsiah and Issaka, 2013).

4.1.2.5 Cassava root fresh weight

There were significant differences ($P<0.05$) in cassava fresh root tuber weight as influenced by plant population density (Table 8). However, the interaction effect of plant population density and cassava varieties was not significant ($P>0.05$) (Appendix 4). Fresh root tuber weight from sole cropping was higher ($P<0.05$) than that from the intercrops in NAROCASS 1/Maize intercrops (Table 8). Furthermore, fresh weight of root tubers from low intercrop density (1C:1M) was greater ($P<0.05$) than that of root tubers obtained from higher intercrop density (1C:2M). Overall, root tuber weights decreased in the order SC > 1C:1M > 1C:2M indicating that as plant population density increased, root tuber weight gradually decreased (Table 8).

In contrast, for the NASE 14/Maize intercrops, cassava root tuber weight from sole cropping was significantly ($P<0.05$) higher than that from the intercrops (1C:1M and 1C:2M).

However, root tuber weights at both the lower (1C:1M) and higher (1C:2M) plant population densities were not statistically ($P>0.05$) different (Table 8).

The decline in fresh root tuber weight in the order SC > 1C:1M > 1C:2M could be attributed to the availability of wider space per plant in the sole cropping (SC) system than in the intercrops (1C:1M and 1C:2M), that could have favored tuber development and consequently higher tuber weight. Anil-Kumar and Sasidhar (2010) reported reduced competition when cassava was planted at lower density owing to more light and nutrients availability positively affected cassava root weight.

4.1.2.6 Cassava root yield

Cassava root yield was significantly ($P<0.05$) influenced by plant population densities (Table 8). However, the interaction between the plant density and cassava varieties was not significant ($P>0.05$) (Appendix 4). Cassava root yield from sole cropping was significantly ($P<0.05$) higher than that from the intercrops for both cassava varieties (Table 8). However, cassava root yield from low intercrop density (1C:1M) was higher ($P<0.05$) than that of higher intercrop density (1C:2M). Overall, cassava root yield decreased in the order SC > 1C:1M > 1C:2M indicating that as plant population density increased, the root yield gradually decreased (Table 8).

Therefore, as plant population increases, competition for growth resources sets in resulting in significant reduction in tuber yield. According to Ayoola and Makinde (2007a), increasing maize populations in a cassava/maize intercrop from 30,000 to 60,000 plants/ha led to significant reduction in root tuber yield. Osiru and Ezumah (1991) observed a similar trend of decreasing cassava root yield and related characteristics with increasing maize plant population density in the cassava/maize cropping system.

4.1.2.7 Land equivalent ratio (LER) of the cassava/maize cropping system

The LER of the different intercropping systems (1C:1M and 1C:2M) is presented in Table 9. In both cases, LER value was greater than one indicating the yield advantage of intercropping over sole cropping. According to Thobatsi (2009), this means that the intercrops were efficient in utilizing the resources, hence the yield advantage. There could also be both temporal and spatial complementarities between the component crops (Fukai and Midmore, 1993) that led to the yield advantage.

These results are in agreement with those reported by Ibeawuchi and Ofoh (2003). Also, result from this study showed that cropping systems (1C:1M and 1C:2M) had total LER that were greater than one, which shows an advantage of intercropping maize with cassava compared with growing each crop alone (SC and SM). In other words, these results signify that it is advantageous having both crops in mixture than growing them separately. This could be due to greater efficiency of resource utilization under intercropping. In fact, the intercrop combination of one row of cassava to one row of maize (1C:1M) is fitting for intercropping with cassava, because its density promotes more sunlight and other growth resources utilization (Fisher, 1977).

Other researchers have reported similar LERs, for example, Ibrahim Hamza (2008) reported a LER of 2.29 when cassava was intercropped with maize. In contrast, when LER < 1 is obvious disadvantage of the intercropping because the available resources are not efficiently used by the sole crop than by the intercrop (Workayehu, 2014). In fact, Mariotti *et al.* (2006) and Kitonyo *et al.* (2013) stressed that LER > 1, indicates improved use of available resources by the intercrop than sole crop.

According to Ijoyah *et al.* (2013), 28.6 and 22.5% of land were saved in two separate growing seasons of intercrops, suggesting that the saved land could be used for other production activities. According to Matusso *et al.* (2014) one of the most important reasons for intercropping is to ensure that an increased and diverse productivity per unit area is obtained compared to sole cropping. Muoneke *et al.* (2007) reported productivity of the intercropping system with yield advantage of 63%. The findings of this study are similar to those of Nyasasi and Kisetu (2014).

Table 9: Land equivalent ratios (LERs) of the cassava/maize cropping system at Kyambogo, 2016/2017

	Yields (MT/ha)		**Mean yields**	**Partial LERs**		**Total LER**
Treatments	**NAROCASS 1/ Maize intercrop**	**NASE 14 / Maize intercrop**		Y*Ci / Y*Cm	Y*Mi / Y*Mm	
SM	1.31	1.69	1.50			
1C:1M	1.92	2.22	2.07			
1C:2M	1.01	1.08	1.04			
SC	37.38	34.83	36.11			
1C:1M	28.79	25.42	27.11	0.75	1.38	**2.13**
1C:2M	23.63	23.00	23.32	0.65	0.69	**1.34**

4.2 Effect of NPK fertilizer on the growth characteristics and yield performance of newly developed cassava varieties

4.2.1 Effect of NPK fertilizer on the growth characteristics of cassava

4.2.1.1 Cassava plant height at first branching and at harvest

There were significant differences ($P<0.05$) in cassava plant heights at branching and at harvest due to fertilizer treatments (Table 10). However, the interaction effect of NPK fertilizer application and cassava genotypes was not significant ($P>0.05$) (Appendix 5).

Cassava height at branching varied significantly ($P<0.05$) with increasing NPK fertilizer levels for both the newly developed varieties (Table 10). Overall, cassava heights were significantly ($P<0.05$) higher for treatments with higher fertilizer levels than the control. However, for NAROCASS 1, the increase in fertilizer level from 200 to 400 kg/ha was significant but not for NASE 14. Interestingly, increasing the fertilizer levels from 400 to 600 kg/ha did not ($P>0.05$) cause a significant increase in cassava heights for both NASE 14 and NAROCASS 1 (Table 10).

A similar trend in cassava heights was observed at harvest (Table 10). However, there were no significant ($P>0.05$) increases in heights as the fertilizer levels were increased from 200 to 600 kg/ha for NAROCASS 1. In contrast, for NASE 14, there was significant ($P<0.05$) increase in height at 600 kg/ha when compared with the control (Table 10). For both cassava varieties, there was an increase in the number of stems when the fertilizer was applied when compared with the control treatments. But the number of stems did not increase significantly ($P>0.05$) as the fertilizer levels were increased from 200 to 600 kg/ha (Table 10).

The increment in the heights of cassava stems is probably attributed to the effect of fertilizer in promoting vegetative growth and development (Pellet and El-Sharkawy, 1997). Therefore, increasing the amount of NPK fertilizer application promotes plant height implying that farmers can apply NPK to cassava for faster cassava growth if sufficient and adequate planting material is required within a short period of time.

These observations are in line with the findings of Howeler (1990) who demonstrated that application of high levels of inorganic fertilizer leads to an increase in the vegetative growth of cassava. On the contrary, low plant heights recorded in unfertilized plots is in line with the findings of Adoa (2009) who reported significant reduction in plant growth parameters when the soil is deficient in some notable nutrients, especially nitrogen.

Table 10: Effect of NPK fertilizer on the cassava stem heights and number of stems per plant at Kyambogo, 2016/2017

	Cassava height at branching		**Cassava height at harvest**		**Number of stems per plant**	
NPK application rates, kg/ha	NAROCASS I	NASE 14	NAROCASS I	NASE 14	NAROCASS I	NASE 14
0 (Control)	64.98[a]	54.22[a]	142.50[a]	130.60[a]	1.90[a]	1.90[a]
200	99.88[b]	89.53[b]	193.90[b]	152.90[ab]	3.10[b]	3.33[b]
400	103.90[c]	94.30[b]	200.30[b]	168.50[ab]	3.07[b]	3.07[b]
600	106.53[c]	101.73[b]	212.10[b]	190.90[b]	3.13[b]	3.27[b]
Mean	**93.82**	**84.95**	**187.20**	**160.73**	**2.80**	**2.89**
F-Prob.	**<.001**		**<.001**		**<.001**	
$LSD_{(0.05)}$	**12.28**		**40.59**		**0.78**	

[abc]=Means within the same column having different superscripts are significantly ($P \leq 0.05$) different from each other.

4.2.2 Effect of NPK fertilizer on the yield performance of cassava

4.2.2.1 Number of cassava root tubers per plant

Cassava root tuber numbers per plant significantly ($P<0.05$) varied with NPK fertilizer levels and cassava varieties (Table 11). Similarly, the interaction effect of NPK fertilizer application and cassava varieties was also significant ($P<0.05$) (Appendix 6). For both cassava varieties, the root tuber numbers per plant significantly ($P<0.05$) increased with NPK fertilizer levels up to 400 kg/ha when compared to the control treatments. But there was a decline in numbers when the fertilizer level increased to 600 kg/ha (Table 11).

The findings of this study, therefore, have shown that fertilizer application had a positive effect on tuber numbers for newly developed cassava varieties. In fact, cassava response to fertilizer application has been reported in many African countries by FAO (2013), Agbaje and Akinlosotu (2004), Howeler *et al.* (2000) and Fermont *et al.* (2009).

Besides the observed increase in root tuber numbers, the application of NPK fertilizer also increased the available **P**, which is required for root tuber formation in tuberous crops. Issaka *et al.* (2007) reported that an increase in nutrient levels results in increased numbers of roots formed. On the other hand, the observed reduction in number of tubers per plant following the increase in NPK levels to 600 kg/ha is most likely due to oversupply of nitrogen, which usually result in vegetative growth at the expense of tuber development (Howeler, 2002).

Table 11: Effect of NPK fertilizer on the yield of cassava at Kyambogo, 2016/2017

NPK application rates (kg/ha)	Cassava varieties									
	NAROCASS I					NASE 14				
	RN	RL (cm)	RG (cm)	RW (kg)	RY (MT/ha)	RN	RL (cm)	RG (cm)	RW (kg)	RY (MT/ha)
0 (Control)	10.07^{a}	19.98^{a}	8.63^{a}	9.40^{a}	23.33^{a}	9.28^{a}	15.27^{a}	10.42^{a}	8.90^{a}	22.25^{a}
200	25.73^{b}	40.03^{b}	16.95^{b}	12.00^{b}	32.92^{b}	16.73^{b}	35.80^{b}	17.00^{b}	11.03^{b}	30.58^{a}
400	29.20^{c}	42.75^{b}	20.35^{b}	13.40^{b}	35.75^{b}	20.83^{c}	41.53^{b}	24.13^{c}	13.37^{c}	34.38^{b}
600	26.97^{b}	41.60^{b}	18.67^{b}	11.92^{b}	33.75^{b}	17.60^{b}	37.53^{b}	20.87^{bc}	12.53^{bc}	33.72^{b}
F-Prob.	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**					
Mean	**19.55**	**34.31**	**17.13**	**11.57**	**30.33**					
$LSD_{(0.05)}$	**1.85**	**7.10**	**4.75**	**1.84**	**5.47**					

abc=Means within the same column having different superscripts are significantly ($P \leq 0.05$) different from each other, **RN**= Number of cassava root tubers per plant, **RL**= Cassava root tuber length, **RG** = Cassava root tuber girth, **RY** = Cassava root tuber yield, **RW** = Root tuber weight.

4.2.2.2 Cassava root tuber length

There were significant differences ($P<0.05$) in cassava root tuber lengths amongst the treatments (Table 11). But the interaction between NPK fertilizer and cassava varieties was not significant ($P>0.05$) (Appendix 6).

Application of 200 kg/ha of NPK fertilizer significantly ($P<0.05$) increased the cassava root lengths for both varieties as compared with the control (Table 11). But the increase in NPK fertilizer levels from 200 to 600 kg/ha did not ($P>0.05$) cause significant change in the cassava root lengths (Table 11).

Perhaps, the observed increase in root tuber length following fertilizer application could be as a result of increased availability of nutrients (N, P & K) required for cassava tuber growth and development (Ayoola & Makinde, 2007b; Mengel & Kirkby, 2004; Nguyen *et al.*, 2002).

4.2.2.3 Cassava root tuber girth

There were significant differences ($P<0.05$) in the cassava tuber girths amongst the treatments for both varieties. Also, the interaction effect of NPK fertilizer and cassava varieties was significant ($P<0.05$) (Appendix 6). For both cassava varieties, the application of NPK fertilizer significantly ($P<0.05$) increased the cassava root tuber girth compared to the control treatment (Table 11). The incremental addition of NPK up to 400 kg/ha significantly ($P<0.05$) increased the tuber girth for NASE 14, but not for NAROCASS 1. Also, tuber girth for NASE 14 declined when the NPK application rate was increased to 600 kg/ha (Table 11).

The larger tuber girths of the NPK fertilizer-treated cassava plants could be attributed to the availability of nutrients (N, P and K) which were used in tuber bulking. Similar observations were reported by Leo and Kabambe (2014).

4.2.2.4 Cassava fresh root tuber weight

The application of NPK fertilizer significantly ($P<0.05$) increased the cassava fresh root tuber weight when compared with the control for both cassava varieties (Table 11). However, the interaction effect of NPK fertilizer and cassava varieties was not significant ($P>0.05$) (Appendix 6). Overall, the variations in fresh root tuber weights followed a similar trend as the root tuber girths (Table 11).

The positive response shown by cassava root tuber weight as a result of applied NPK fertilizer could be due to the increased supply of N, P and K nutrients (Ayoola *et al.*, 2007; Leo and Kabambe (2014). Increased root tuber weight could also be linked to the well-developed photosynthetic surfaces and increased physiological activities in the fertilized treatments as a result of NPK fertilizer application that led to more assimilates being produced and subsequently translocated to the tubers (Howeler *et al.*, 2000; Hillocks, 2002).

4.2.2.5 Cassava root yield

The application of NPK fertilizer significantly ($P<0.05$) increased the fresh cassava root tuber yield as compared to the control for both varieties (Table 11). Similarly, the interaction effect of NPK fertilizer and cassava varieties was significant ($P<0.05$) (Appendix 6). Also in both varieties, increasing the NPK application rates from 200 to 600 kg/ha did not significantly ($P>0.05$) affect the cassava root tuber yields (Table 11).

Generally, cassava tuber yield in both cassava varieties were significantly increased by NPK fertilizer application compared to the control. The increase in tuber yield is certainly because the fertilizer provided the necessary nutrients for production of assimilates needed for root formation, and for increasing the photosynthetic capacity of the leaf area which provided photosynthates for tuber bulking (Hugh and Althea, 1994). However, the observed negative response in root tuber yield following the high rate of NPK fertilizer application (600 kg/ha) could be due to the diversion of photosynthates to vegetative development than to the tuber bulking. The same reason could be responsible for the decline in almost all the yield components when NPK application rate was raised to 600 kg/ha. Similar results were reported by Fermont (2009) and Howeler (2002) who observed increased vegetative growth with consequent reduction in root growth and yield at high fertilizer application rates.

The findings of this study has therefore, shown that when fertilizer is applied at the required quantities, it will lead to higher yield per hectare as earlier reported by Fermont (2009). However, this is contrary to the findings of Howeler (1998), Adeniyan *et al.* (2014) and Adoa (2009) who reported that cassava yield components that are of interest to the commercial cassava producers such as dry matter, average root weight and percentage of marketable roots were not affected by fertilizer application.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

The general objective of the study was to evaluate yield response of cassava/maize intercrops by manipulating maize planting density and applying mineral fertilizers. Specific objectives of the study were (i) to determine the effect of maize planting density in the cassava/maize intercrop on the growth characteristics and yield performance of the component crops, and (ii) to determine the effect of NPK fertilizer on the growth characteristics and yield performance of the newly developed cassava varieties.

In experiment one, intercropping maize with cassava varieties significantly ($P<0.05$) increased the maize plant heights. In both NAROCASS I/Maize and NASE 14/Maize intercrops, maize plant heights at 2 MAP, at tasseling and at harvest under the intercropping system 1C:2M were significantly ($P<0.05$) higher than those of maize plants under sole maize cropping as well as in the 1C:1M intercropping system. Intercropping maize with cassava varieties significantly ($P<0.05$) reduced the cob length. The lengths of cobs from sole maize cropping were higher ($P<0.05$) than those of cobs obtained from the 1C:2M intercropping. The cob length decreased in the order SM > 1C:1M >1C:2M indicating that as the plant population density increases, the cob length gradually decreases. Intercropping maize with cassava varieties significantly ($P<0.05$) reduced the maize grain weight when compared to sole maize. Increasing the maize population density to 1C:2M significantly reduced the grain yields when compared with the grain yields obtained at the lower plant population density (1C:1M), as well as in the sole maize cropping.

Intercropping maize with cassava varieties significantly ($P<0.05$) increased the cassava plant heights. In the NAROCASS I / Maize intercrop, cassava heights at 2 MAP and branching were in the order SC < 1C:1M < 1C:2M indicating that as plant population density increased, the cassava plant height also increased. But at the time of harvest, the height of cassava plants under intercropping system were similar but significantly ($P<0.05$) shorter than the heights of cassava plants from sole cassava cropping for both intercrops. Intercropping maize with cassava varieties significantly ($P<0.05$) reduced the number of cassava root tubers, tuber girth, tuber length and fresh root tuber weight when compared with sole cropping. The number of cassava root tubers per plant from the intercrops (1C:1M and 1C:2M) was significantly ($P<0.05$) lower than that in sole cropping. Cassava root tuber girth significantly ($P<0.05$) decreased under intercropping compared to sole cassava cropping for both intercrops. Cassava tubers from the low intercrop density (1C:1M) were longer ($P<0.05$) than those obtained at the higher intercrop density (1C:2M) or sole cropping. Fresh root tuber weight from sole cropping was higher ($P<0.05$) than that from both intercrops, but root tuber weights at both the lower (1C:1M) and higher (1C:2M) plant population densities were not statistically ($P>0.05$) different. Cassava root yield from sole cropping was significantly ($P<0.05$) higher than that from the intercrops for both cassava varieties. However, cassava root yield from low intercrop density (1C:1M) was higher ($P<0.05$) than that of higher intercrop density (1C:2M). In both intercrops, the LERs were greater than one indicating the yield advantage of intercropping over sole cropping.

In experiment two, cassava stem heights at branching varied significantly ($P<0.05$) with increasing NPK fertilizer levels for both the newly developed varieties. Overall, cassava heights were significantly ($P<0.05$) higher for treatments with higher fertilizer levels than the control. For both cassava varieties, the root tuber numbers per plant significantly ($P<0.05$)

increased with NPK fertilizer levels up to 400 kg/ha when compared to the control treatments. But there was a decline in numbers when the fertilizer level increased to 600 kg/ha. The application of 200 kg/ha of NPK fertilizer significantly ($P<0.05$) increased the cassava root tuber length and girth, as well as the cassava fresh root tuber weight for both varieties when compared with the control treatment. The incremental addition of NPK up to 400 kg/ha significantly ($P<0.05$) increased the tuber girth for NASE 14, but not for NAROCASS 1. In both varieties, increasing the NPK application rates from 200 to 600 kg/ha did not significantly ($P>0.05$) affect the cassava root tuber yields.

5.2 Conclusions

Intercropping maize with the newly released cassava varieties in the ratio of 1:1 (1C:1M) significantly increases maize grain yields than in sole maize cropping as well as when the population density of maize in the intercrop is increased to 1:2 (1C:2M).

Intercropping maize with cassava varieties significantly reduces the number of cassava root tubers, tuber girth, tuber length and consequently the fresh root tuber weight. However, cassava tubers from the low intercrop density (1C:1M) were longer ($P<0.05$) than those obtained at the higher intercrop density (1C:2M). Also, cassava root yield from low intercrop density (1C:1M) was higher ($P<0.05$) than that of higher intercrop density (1C:2M).

Though there was significant reduction in cassava root yield, the land equivalent ratio (LER) has shown yield advantage in the intercropping system, especially when the ratio of 1:1 is adopted. Therefore, intercropping cassava and maize in the ratio of 1:1 increases total productivity of the land.

The application of up to 400 kg/ha of NPK fertilizer to the newly released cassava varieties significantly increases the root tuber numbers per plant, the cassava root tuber length and girth, and consequently the cassava fresh root weight and yield/ha.

5.3 Recommendations

Based on the results, the following are recommended:

1. Intercropping maize with newly released cassava varieties in the ratio of 1:1 is a feasible multiple cropping system that farmers growing maize and cassava should adopt in order to increase total productivity of the land.

2. Growers of the newly released cassava varieties should consider applying NPK fertilizer in order to improve growth and yield potential of cassava. Poor farming practices and soil miming as a result of continuous harvest and failure to apply fertilizers have caused soil fertility depletion. Therefore, the thinking that cassava can tolerate low soil fertility conditions needs to change if cassava tuber yields are to be improved, and in turn improve food supply that will meet the needs of the ever increasing human population.

3. More research is needed to further enhance the productivity of cassava/maize cropping system. Such research can include (i) scaling up the study to include more maize and cassava genotypes, and be carried out in different agro-ecological zones of Uganda where cassava and maize are grown, and (ii) determining the agronomic and economic use efficiencies of inorganic fertilizers in cassava/maize intercropping systems.

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APPENDICES

Appendix 1: Mean square values of ANOVA for the effects of plant population density on maize height different growth stages

Source of variation	DF	Maize height at 2 MAP	Maize height at 3 MAP	Maize height at tasseling	Maize height at harvest
Plant density	2	216.44**	2012.0 NS	11796.0**	30949.0**
Variety	1	2.30**	220.0 NS	19.42*	12514.0*
Plant density x variety	2	1.27 NS	145.0 NS	19.0 NS	2920.0 NS

***Significant at 0.001 **Significant at 0.01 *Significant at 0.05 NS: Not Significant

Appendix 2: Mean square values of ANOVA for the effects of plant population density on yield performance of maize under cassava/maize intercropping

Source of variation	DF	Maize cob length	Maize rows per cob	Maize grain yield	Maize grain weight
Plant density	2	24.133**	40.5017**	1582153.0**	1216791.0**
Variety	1	16.723*	0.6050*	269500**	12561.0*
Plant density x variety	2	12.005*	1.4933*	38621 NS	13474.0 NS

***Significant at 0.001 **Significant at 0.01 *Significant at 0.05 NS: Not Significant

Appendix 3: Mean square values of ANOVA for the effects of plant population density on cassava height at different stages of growth

Source of variation	DF	Cassava height at 2 MAP	Cassava height at branching	Cassava height at harvest
Plant density	2	216.920**	6996.4**	18837.3**
Variety	1	11.447*	1046.5**	346.6 NS
Plant density x variety	2	2.797 NS	1226.0*	59.9 NS

***Significant at 0.001 **Significant at 0.01 *Significant at 0.05 NS: Not Significant

Appendix 4: Mean square values of ANOVA for the effects of plant population density on yield performance of cassava

Source of variation	DF	Number of root/plant	Root tuber girth	Root tuber length	Root tuber weight	Root tuber yield
Plant density	2	903.61**	821.64**	1041.38**	74.721**	4.27E+07
Variety	1	33.64 NS	184.96 NS	317.43**	2.007 NS	1.25E+07
Plant density x variety	2	9.00 NS	29.06 NS	167.71*	1.034 NS	6.47E+06

***Significant at 0.001 **Significant at 0.01 *Significant at 0.05 NS: Not Significant

Appendix 5: Mean square values of ANOVA for the effects of NPK fertilizer on cassava height at branching and at harvest

Source of variation	DF	Cassava height at branching	Cassava height at harvest
Fertilizer rate	3	5029.4**	9068.0**
Variety	1	893.6*	8427.0*
Fertilizer rate x variety	3	19.9 NS	481.0 NS

***Significant at 0.001 **Significant at 0.01 *Significant at 0.05 NS: Not Significant

Appendix 6: Mean squares of ANOVA for effects of NPK fertilizer on yield performance of cassava

Source of variation	DF	No. of stems per plant	No. of roots per plant	Root tuber length	Root tuber girth	Fresh root tuber weight	Root tuber yield
Fertilizer rate	3	4.825**	827.879***	2282.19***	546.40***	57.45***	5.21E+08***
Variety	1	0.101 NS	286.005***	75.97**	23.010**	0.292 NS	1.79E+07**
Fertilizer rate x variety	3	0.039 NS	75.844***	11.31 NS	10.584*	2.051 NS	3.11E+07*

***Significant at 0.001 **Significant at 0.01 *Significant at 0.05 NS: Not Significant