EFFECT OF INTERCROPPING ORANGE-FLESHED SWEETPOTATO (*Ipomea batatas* L.) AND MAIZE (*Zea mays* L.) AT VARIED POPULATIONS ON YIELD AND β-CAROTENE CONTENT

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DECLARATION AND RECOMMENDATION

DECLARATION

This thesis is my original work and to the best of my knowledge has not been presented for any degree in any university.

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RECOMMENDATION

This research has been submitted with our approval as University supervisors

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DEDICATION

I affectionately dedicate this thesis to my beloved family, my parents, sisters and brothers for the moral and financial support they have accorded me during the study period.

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ABSTRACT

Food and nutrition insecurity are major problems affecting many communities in Uganda. Orange-fleshed sweetpotato (*Ipomea batatas* L.) was introduced to combat vitamin A deficiency in addition to providing the daily calorie requirement. Quality protein maize (*Zea mays* L.) is being promoted to provide a source of protein. With dwindling arable land due to increasing population, intensive production by intercropping could increase yield and improve nutrition. Compatibility of sweetpotato and maize in an intercrop system has however not been determined. An experiment was carried out to determine the effect of varying the maize population on growth and yields of both crops and β-carotene in sweetpotato. It was laid out in a Randomized Complete Block Design (RCBD) with four blocks. Intercrop density 1, 2 and 3 had 41,666, 55,555 and 88,888 maize plants ha^{-1}, respectively. Data were subjected to Analysis of Variance (ANOVA) using SAS version 9.0 and means separated using Least Significant Difference (LSD) at $\alpha \leq 0.05$. β-carotene in roots was determined using the Near-infrared reflectance spectroscopy. A partial budget was calculated to evaluate the economic relevance of intercropping and calorific yields of all treatments were calculated using relative energy values from a food composition table prepared by Hotz *et al.* (2012). Intercropping and maize density reduced the number of main stems, branches and leaves per sweetpotato plant but increased stem length. Total and commercial storage root numbers and yields (t ha^{-1}) reduced significantly due to intercropping. β-carotene content in sweetpotato storage roots significantly reduced at high maize densities. Variety Naspot 9 had higher yield than Ejumula. Intercropping reduced maize height and grain yield but increased the LAI. The 100 seed weight did not however vary with intercropping and maize density. The LER shows that intercrop density 1 and 2 consistently had ratios above 1. The economic analysis illustrates that sole crops would fetch better benefits than the intercrops. Sole Naspot 9 performed better compared to sole maize and other treatments of Naspot 9. Across the cropping systems, sole Naspot 9 had the highest profit of UGX 4,764,660 ($ 1,764.69) followed by intercrop densities 2 and 1 [UGX 4,282,713 ($ 1,586.19), UGX 4,254,635 ($ 1,575.79)], respectively. Sole maize and sole Naspot 9 were the most profitable in comparison with Ejumula and Naspot 9 treatments, respectively. In the calorific yield analysis, intercrops had high energy value depending on the sweetpotato variety. This illustrates the nutritional advantage of intercropping.

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LIST OF ACRONYMS

AfDB	African Development Bank
ANOVA	Analysis of Variance
APC	Agricultural Policy Committee
ASARECA	Association for Strengthening Agricultural Research in East and Central Africa
CIP	International Potato Center
CIMMYT	International Maize and Wheat Improvement Center
DONATA	Dissemination of New Agricultural Technologies in Africa
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
IFPRI	International Food Policy Research Institute
LAI	Leaf Area Index
LER	Land Equivalent Ratio
LSD	Least Significant Difference
OFSP	Orange-Fleshed Sweetpotato
PRB	Population Reference Bureau
QPM	Quality Protein Maize
SCN	Standing Committee on Nutrition
UBOS	Uganda Bureau of Statistics
ZARDI	Zonal Agricultural Research and Development Institute

CHAPTER ONE

INTRODUCTION

1.1 Introduction

Agriculture plays an important role in the Ugandan economy. The sector provides food, improving the livelihoods of the citizens and contributes about 22.5 % to the national GDP and about 46% of the total export earnings (UBOS, 2011). It has thus been identified as a means to sustain nutritional quality and control poor health and chronic diseases especially in low income families (Wiesler *et al.*, 2003). An estimated 1.4 million people in Uganda are food insecure (SCN, 2010), and 33% of the children under 5 years are malnourished (UBOS, 2012). Estimates on sweetpotato indicate that by 2020 it will remain to be an important source of food particularly in East Africa where trends of malnutrition, food insecurity and poverty are on the increase (Scott *et al.*, 2000; SCN, 2004).

Vitamin A deficiency is a major problem in Uganda where 20% of the children and 19% of the women are affected (UBOS, 2007). Vitamin A deficiency causes anemia and in children causes blindness, high death rates due to diarrhea, measles and malaria and reduces the likelihood that mothers survive childbirth (Black, 2003). The increasing rates of child malnutrition, household food insecurity and poverty call for concerted efforts to curb the vitamin A deficiency.

Sweetpotato is one of the most important food crops in Uganda. In sub-Saharan Africa over 7 million tons (5% of global production) of sweetpotato is produced annually (Kapinga *et al.*, 2003; CIP, 2010). In East Africa, in 2011, Uganda led in production followed by Rwanda and Kenya with 2,554, 845.1 and 759.5 metric tons, respectively (FAOSTAT, 2011). In the war affected region of northern Uganda, sweetpotato is a preferred disaster mitigation crop because it is hardy, requires minimum care and produces sufficient quantities of food in a short time (Odongo *et al.*, 2007). White-fleshed sweetpotato varieties that are rich in starch have been used for improved food security for a long time. The varieties are however devoid or contain negligible amounts (about 35 μg/100 of edible portion) of β-carotene, the precursor for vitamin A. Orange-fleshed sweetpotato (OFSP) varieties that contain large amounts (300-4620 μg/100 of edible portion) of β-carotene have lately been developed to combat vitamin A deficiency

(Tumwegamire *et al.*, 2004). They give equal or better yields compared to the local varieties (Mwanga *et al.*, 2009).

Maize (*Zea mays L.*) is one of the major staple food crops in Uganda (APC, 1991). Conventional white maize is however deficient in protein because of the limiting quantities of essential amino acids - lysine and tryptophan (Vasal, 2001). In developing countries most people depend on maize as a major source of energy and dietary protein. The practice exposes them to the risk of protein or essential amino acid deficiencies because conventional white maize is low in protein (Krivanek *et al.*, 2007). Complementary protein sources such as animal products are however too expensive for the resource deprived small scale farmers. Quality protein maize (QPM) with twice the content of limiting amino acids- lysine and tryptophan (tryptophan 0.11%, lysine 0.475 % and protein 11.0% of the whole grain compared to 0.05, 0.225, and 8.5% in normal maize, respectively) has been introduced to help reduce human malnutrition in areas where protein deficiency is prevalent and where maize is the major protein source in the diet (Córdova, 2000).

Innovative technologies like QPM and OFSP have been introduced to alleviate vitamin A and protein deficiencies. In view of the dwindling land area per capita, intensification in production is needed. Intercropping (growing two or more crops on the same piece of land in the same season) is one of the intensification practices (Lithourgidis *et al.*, 2011). Under intercropping, yield stability is achieved by one crop compensating for the poor performance of the other crop (Fussell and Serafini, 1987). For successful intercropping, component crops must be compatible i.e. vary in rooting depths, height and tolerance/access to light (Lynch, 2007). Therefore if the two crops with a big potential to increase food production per unit area with enhanced nutrients are incorporated, the poor will be able to improve their food and nutrition security. Traditionally, sweetpotato has been grown as an intercrop with beans, cassava, maize and pigeon pea (Bashaasha *et al.*, 1995; Gibson, 2006)

1.2 Statement of the problem

Malnutrition and food scarcity are major problems facing communities in northern Uganda, a region that has been affected by war. Vitamin A and protein deficiency are two problems prevalent in this area. Orange fleshed sweetpotato and Quality Protein Maize have been introduced to alleviate vitamin A and protein deficiencies, respectively. Amid a rising

population and diminishing agricultural land, growing these crops as a mixture would increase yield, enhance food security and provide the essential nutrients. Little information is, however, available about the effect of intercropping Orange-fleshed sweetpotato and Quality Protein Maize on yield of the individual crops and β-carotene in sweetpotato.

1.3 Objectives

1.3.1 Broad objective

To contribute to enhanced food productivity and nutrition through optimal utilization of the available arable land.

1.3.2 Specific objectives

1. To determine the effect of intercropping QPM and OFSP on growth, yield and β-carotene content of orange-fleshed sweetpotato.
2. To determine the effect of intercropping QPM and OFSP on growth and yield of maize.
3. To determine the optimal plant population ratios of intercropping sweetpotato and maize.
4. To determine the economic and calorific yield benefits of intercropping OFSP and QPM.

1.4 Hypotheses (H_0)

1. Intercropping QPM and OFSP does not influence the growth, yield and β-carotene content of sweetpotato.
2. Intercropping QPM and OFSP does not influence the growth and yield of QPM.
3. The plant population ratios in the sweetpotato-maize intercrops are not significantly different.
4. Intercropping OFSP and QPM has no economic and calorific yield benefits.

1.5 Justification

Malnutrition is wide spread and severe among children and women in Uganda. About 20% of the children and 19% of the women are vitamin A deficient (UBOS, 2007). Individuals dependent on maize as a major source of dietary protein are susceptible to risk of essential amino

acid- lysine and tryptophan- deficiency. Orange-fleshed sweetpotato and quality protein maize have the potential to combat vitamin A and protein deficiencies, respectively.

In Uganda, about 12.8 million ha of the total 19.9 million ha is under agriculture (FAOSTAT, 2009). Increase in crop production over the past few years have been achieved mainly through expansion of cultivated land rather than from increased productivity. With the current high population density of 143 people km^{-2} and annual growth rate of 3.3 (Haub and Gribble, 2011) there is need for intensive production to feed the rising population. Intercropping is one of the ways for increased productivity and intensified land use. By intercropping the most important staple crops that provide vital micro nutrients, it will be possible to increase food production for the increasing population and at the same time reduce malnutrition.

CHAPTER TWO

LITERATURE REVIEW

2.1 Orange-fleshed sweetpotato production

Orange-fleshed sweetpotato are sweetpotato varieties whose internal root color is orange contrary to the cream and white-fleshed varieties which contain little or no β-carotene (Mbwaga *et al.*, 2007). Introduction of orange-fleshed sweetpotato (OFSP) has provided one of the means of reducing vitamin A deficiency that has previously been addressed using the expensive and inadequate vitamin A capsules (Low *et al.*, 2007). A food-based approach that includes fruits, vegetables, meat, eggs and milk that are rich in β-carotene or vitamin A is preferred. Most animal derived foods are however too expensive. Sweetpotato is a widely grown crop that is highly productive, available for most of the time in a year and supplies significant amounts of vitamin A and energy compared to vegetables (Anderson *et al.*, 2007). The β-carotene- rich OFSP was introduced to create healthy rural populations through food-based approaches to nutrition focused on vitamin A (Hagenimana and Low, 2000).

Sweetpotato is one of the most important food crops in Africa. In Central Uganda the land under OFSP was estimated to be 130 ha (Kapinga *et al.*, 2003) which has increased over time with increasing adoption countrywide (Kapinga *et al.*, 2007). Breeding activities in OFSP have always aimed at high dry matter, disease and pest resistance, adaptation to the environment, culinary qualities and β-carotene content (precursor to vitamin A) (Van Jaarsveld, 2007; Mwanga *et al.*, 2007b; Andrade *et al.*, 2009).

2.2 Maize production

Since its introduction, breeding programs for maize in Uganda have mainly aimed at developing cultivars that are tolerant to biotic and abiotic stresses and superior in yield (Diallo *et al.*, 1989; Balirwa, 1992). Quality is however becoming important because of the role in human nutrition and the increasing need to improve nutritional value (Diallo *et al.*, 1989).

Maize is a major source of carbohydrates, proteins and fats in developing countries. Cereal proteins, however, have poor nutritional value for monogastric animals, including humans because of the low amounts of essential amino acids such as lysine, tryptophan and threonine

(Prasanna *et al.*, 2001). Cereal proteins on average contain about 2% lysine, which is less than one-half of the concentration recommended for human nutrition. Animal protein, the alternative diet is scarce and expensive to many people in developing countries. Grain supplementation with essential amino acid produced by bacterial fermentation is expensive and leads to amino acid loss during processing in grain meals (Prasanna *et al.*, 2001).

In the 1960s, maize mutations namely *opaque-2* and *floury-2* with high levels of lysine and tryptophan were identified (Krivanek *et al.*, 2007) and have been undergoing improvement. In 2000, the first Quality Protein Maize (QPM) cultivar - Longe-5 "Nalongo" which is an Open Pollinated Variety (OPV) was released in Uganda (Córdova, 2000). The area under QPM has since been increasing. The positive developments and increase in population all require more land. Land for production is low hence calling for intensification in space and time.

2.3 Intercropping for improved production and resource use efficiency

Importance of intercropping

Intercropping is the growing of different crops in association on the same piece of land in the same cropping season (Andrews and Kassam, 1976; Ossom *et al.*, 2009). The system can either be mixed intercropping, row intercropping, strip intercropping or relay intercropping, depending on the spatial or temporal distribution of the crops (Vandameer., 1992). Strip intercropping is the growing of two or more crops simultaneously in different strips wide enough to permit independent cultivation but narrow enough for the crops to interact agronomically (Andrews and Kassam, 1976).

Intercropping is usually practiced to maximize returns from limited resources such as land and labour, to ensure food security, yield and income stability, to diversify the diet and to minimize dependence on agrochemical inputs (Francis, 1981; Fussell and Serafini, 1987; Vandameer., 1992). Stoskopf (1981) stated that there is no single cultivar which has all the best traits desirable to obtain the maximum production. Thus, if two crops with good traits are grown together a yield advantage can be obtained. This is possible through a more efficient use of light by the canopies, and water and nutrients by the roots (Lichtfouse *et al.*, 2009). Yield advantages from intercropping have been reported in a number of experiments (Muhammad, 2010; Shahbazi and Sarajuoghi, 2012).

The advantages of intercropping are attributed to better resource use efficiency (Lithourgidis *et al.*, 2011). The component crops normally have different root systems taking advantage of the moisture and nutrients at different soil depths. The canopies of the component crops in the intercrops occupy different heights providing a better cover for radiation interception while reducing water loss through soil evaporation and evapotranspiration. The result is that plants maximize resource acquisition to produce better yields (Black and Ong, 2000). Solanki *et al.* (2011) noted that in a maize based intercropping system radiation use efficiency and water use efficiency were higher in intercrops and resulted in more yield than maize alone. Intercropping baby corn with groundnut increased atmospheric nitrogen fixing ability and total productivity per unit area (Banik and Sharma, 2009).

Low input systems become more productive under intercropping especially for the cereal-legume intercrop. Maize yields when intercropped with pigeonpea or cowpea without application of mineral fertilizers were higher in the intercrops than sole maize (Waddington *et al.*, 2007). Application of nitrogen fertilizer causes a great reduction in the legume seed yield than when nitrogen is not applied because legumes fix less atmospheric nitrogen if the soil has a high content of native or applied nitrogen limiting nutrient benefits in intercropping to low input systems (Ramesh *et al.*, 2005).

The weed suppression ability of intercrops has been shown to provide a feasible solution to some of the noxious weeds. For example, maize grown in association with non-host crops is less infested with striga (Oswald *et al.*, 2002). Though the maize yields decline due to intercropping, the overall productivity is higher in intercropping systems. The associated crops suppress striga by acting as trap crops, stimulating suicidal striga germination or by altering of the microclimate. Intercrops with a dense canopy and creeping growth such as desmodium provide better striga suppression (Oswald *et al.*, 2002).

Other benefits of intercropping include hindering the spread of pests and diseases, and reducing erosion (Squire, 1990). The push and pull strategy where a protected crop is intercropped with another that repels pests (push) and a trap crop grown in the surrounding which attracts the pests (pull) has been used successfully against pests (Cook *et al.*, 2006). This is habitat management, a form of conservation biological control, with ecologically based approach aimed at favoring natural enemies and enhancing biological control in agricultural systems (Landis *et al.*, 2000). Intercropping significantly reduced the nymphs and adult

whiteflies the main vectors of sweetpotato virus disease in a sweetpotato-maize intercrop (Byamukama *et al.*, 2007). Intercropping sweetpotato with corn and/or soybean reduced the density of sweetpotato weevil population, rate of colonization by sweetpotato weevil, and associated level of damage to the sweetpotato storage roots. Although the sweetpotato weevil was controlled, the yield was lower in intercrops with an eventual higher marketable yield and monetary value for sweetpotato monocrop (Yaku *et al.*, 1992).

Intercropping serves as a protection against risks of total crop failure (in case of adverse weather conditions) and unstable market prices such that if one crop fails, the other may still be harvested and if prices of one of the crops are low, a farmer will suffer less due to poor prices of one crop (Lithourgidis *et al.*, 2011). The crops also provide an alternative food for farmers to improve their nutrition (Francis, 1981).

Intercrops exhibit a faster leaf area development and a more horizontal ground cover which facilitates higher trapping of photosynthetic active radiation. Below the canopy, a microclimate is formed with temperatures lower than in the sole crop or surrounding environment. The low temperatures help to reduce evapotranspiration and maintain moisture for plant growth (Ghanbari *et al.*, 2010)

2.3.1 Management of intercropping systems

Choice of species

Different species grown together interact with each other and the environment through competition or facilitation (Lichtfouse *et al.*, 2009). Competition or interference is the process in which two individual plants or two populations of plants interact such that at least one exerts a negative effect on the other (Vandameer, 1992). Growing compatible crops in association seldom affects their physiological attributes. A taller and dominant species in the intercrop usually a cereal, intercepts more solar radiation, because it either produces more leaves, or because of the erect canopy while allowing sufficient amount of radiation to reach the subordinate crop (Squire, 1990). The shorter species, usually C_3 have planophile canopies which trap the maximum amount of radiation transmitted from the dominant crop and use it more efficiently. The mixed canopy as a whole uses solar energy more efficiently. The advantage is such that 20-30% more

land is usually needed to produce the same total yield if the components were grown as sole crops (Squire, 1990; Awal *et al.*, 2004).

The complementarity of crops grown in association results from the spatial and temporal differences which exist in their growth habits. Temporal differences occur when peak demands for resources vary with time and thus exploit the resource base fully overtime whereas spatial differences exist when crops vary in root and canopy architecture and can thus acquire light and soil based resources at different levels. Differences in resource use overtime generally result in yield advantages in intercropping systems (Szumigalski and Van Acker, 2008; Fussell and Serafini, 1987).

Most work done on intercropping in sub-Saharan Africa has mainly focused on cereal-legume intercrops (Saka *et al.*, 2007). Legumes are preferably included in the cropping system because they reduce soil erosion, suppress weeds and fix biological nitrogen and provide food to humans and or livestock (Jeranyama *et al.*, 2000). Growth and yield of the legume component are reduced markedly when intercropped with high densities of the cereal component. Cultivars that are highly competitive depress the yield of component plants in an intercrop. An ideal cultivar in an intercrop should be one with reduced competitive effect on the companion crop in the mixture, but still with high productivity (Mutungamiri *et al.*, 2001).

Spatial and temporal distribution of crops in intercropping systems

Plant population density is one of the factors that influences yield parameters and resource use in intercropping systems. In a sweetpotato-groundnut intercrop, a high plant population resulted in reduction of yield components and subsequent yield (Ossom *et al.*, 2009). Sarlak *et al.* (2008) reported that in a sweet corn-mung bean intercrop, plant density did not have a significant effect on the studied traits (ear, kernel, cob and husk dry weight) instead the ratios in which the two crops were mixed caused a significant effect on these traits. Zamir *et al.* (1999) reported that increasing plant density by reducing the spacing caused a substantial reduction in the yield components (grains per cob and 1000 grain weight) but gave the highest grain yield in comparison with a wide spacing that had a lesser plant density. Mutungamiri *et al.* (2001) noted that spacing and plant arrangement significantly influenced the bean yield, while interaction between maize density and bean spatial arrangement had significant effect on maize yield.

Sowing maize and sesame simultaneously significantly reduced maize biomass and grain yields, but reductions were lower with delayed inter-seeding of sesame. On the other hand, delayed seeding led to a significant reduction in sesame dry matter and seed yield as a result of late sowing and increased competition from maize but since farmers considered sesame a secondary crop in this case, its yield shortfall was acceptable (Mkamilo, 2004). Farmers preferred intercropping to ensure food security even if there was no yield advantage (Diangar *et al.*, 2004).

Intercropping maize and sweetpotato at 50% of each crops' recommended plant population gave the highest yield, while the other mixtures with more or less of maize or sweetpotato gave less maize yields (Oswald *et al*, 1996). Intercropping reduced tuber sink-formation in sweetpotato and ultimately tuber yield. Interspecific competition on sweetpotato reduced assimilate production more severely than an altered assimilate partitioning causing a decline in tuber yields (Oswald *et al.*, 1996). Intercropping sweetpotato and maize did not reduce the yield of the latter unlike that of the former (Webi, 2007).

In an experiment where a constant maize population was intercropped with sweetpotato at recommended sweetpotato spacing and 50% population, Ossom (2010) reported a significant higher yield in both sole crops than intercrops. Egbe and Idoko (2009) found that intercropping sweetpotato and pigeonpea reduced the fresh storage root yield of five varieties. Intercropping sweetpotato and maize entails interaction of the two crops for water, nutrients, space and most importantly light which results in shading effect on sweetpotato. The degree of shading had varying consequences on yield and shoot growth at different stages of growth for different cultivars (Oswald *et al.*, 1994; 1995a and 1995b).

2.3.2 Effect of intercropping on sweetpotato

Depending on the level of shade imposed, some cultivars show shade tolerance while others show a yield decline. Shading may impede or modify certain physiological processes within the plant and as a consequence reduce plant growth and tuber development (Oswald *et al.*, 1995a). The development of storage parenchyma inside the tuber depends on the meristematic activity of the primary and secondary cambium which can be significantly reduced by shade (Oswald *et al.*, 1995b). Reduction in yield is associated with altered partitioning (to the shoot)

within the plant, a lower assimilate production and a smaller sink capacity which result in lower tuber weight. The yield decline generally increases with increasing shade (Oswald *et al.*, 1995b).

Oswald *et al.* (1995a) noted that storage root initiation is not adversely affected by shade and occurs in the first months at which stage storage root enlargement is minimal. They also observed about 50-60% reduction in total tuber yield due to an altered mode of assimilate partitioning (to the shoot) during the 9^{th}-13^{th} weeks after planting (Oswald *et al.*, 1994).

In some cultivars, deep shade delayed the time of storage root initiation and all shade levels reduced the number of storage roots/m^2, hence the sink-size (Oswald *et al.*, 1995a). The number of storage roots m^{-2} and storage root weights which are dependent on storage root initiation and formation are the main factors that determine storage root yield.

2.4 Factors that determine the enhanced quality of orange-fleshed sweetpotato and quality protein maize

β-carotene and Quality Protein are varietal traits. β-carotene content in sweetpotato varies greatly depending on flesh colour (Teow *et al.*, 2007) and variety (Kapinga *et al.*, 2010). Orange-fleshed sweetpotatoes have the highest amount of β-carotene which reduces as the color changes in the yellow-fleshed and the white-fleshed respectively (Teow *et al.*, 2007). β-carotene is a carotenoid- a group of pigmented compounds synthesized in bacteria, fungi, algae and plants (Rasid *et al.*, 2009). In plants carotenoids are synthesized in the plastids (Cunningham, 2002). The pigments also accumulate in chromoplasts besides the chloroplasts, providing the yellow, orange, and red colors of many flowers, fruits, and storage roots (Cunningham and Gantt, 1998; DellaPenna and Pogson, 2006). In photosynthetic tissues, the carotenoid colors are masked by chlorophyll, but these pigments contribute to the bright colors of flowers, fruits and roots in late stages of plant development. They are lipid soluble pigments that are important in photosystem assembly, light harvesting and photoprotection, photomorphogenesis, nonphotochemical quenching, lipid peroxidation and affect the size and function of the light-harvesting antenna and seed set (Bartley and Scolnik, 1995; DellaPenna and Pogson, 2006). The nonoxygenated carotenoids are referred to as carotenes with their oxygenated derivatives as the xanthophylls. Predominant carotenes are β-carotene and lycopene (Bartley and Scolnik, 1995: Rodriguez-Amaya, 2001).

In human and animal diets, carotenoids are precursors of vitamin A which is important for development and prevention of some diseases such as xerophthalmia and cancer (Cunningham and Gantt, 1998). Antioxidants prevent damage to DNA, proteins, and cellular tissues by quenching reactive oxygen species of oxidants produced during normal body metabolism and immune defense. This reduces aging and degenerative diseases and potentially alleviating a number of chronic diseases. Enzymatic and photooxidative derivatives of carotenoids are also used to impart odor and flavor in food fragrance and cosmetic industries (DellaPenna and Pogson, 2006; Rasid *et al.*, 2009).

Phytoene synthase (PSY) is the enzyme that catalyses the first important step in the plant carotenoid pathway and is believed to be rate limiting (Rasid *et al.*, 2009). Overexpression of the *psy* gene has been found to increase the amount of carotenoids in plant tissues. The gene has thus been targeted for over-expression in various commercial crops through breeding and genetic modification to elevate the pro-vitamin A carotenoid levels mainly, β-carotene in bid to combat vitamin A deficiency. The crops include Orange-fleshed sweetpotato, tomato and golden rice (DellaPenna and Pogson, 2006; Rasid *et al.*, 2009). The over-expression of phytoene synthase has a particularly potent effect on storage organ carotenoid levels (Othman, 2009).

Quality protein maize (QPM) describes a range of maize cultivars with increased amounts of limiting amino acids lysine and tryptophan compared to conventional maize and has been developed to reduce protein deficiency (Krivanek *et al.*, 2007). Maize mutations opaque-2 (o2) and floury-2 (fl2) which give a soft floury/opaque endosperm with almost twice the levels of lysine and tryptophan compared to normal genotypes were discovered in the 1960s and this sparked off initiation of breeding programmes. Opaque-2 endosperm modifiers that give the endosperm a normal hard appearance (50% translucent and 50% opaque) instead of the soft, chalky nature- were later identified and used to develop varieties and hybrids comparable to conventional maize in grain type and yields with a higher biological value in protein (Prasanna *et al.*, 2001; Sofi *et al.*, 2009). The increase in the lysine and tryptophan levels in the endosperm is largely due to a reduction in zein protein fraction (Vasal, 2000).

2.5 Management of β-carotene in sweetpotato and lysine and tryptophan in maize

Li *et al.* (2002) reported that *Dioscorea zingiberensis* (a pharmarceutical industry plant) grown at different light intensities produced varying levels of carotenoids and

carotenoid/chlorophyll ratios. In the normal green form, total carotenoids make up 1.3% of the total leaf lipids, corresponding to a carotenoid/chlorophyll ratio of 1:6. The carotenoid/chlorophyll ratio was found to be 1:3 and 1:2 for light-green and yellow-green leaves respectively. This increase in carotenoids in the two phenotypes refers to β-carotene as well as to the xanthophylls lutein and violaxanthin (Li *et al.*, 2002). At lower and higher light intensities of 10 and 270 $\mu E \cdot m^{-2} \cdot sec^{-1}$, carotenoids increase more than in intermediate intensities. This is because, in shaded conditions lutein and violaxanthin appear in considerably higher concentrations and play a role in light absorption, while at high light intensities carotenoids manifest as lutein, neoxanthin and β-carotene and protect the plant from excessive light (Li *et al.*, 2002). Carotenoids in the non-photosynthetic organs widely differ in amount and composition. The chromoplast carotenoid pathway is however highly regulated (Rasid *et al.*, 2009).

Other factors that influence carotenoid composition include cultivar/variety, stage of maturity and climate/geographic site of production (Van Jaarsveld, 2007). Levels of β-carotene vary with stage of growth and cultivar (Anderson *et al.*, 2007). As the storage roots continue to grow the amount of β-carotene increases while genotypes grown at higher altitudes show an increase in β-carotene (Manrique and Hermann, 2000).

Accumulation of optimal levels of β-carotene also requires specific management systems. Kapinga *et al.* (2004) found that viral infection reduced the carotenoid content of the test variety (Resisto) by 16-43%, depending on the type of virus and their association. Guertal and Kemble (1997) reported that nitrogen fertilization did not affect yield or quality of sweetpotato and there was no significant interaction between row spacing and N rate. Environment, genotype and GxE interaction however influenced the β-carotene content in the storage roots. Genotypes appear to contribute more to the total variability of β-carotene than the environment i.e. β-carotene content increased with altitude and genotypes (Manrique and Hermann, 2000).

In maize production factors that increase grain yield also increase the starch concentration of the grain, but reduce the grain protein concentration. Grain yield is inversely proportional to grain protein concentration and is partly associated with the higher glucose costs for synthesis of protein than carbohydrates (Basra and Randhawa, 2002). The relationship does not apply for hybrids with a wide range of protein concentrations. At high nitrogen levels, grain yield and proportion of protein increase but grain protein concentration decreases because of the

preferential deposition of zein over the other endosperm proteins (Basra and Randhawa, 2002). Zein level increase with protein content in the conventional maize but not in grains of opaque-2 hybrids. Zein contains low quantities of the most limiting amino acids lysine and tryptophan thus increased grain yields change the amino acid balance by reducing lysine and tryptophan concentrations, leading to a low biological value of the grain protein. Conversely, Basra and Randhawa (2002) reported that with opaque-2 maize a constant increase in grain lysine concentration was obtained with increased nitrogen supply.

The opaque-2 (o2) gene in QPM partially suppresses zein synthesis manifested by very late initiation and a lower biosynthetic rate of zein and zein-like proteins during kernel development, ultimately resulting in an increase in lysine and tryptophan proportions (Ortega *et al.*, 1991). The protein composition of cereal grains in the endosperm is dependent on the genotype and environmental factors, temperature, moisture, soil fertility and N fertilization (Rao *et al.*, 1993; Azevedo *et al.*, 2003). Fernandez-Figares *et al.* (2000) reported that there exists competition in the transport of proteins and sugars to the grain under some conditions where an increase in carbohydrate-accumulation rate was related to a decrease in the respective protein-accumulation rate. This competition could be responsible for the inverse relationship between grain yield and grain-protein content commonly found in cereals.

Studies on intercropping have mainly focused on yield and economic benefit from the component crops (Kassie, 2011). Besides food insecurity and economic benefit, nutritional insecurity is increasingly becoming important. It is thus imperative to find out the effect of cropping system on the quality of the crops.

2.6 Evaluation of intercropping effects using Land equivalent ratio

The benefits of intercropping systems can be evaluated by measuring productivity using Land Equivalent Ratio (LER). LER is the area that would be needed in sole crops to obtain the same total yield as produced by unit area in the crops mixture at an equal management level (Andrews and Kassam, 1976). Provided all factors are uniform, LER compares the yield obtained by growing two or more crops as an intercrop with growing the same crops as monocultures or pure stands (Mead and Willey 1980; Dariush *et al.*, 2005). The idea of intercropping is to capitalize on the beneficial interactions between crops, while avoiding

negative interactions and the LER measures the effect of both beneficial and negative interactions between crops (Kantor, 1999).

Various computations are available for evaluating intercropping effects but LER is preferred because it is simple, easy to use and not affected by market value of crops and inputs. The LER however does not indicate the economic benefit of yield levels and quality of crops. It however still remains an important index of productivity in intercropping systems (Gupta and O'Toole, 1986).

Relative Crowding Coefficient (RCC) is used to estimate the competitive effect of one crop over the other and the advantage of intercropping. The crop with a higher coefficient is said to be dominant. If the product of the coefficients of component crops is less than, equal or greater than 1, then intercropping would have had negative effect on yield, no yield advantage or a yield advantage, respectively (Willey and Rao, 1980).

2.7 Importance of economic evaluation in cropping systems

The primary concern of many farmers is to ensure adequate food supply for their families. They do this by producing much of the required food on their farms or by selling certain quantities of their output and using the income to buy food (CIMMYT, 1998). Whether the farmers market little or most of their produce, their major interest is on economic returns. They will consider the costs of changing from one practice to another and the economic benefits resulting from that change. Benefits gained may be weighed in form of the harvest against the costs in form of labor or cash given up (CIMMYT, 1998).

Currently, agroecology strongly focuses on food production but also more attention is drawn to social and economic aspects that limit sustainability in food systems in modern industrial agriculture (Gliessman, 2013). Intercropping is a dominant practice (Ndaeyo *et al.*, 2001; Ghosh *et al.*, 2007) and a cropping system needs to be economically feasible and meet the farmer's food requirements in order to be adopted and sustained (Kassie, 2011).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Site Description

The trial was carried out at Ngetta Zonal Agricultural Research and Development Institute, Lira District, Northern Uganda. The Institute lies at an altitude of 1091 m.a.s.l, latitude 2° 17' N and longitude 32° 56' E with an average temperature of about 22.5 – 25.5°C and rainfall of 1200 – 1600 mm per annum (Appendix 1). The rainfall occurs in two seasons (April – June and August – October). The soils are sandy clay loam classified as Ferralsols with a pH of between 5.2 and 5.8. This experiment was carried out in the first and second seasons of 2011 during the April-June and July-October rains.

3.2 Treatment combinations

3.2.1 Crop species evaluated

Sweetpotato varieties

Sweetpotato varieties Ejumula and Naspot 9 selected based on consumer preference and orange flesh colour were used. Ejumula is the most preferred orange-fleshed variety in most parts of the country due to its early maturity, high starch content, deep orange colour and taste. Naspot 9 is a deep orange variety that is widely adapted to local conditions, gives high yields, is early maturing and highly resistant to sweetpotato virus disease.

Maize variety

Longe-5 "Nalongo" an Open pollinated variety (OPV) of Quality Protein Maize released in Uganda in 2000 was used. It is a synthetic variety that gives higher yield compared to the normal OPVs. The seed was obtained from Elgon Seed Company.

3.2.2 Plant population

The sweetpotato plant population was kept constant in both the sole sweetpotato and in the intercrops. The maize plant population was however varied to give three populations of the intercrop. All together, the intercrops and sole crops made five treatments composed of sole sweetpotato (Sp sole), sole maize (Msole), intercrop Density 1, Density 2 and Density 3.

3.3 Experimental design

The experiment was laid out in a Randomized Complete Block Design (RCBD) with four blocks. In each block 6 treatment combinations of the two sweetpotato varieties with maize and their sole crops were randomly assigned to the experimental plots. Treatment combinations were: Variety (2) and intercropping pressure (with three varying maize plant densities).

All plots measured 4.5 m long and 4.8 m wide consisting of four (4) ridges each 4.5 m long and 1.2 m wide. The ridges were wider to facilitate light penetration through the maize plants to the lower sweetpotato crop. Due to the wide ridges, the sweetpotato population per ridge was increased by planting two rows to make use of the wide space. Controls for maize were planted at a spacing of 75 cm x 30 cm. Sweetpotato was planted at 30cm x 30cm both in sole and intercrop. The three intercrop populations of both sweetpotato varieties with maize were laid out as described below which is a modification of a design by Webi (2007):

(i) Density 1. Two rows of sweetpotato spaced at 30 cm on top of the ridge at intra-row spacing of 30 cm. The maize was then planted on either furrow sides of the ridge at 120 cm between rows (ridge width) and 25 cm within the rows, with one plant per hill. There was a distance of 45 cm between the sweet potato and maize rows on either side of the ridge. Plant population for sweetpotato was 55,555 plants ha^{-1} and for maize 41,666 plants ha^{-1}.

(ii) Density 2. Two rows of sweetpotato spaced 30 cm on top of the ridge and an intra-row spacing of 30cm with maize on either side of the ridge spaced 120cm between rows and 37.5 cm intra-row with 2 seeds per hill. The distance between the sweetpotato and maize rows on either side of the ridge was 45 cm. Plant population for sweetpotato was 55,555 plants ha^{-1} and for maize 55,555 plants ha^{-1}.

(iii) Density 3. Two rows of sweetpotato spaced 30 cm along the ridge and 30 cm within rows with double rows of maize on either side of the ridge. The sweetpotato and maize rows were separated by a distance of 30 cm and spacing between different rows of maize on either side of the ridges was 30 cm. The intra row spacing for maize was 37.5 cm with 2 plants per hill. Plant population for sweetpotato was 55,555 plants ha^{-1} and for maize 88,888 plants ha^{-1}.

A uniform rate of fertilizer was applied to all experimental plots to invigorate the plants with the main focus on maize. In the first season, N: P: K 17:17:17 was applied at a rate of 50 kg ha^{-1}. In the second season, N, P and K were applied singly as urea, triple superphosphate and

muriate of potash at rates of 50, 50 and 60 kg ha^{-1} respectively. The rates were according to the recommendations from Makerere University soil laboratory after analyzing the soil samples. In both seasons, fertilizer was applied a month after planting due to lack of rain in the first weeks.

3.4 Data Collection and analysis

The sample area harvested in each plot measured 2.4 m x 4.2 m determined by excluding the two outer ridges (1.2 m), and one plant on either side of the inner ridges (0.3m). Data on vine length, number of main stems, number of branches and number of leaves for sweetpotato were collected at 9, 12, 15 and 18 weeks after planting (WAP). Main stems were described as vines originating from below ground or branching at the base of a plant. One vine among the main stems was considered for measurement of vine length which was taken with a ruler. In the second season the interval between data collection dates was reduced to closely monitor the growth behavior and data taken at 9, 11, 13, 15 and 17 (WAP). Leaf area index was determined in all plots using the LAI-2200 Plant Canopy Analyzer by placing the optical sensor below the canopy at random chosen locations within each plot while facing in the same direction. Two readings above canopy (for reference in computation) and four readings below the canopy for each above canopy reading were taken in each plot. At 120 days after planting (DAP) maize was harvested while sweetpotato was harvested after 135 (DAP). Data on number of storage roots and weight of storage roots was classified into small (diameter < 35mm) and commercial (diameter > 35mm). The dry matter weight of the storage roots was determined by oven drying samples to constant weight at 70°C. β-carotene in the milled samples of freeze-dried storage root samples was quantified with the Near-infrared reflectance spectroscopy (NIRS) technology (Shenk and Westerhaus, 1993). Each milled sample material (two times 3 g) was analyzed by NIRS within the range of 400 to 2500 nm on a NIRS monochromator model 6500 (NIRSystems, Inc. Silver spring, MD) using small ring cups with sample autochanger. Near-infra-red spectra of each sample were used to determine β-carotene with the latest calibration version for sweetpotato freeze dried samples (Zum Felde, 2009). In this version, the correlations in cross-validation between standard laboratory reference methods and NIRS are 0.97 for β-carotene (Zum Felde *et al.*, 2009). The reference method for NIRS calibration was high performance liquid chromatography (HPLC) according to Rodriguez-Amaya and Kimura (2004) for β-carotene.

Data obtained was subjected to Analysis of Variance (ANOVA) using SAS version 9.0. Count and percentage data were transformed using log and arc-sine transformations, respectively to stabilize variances. Treatment means with significant differences were separated using Least Significant Difference (LSD) at $\alpha \leq 0.05$. The land use efficiency was assessed using the Land Equivalent Ratio (LER) according to Mead and Willey (1980).

3.5 Assessment of the Land use efficiency

The land use efficiency was assessed using the Land Equivalent Ratio (LER). Mean yields of intercrop and sole crops of sweetpotato and maize were used to compute the land equivalent ratio using the formula:

$$LER = \left(\frac{Is}{Ss}\right) + \left(\frac{Im}{Sm}\right)$$

Where I_s and I_m are the yields (t ha^{-1}) of sweetpotato and maize, respectively in the intercrop while S_s and S_m are the corresponding yields in sole stands.

3.6 Computation of the Partial budget analysis

The economic relevance of intercropping OFSP and maize was evaluated by calculating the partial budget as described by CIMMYT (1988) to establish the net benefits from all the treatments. Average yields for each treatment were adjusted downward by 10% to reflect the difference between the experimental yield and the yield farmers could expect from the same treatment. Costs of production for each system were calculated based on the labor and inputs used at the prevailing market rates. Yields were valued at the existing market prices. A marginal analysis was performed in two steps – dominance analysis and marginal rate of return. Net benefits and the costs that vary were compared across treatments in a dominance analysis to eliminate some of the treatments from further consideration on the basis that any treatment with a net benefit equal or less than that of another treatment with a lower cost, is dominated and a farmer would not consider it for investment. The marginal rate of return (MRR) was conducted for treatments that remained more than one after elimination in the dominance analysis to assess the change from one treatment to the other by comparing costs and net benefit of alternative treatments. The MRR is obtained by dividing the difference in net benefits by the difference in costs that vary. A minimum rate of return was fixed at 50% for the Marginal Rate of Return as

the least benefit reference for a farmer to adopt a certain treatment so that any treatment with MRR of 50% and above is considered worthy of investing by a farmer. A minimum returns analysis that accounts for the variability in yield due to uncontrollable risks such as drought was conducted to estimate the results in case of the worst situations.

3.7 Computation of calorific yield

The calorific value from yields of the sole crops and intercrop treatments was calculated using relative rates from a food composition table prepared by Hotz *et al.* (2012). 100g of raw dry grain were estimated to contain 365 Kcal while 100g of raw orange-fleshed sweetpotato were estimated to contain 123 Kcal. Energy yield was computed in all the plots and obtained values were statistically analyzed with SAS.

CHAPTER FOUR

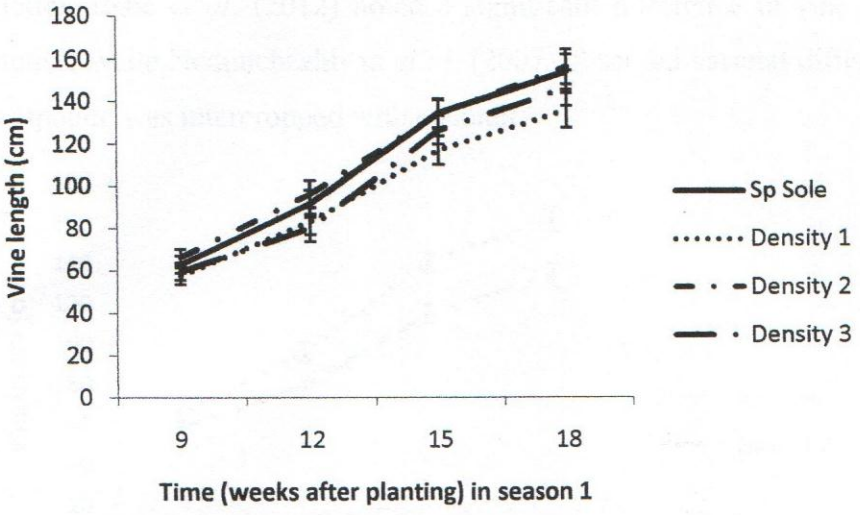
RESULTS AND DISCUSSION

4.1 Effect of intercropping on growth, yield and quality of sweetpotato

4.1.1 Effect of intercropping on sweetpotato growth (vine length, number of main stems, number of branches and number of leaves)

Vine length

Irrespective of stage of growth and intercrop densities, intercropping did not affect the sweetpotato vine length during season 1 (Fig. 1a). During the second season, however, intercropping significantly ($p \leq 0.05$) influenced vine length (Fig. 1b). Plant growth in the first season may have been limited by the low amount of rain (821.2 mm compared to 928.3 mm in the second season. Nevertheless, densities 1 and 2 with the least and intermediate maize populations, respectively had the longest vines (163.9cm and 159.3cm, respectively) while sole sweetpotato had the shortest vines. A reduction in intensity and quality of light in the high density canopy may have triggered elongation and hindered leaf primordial growth to ensure enough resources for elongation as a shade avoidance strategy (Carabelli *et al.*, 2007). Initiation of shade avoidance under low irradiance conditions occurs when auxins are stimulated and cause apical growth (Vandenbussche *et al.*, 2003; Pierik *et al.*, 2009a). Auxins have also been reported to increase expansins (a class of cell wall loosening proteins) that facilitate cell expansion during growth (Pierik *et al.*, 2009b). Ebwongu *et al.* (2001) similarly noted that intercropping maize and potato led to a faster rate of stem extension and leaf formation in potatoes.



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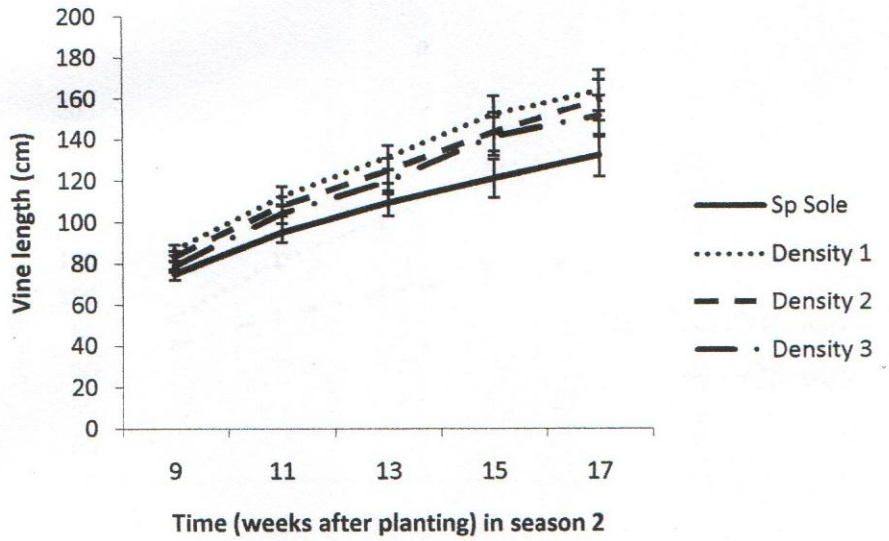

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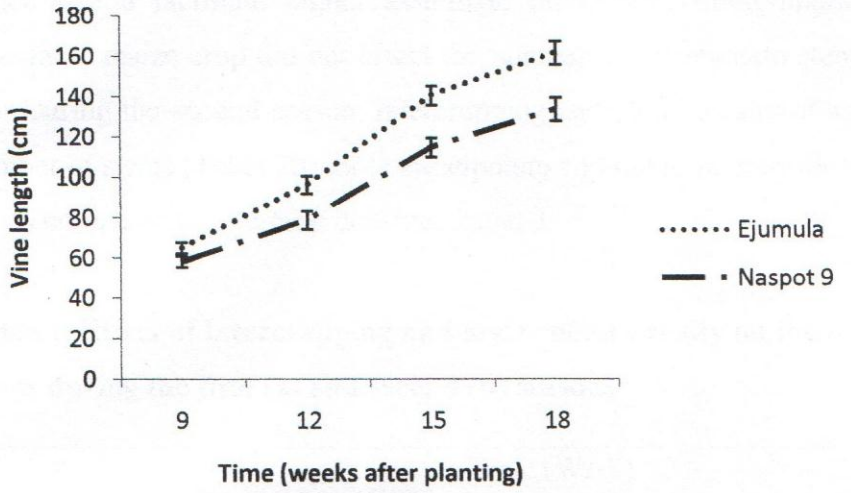
Figure 1. Effect of intercropping and density of associated maize crop on sweetpotato vine length at different periods of growth in seasons one (a) and two (b)

Generally, Ejumula was longer than Naspot 9 (Fig. 2a and 2b). The variation in vine length could be attributed to differences in genetic make-up of the genotypes where Ejumula has higher vine length (Kapinga *et al.*, 2010). In a study of the performance of improved sweetpotato

varieties, Egbe *et al.* (2012) noted a significant difference in vine length among sweetpotato varieties, while Nedunchezhiyan *et al.* (2007) observed varietal differences in vine length when sweetpotato was intercropped with coconut.



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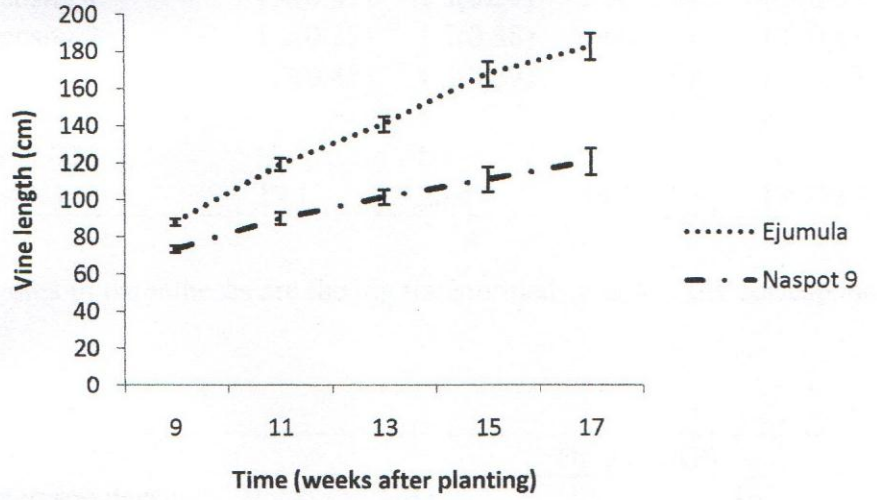

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Figure 2. Effect of varieties on sweetpotato vine length at different periods of growth during the first (a) and second (b) seasons

Number of main stems

Main stems were described as vines originating from below ground or branching at the base of a plant. Higher number of stems corresponds to a high number of branches and leaves which would facilitate higher assimilate production. Intercropping and planting density of associated maize crop did not affect the number of sweetpotato stems during season one (Table 2a). During the second season, intercropping and plant density of associated maize affected the number of stems (Table 2b). Sole sweetpotato and intercrop density 1 had the highest numbers of stems compared to intercrop densities 2 and 3.

Table 1. Effect of intercropping and maize plant density on the number of sweetpotato stems during the first (a) and second (b) seasons

	Time (WAP)			
Intercrop density	9	12	15	18
Sp Sole	1.7(0.42)	1.6(0.40)	1.8(0.44)	1.8(0.44)
Density 1	1.4(0.37)	1.5(0.39)	1.5(0.39)	1.5(0.39)
Density 2	1.5(0.38)	1.5(0.38)	1.6(0.41)	1.6(0.41)
Density 3	1.7(0.42)	1.5(0.39)	1.5(0.39)	1.5(0.39)
Lsd0.05	Ns	Ns	Ns	Ns
Cv(%)	17.1	20.47	19.57	19.572

a

Figures in parentheses are the log transformed values of the corresponding data

	Time (WAP)				
Intercrop density	9	11	13	15	17
Sp Sole	1.70(0.43)	1.53(0.39)	1.70(0.42)	2.00(0.47)	2.00(0.47)
Density 1	1.60(0.41)	1.60(0.41)	1.65(0.42)	1.70(0.43)	1.70(0.43)
Density 2	1.45(0.39)	1.35(0.37)	1.40(0.38)	1.38(0.37)	1.38(0.37)
Density 3	1.25(0.35)	1.18(0.34)	1.10(0.32)	1.18(0.34)	1.18(0.34)
Lsd0.05	0.06	0.06	0.06	0.05	0.05
Cv(%)	14.10	14.26	15.21	12.77	12.77

b

Figures in parentheses are the log transformed values of the corresponding data

The shading effect of maize on sweetpotato may have led to a reduction of main stems in the intercrops. The reduction in the number of stems was higher under higher maize densities probably because of the intensified shade effect. Lower parts of the intercrop canopy are characterized by increased internode lengths, less branching and less leaf production of the shorter component crop because of reduction in intensity and quality of light (Ennin *et al.*, 2002). Varieties did not differ in number of stems at all stages of growth in both seasons (Table 3).

Table 2. Effect of varieties on the number of sweetpotato stems at different periods of growth during the first (a) and second (b) seasons

	Time (weeks after planting)			
Variety	9	12	15	18
Ejumula	1.6(0.41)	1.6(0.40)	1.8(0.43)	1.8(0.43)
Naspot 9	1.5(0.39)	1.4(0.38)	1.4(0.38)	1.4(0.38)
Lsd0.05	Ns	Ns	Ns	Ns
Cv(%)	17.10	20.47	19.57	19.57

a

Figures in parentheses are the log transformed values of the corresponding data

	Time (WAP)			
Variety	9	12	15	18
Ejumula	1.6(0.41)	1.6(0.40)	1.8(0.43)	1.8(0.43)
Naspot 9	1.5(0.39)	1.4(0.38)	1.4(0.38)	1.4(0.38)
Lsd0.05	Ns	Ns	Ns	Ns
Cv(%)	17.10	20.47	19.57	19.57

b

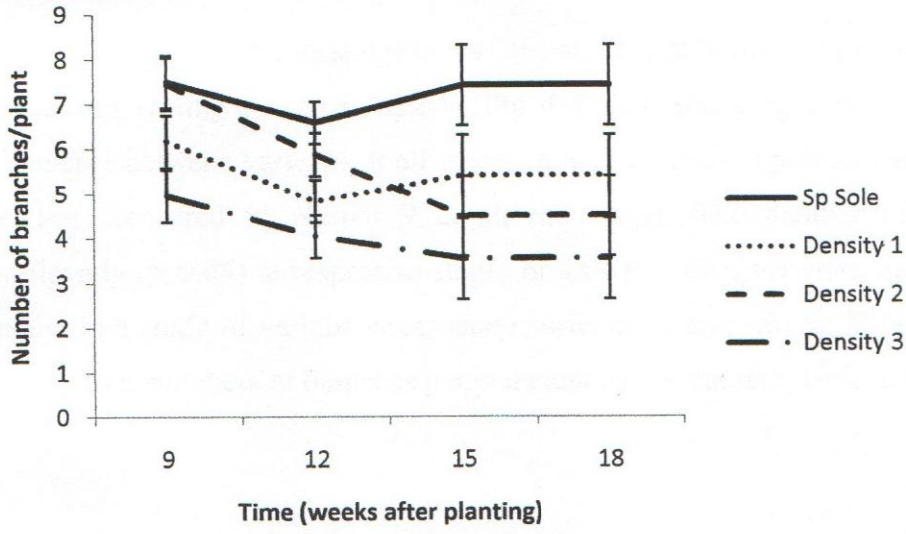
Figures in parentheses are the log transformed values of the corresponding data

Number of branches

During the first and second seasons, intercropping significantly ($p \leq 0.05$) affected the number of branches in sweetpotato. Sole sweetpotato produced the highest number of branches compared to the intercrops. The number of branches varied significantly with intercropping

densities. As the maize population increased in the intercrops, the number of branches of sweetpotato proportionately decreased in both seasons (Fig. 3).

The reduction in number of branches could be a shade avoidance response. Plants initiate shade avoidance responses on perceiving a low quality of irradiance by enhancing elongation into sections of un-attenuated light and preventing branching to save assimilates for continued growth (Kebrom *et al.*, 2010). Similarly, in a pigeonpea-sweetpotato intercrop, Egbe (2012) noted that sole sweetpotato had higher number of branches. Also Menzel and Simpson (1989) reported that shading in passion fruit plants increased vine extension and reduced the number of floral buds. Seedlings grown in shade have been found to develop more branches with decreasing shade and the number of leaves decreased under shaded conditions (Gottschalk, 1994). Besides the shade avoidance response, plants also employ phototropism - the adaptive direct growth behavior towards light which causes elongation in low light conditions (Grebe, 2011).



(a)

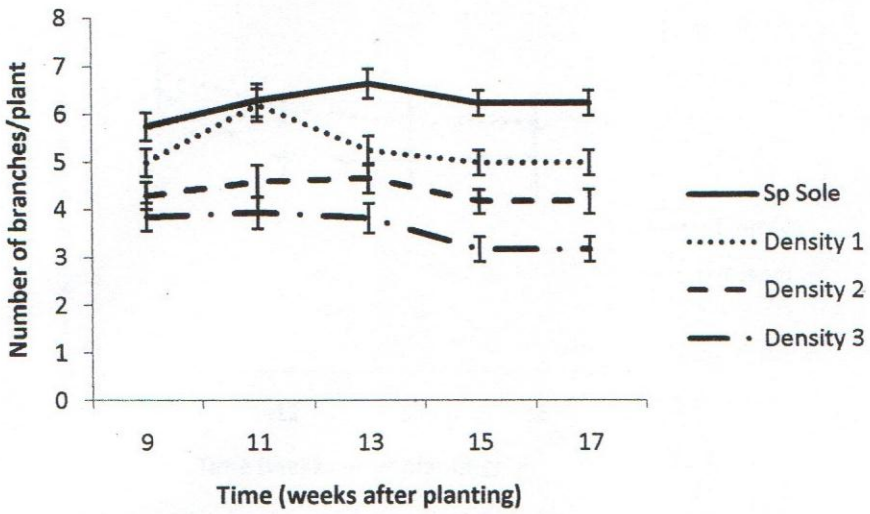


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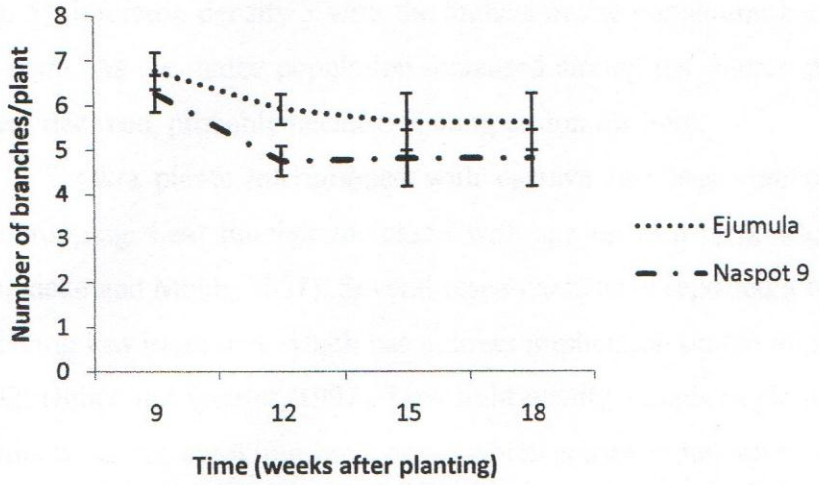
Figure 3. Effect of intercropping and density of associated maize crop on the number of sweetpotato branches at different periods of growth during the first (a) and second (a) seasons

During the first season (Fig. 4a), the number of branches varied only at 12 WAP among the varieties. During the second season (Fig. 4b), there was a significant difference in the number of branches between varieties at all stages of measurement. Ejumula had the highest number of branches compared to Naspot 9 at all the stages. The number of branches thus varied significantly ($p \leq 0.05$) at respective stages of growth within varieties and the variation could be genetic. In a study of various sweetpotato varieties in sole stands, Egbe *et al.* (2012) observed differences in numbers of branches per plant among sweetpotato varieties.



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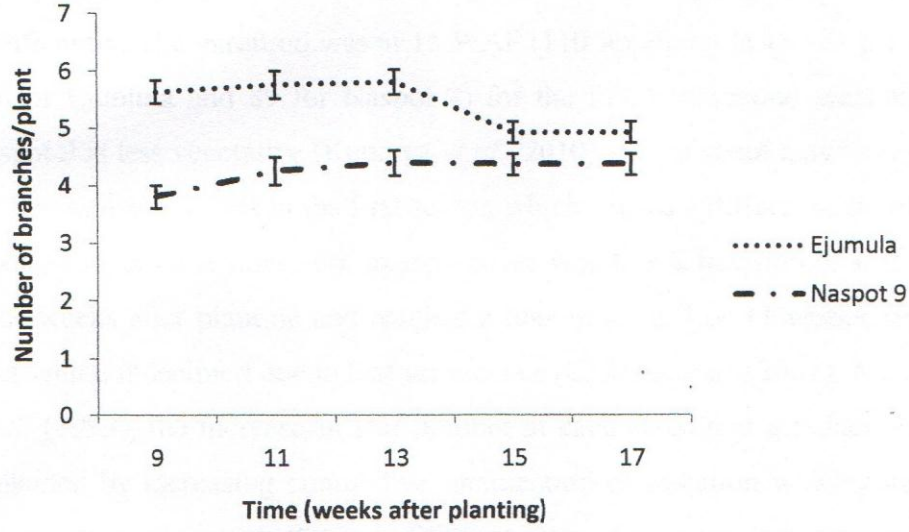

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Figure 4. Effect of varieties on the number of branches at different periods of growth during the first (a) and second (b) seasons

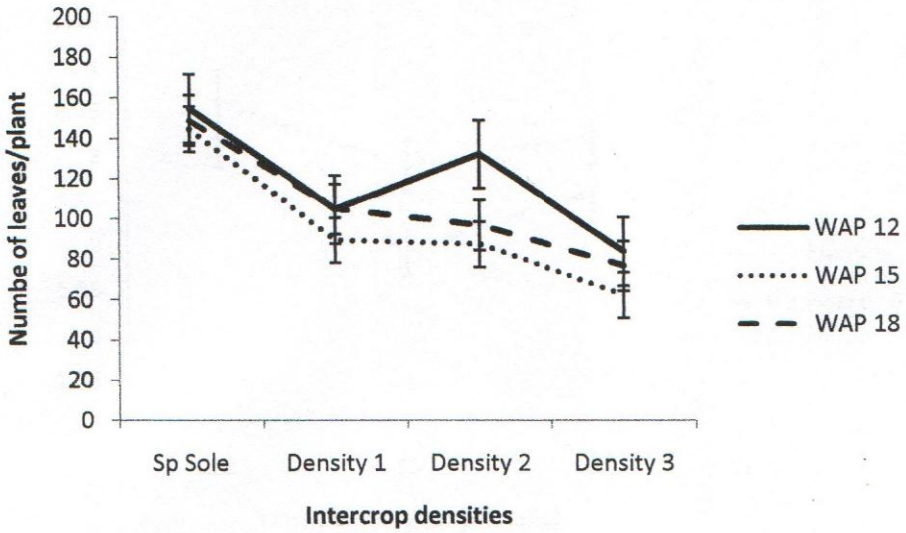
Number of leaves

Intercropping significantly affected the number of leaves. Sole sweetpotato produced a significantly ($p \leq 0.05$) higher number of leaves (155, 144 and 149 for season 1 and 110, 119, 116, 123 and 115 for season 2 at respective WAP) than the intercrops at all the counting intervals

(Fig. 5). Intercrop density 3 with the highest maize population had the lowest number of leaves per plant. As the maize population increased among the intercrops, the number of sweetpotato leaves declined, probably because of competition for light.

Okra plants intercropped with cassava had less number of leaves per plant due to intercropping. Leaf number increased with age up to a peak after which the number declined (Muoneke and Mbah, 2007). Several researchers have reported a reduction of branches in plants receiving low irradiance which has a direct implication on the number of leaves (Kemball *et al.*, 1992; Huber and Stuefer, 1997). Low light quality signals in plants (low red:far-red ratio) cause auxins to induce cytokinin breakdown which causes reduction in frequency of leaf cell division and diminished activity in the vegetative shoots and leaf primordia, resulting in the arrest of lateral buds and leaf development (Carabelli *et al.*, 2007).

During the two seasons, the number of leaves for the two varieties differed significantly. The variation was at 15 WAP (110 for Ejumula and 81 for Naspot 9) and 17 WAP (73 for Ejumula and 89 for Naspot 9) for the first and second seasons, respectively (Fig. 6). Naspot 9 is less vegetative (Kapinga *et al.*, 2010) and its shoot may have been limited further by the low moisture levels in the first season which caused a difference in total number of leaves. In a potato-sugar cane intercrop, canopy cover which is a function of leaf growth increased from three weeks after planting and reached a maximum at 7 or 11 weeks, depending on the variety after which it declined due to leaf senescence (Cadersa *et al.*, 2001). According to Foroutan-pour *et al.* (1999), the increase in leaf number at each stage and a reduction in final stages can be explained by increasing cumulative interception of radiation which causes an increase in total dry matter until towards the end of the cropping cycle when senescence begins and organs such as leaves are lost.



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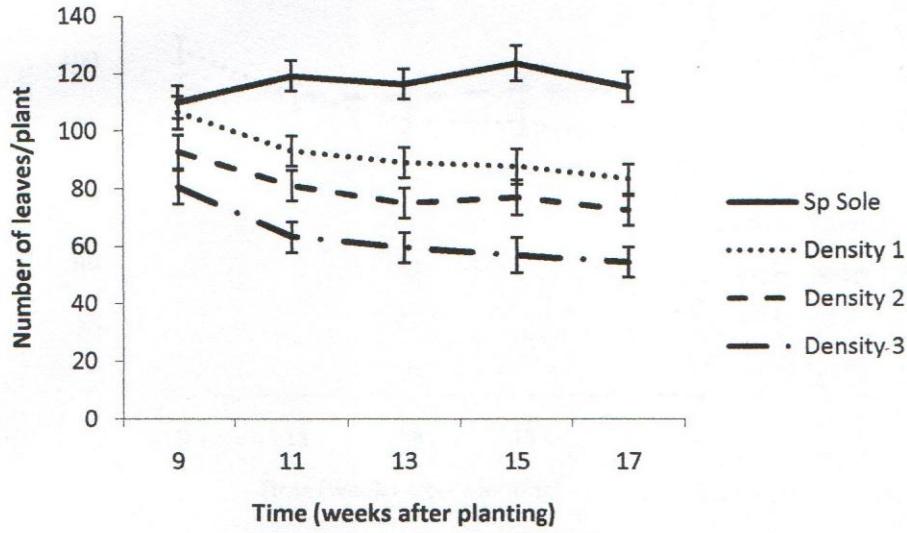

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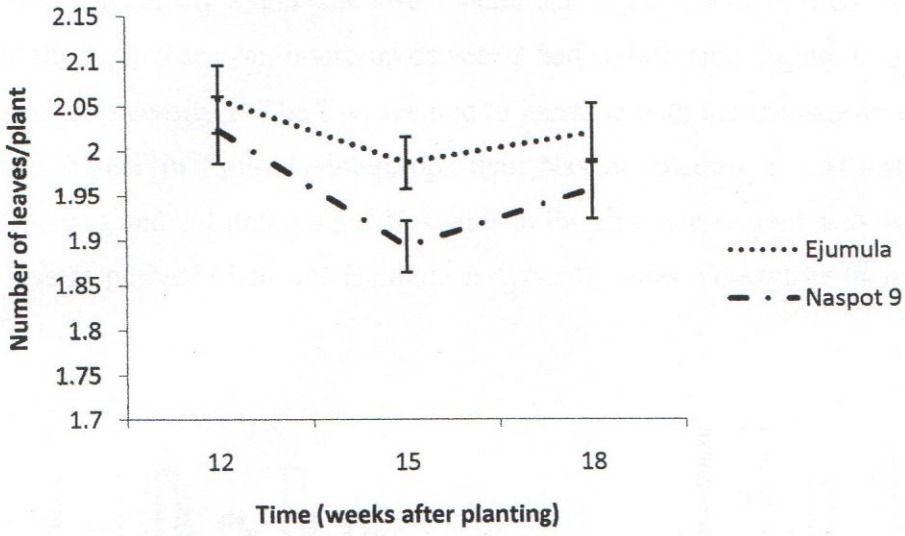
Figure 5. Effect of intercropping and intercrop maize densities on the number of sweetpotato leaves at different periods of growth during the first (a) and second (b) seasons



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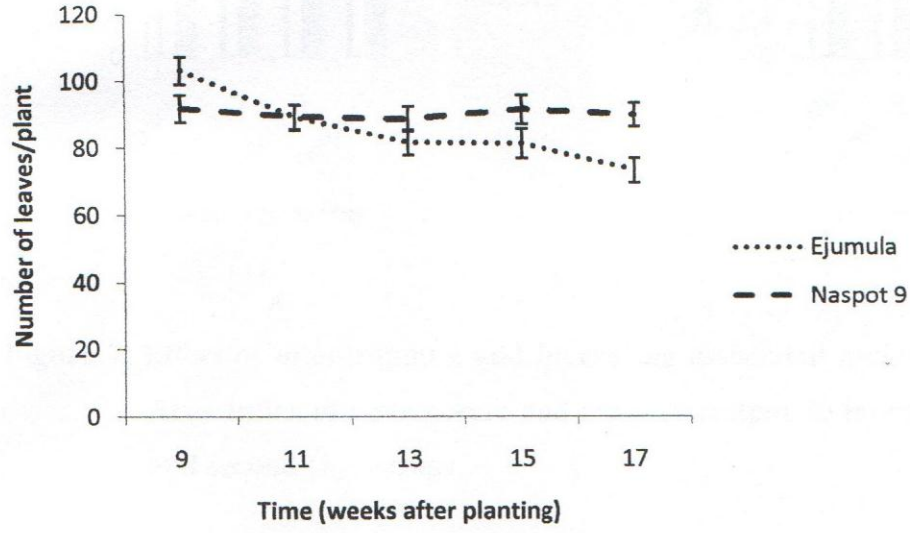


b

Figure 6. Effect of varieties on the number of leaves at different intervals of growth during the first (a) and second (b) seasons. Figure 6(a) is presented with log transformed values.

Leaf Area Index

Intercropping significantly ($p \leq 0.05$) affected the Leaf Area Index (Fig. 7). Season 2 had higher LAI compared to season 1 probably because of rainfall patterns. In the first season,

intercrop density 2 and sole sweetpotato had higher LAI followed by intercrop density 1 and 3. In the second season, intercrop density 3 had significantly higher LAI than sole sweetpotato and intercrop density 1. The LAI seemed to increase with the increase in maize population. The LAI was higher in Ejumula intercrops than Naspot intercrops. LAI values were 2.9 and 4.2 for Ejumula and 2.4 and 3.4 for Naspot 9 in the first and second seasons, respectively were noted. This is probably because Ejumula is typically more vegetative than Naspot 9 (Kapinga *et al.*, 2010).

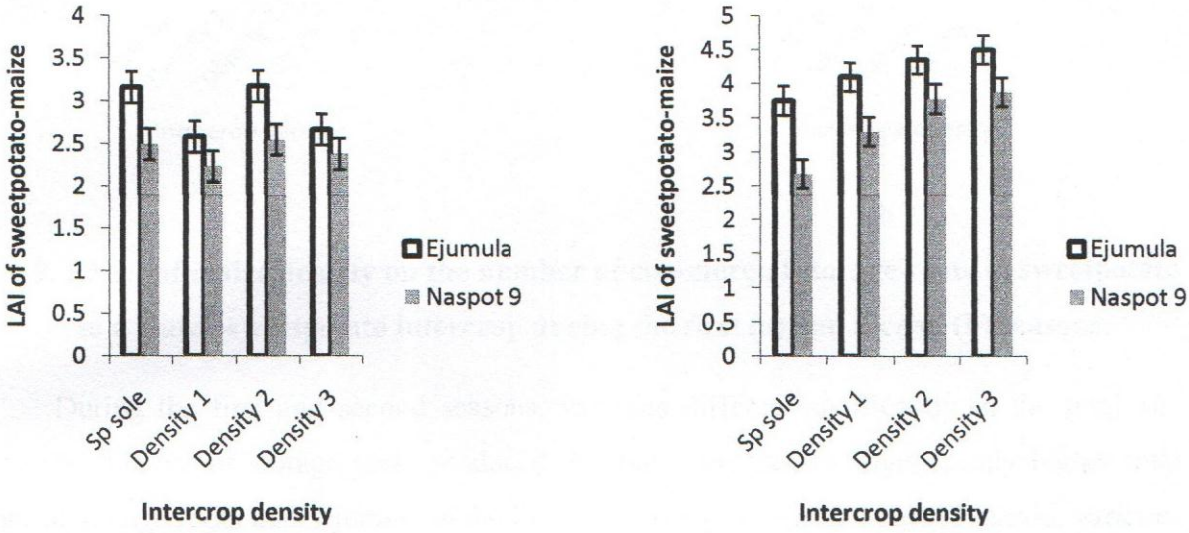


Figure 7. Effect of intercropping and increasing associated maize population on the Leaf Area Index of sweetpotato and maize-sweetpotato intercrops during the first (a) and second (b) seasons

4.1.2 Effect of intercropping on sweetpotato yield

Number of total and commercial storage roots

Intercropping significantly reduced the total number of storage roots and the proportion of commercial (diameter > 35mm) storage roots in the two seasons. The total number of storage roots was highest in sole sweetpotato during the first season (Fig. 8). Increasing the maize plant population significantly ($p \leq 0.05$) reduced the number of commercial storage roots (Fig. 9). During the second season sole sweetpotato had the highest total number of storage roots followed by intercrop density 2, density 1 and intercrop density 3 that had the highest maize population produced the lowest number of storage roots.

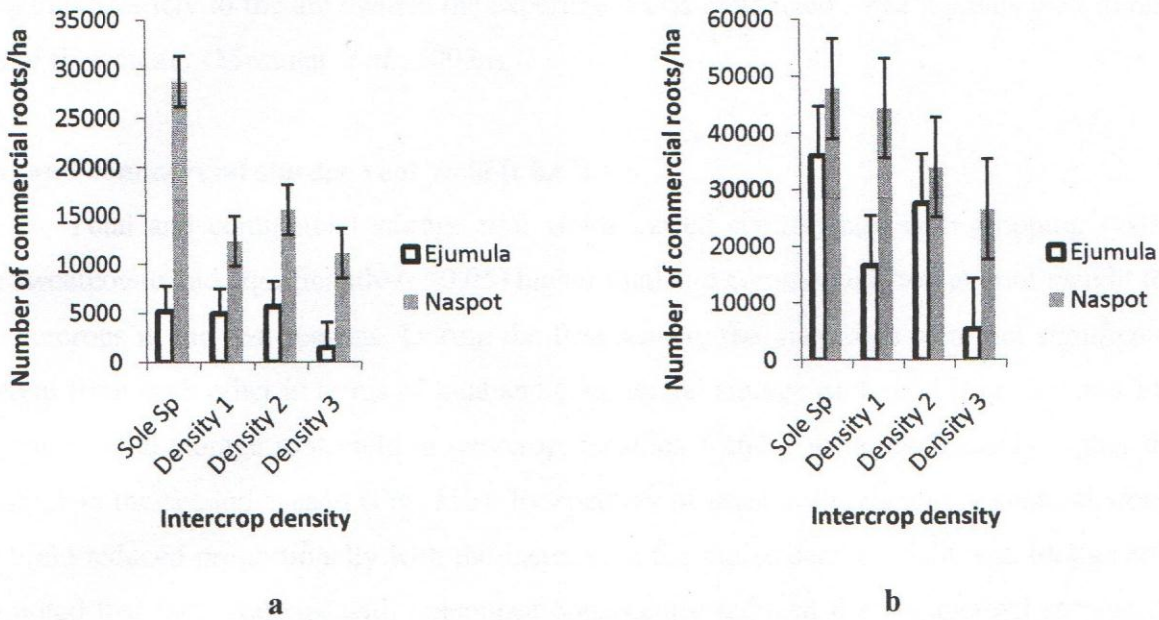


Figure 9. Effect of maize density on the number of commercial storage roots of sweetpotato in a maize-sweetpotato intercrop during the first (a) and second (b) seasons.

During the first and second seasons, varieties differed significantly in the total and commercial number of storage roots produced. Naspot 9 produced a significantly higher total number of storage roots than Ejumula in the first season (Fig. 8a). In the second season, varieties differed significantly in the total number of storage roots produced in densities 1 and 3 (Fig. 8b).

Naspot 9 had a higher number of commercial storage roots compared to Ejumula in both seasons. There was an improvement in the number of commercial storage root production in both varieties in the second season, though Naspot 9 remained superior (Fig. 9b). The commercial number of storage roots however varied significantly in the second season. Naspot 9 had a significantly higher number of commercial storage roots compared to Ejumula. The yields reported by Mwanga *et al.* (2007a) and Mwanga *et al.* (2009) for Ejumula and Naspot 9, respectively, were higher for Naspot 9 than Ejumula despite the variations across locations in both varieties due to environmental factors such as rains and soil types. For example, in the second season of this experiment, there was an improvement in number of commercial storage root production in both varieties, and the total number of storage roots did not vary between varieties which are attributed to more rainfall. Increase in the number of storage roots in Ejumula in the second season did not increase the commercial yield probably due to reduction in assimilate production or limited partitioning to the storage roots and/or to the poor adaptation of

the Ejumula variety to the area where the experiment was conducted since it yields well in other parts of the country (Mwanga *et al.*, 2007a).

Total and commercial storage root yield (t ha^{-1})

Total and commercial storage root yields varied significantly with cropping system. Sole sweetpotato had significantly ($p \leq 0.05$) higher total and commercial storage root weight than the intercrops in the two seasons. During the first season, the intercrops were not significantly different from each other in terms of total and commercial storage root yield (Fig. 10a and 11a). The commercial storage root yield in intercrop densities 1 and 2 were significantly higher than density 3 in the second season (Fig. 11b). Irrespective of season, the mean commercial storage root yield reduced proportionally with the increase in the maize density. Egbe and Idoko (2009) also noted that intercropping with pigeonpea consistently reduced the commercial storage root yield of sweetpotato. The yield reduction is attributed to the increase in the competitive ability of maize with increasing population. The reduction in yield may have been caused by competition and interruption in assimilate distribution. Sale (1976) reported shade to have caused a decrease in number of tubers and bulking rate of potato. In the potato-maize mixture, increase in maize population resulted in a decline in storage root yield (Ebwongu *et al.*, 2001; Ossom, 2010). Jamshidi *et al.* (2008) reported that intercropping and increasing the maize plant density reduced the potato yield. Oswald *et al.* (1995a) noted a relative decline in sweetpotato storage root yield with increasing shade. Similarly, Oswald *et al.* (1996) observed that the proportion of the commercial storage root yield declined when sweetpotato cultivars were intercropped with maize, but increasing maize density did not reduce the commercial storage root further.

The observed reduction in the total and commercial storage root weight could have been due to reduced photosynthetic efficiency of the sweetpotato crop due to shading by maize. Chen and Setter (2003) noted that shade caused a substantial reduction in potato cell proliferation and cell volume, resulting in a decline in fresh weight. They further noted that cell proliferation is positively correlated to plant photosynthate status. In this experiment, intercropping with maize reduced the vine length, number of stems, number of branches and number of leaves in sweetpotato which negatively affects assimilate production in sweetpotato. In addition to increased competition for moisture and nutrient resources in the soil, maize is a C_4 plant and efficient in trapping sunlight which could explain the reduction in storage root yields with

increase in maize plant population. Sweetpotato density was constant in the sole and intercrops although the commercial yield and total yields were significantly different denoting the effect of intercropping on sweetpotato. In a cassava-okra intercrop tuber yields were not affected by intercropping (Muoneke and Mbah, 2007) probably because of the large difference in maturity periods of the two crops. Shade on sweetpotato in the last stages of growth was reported to have a more negative effect on storage root yield than during the early stages of development (Oswald *et al.*, 1995b). Thus, sweetpotato can best tolerate other crops up to the third month without a significant loss if grown in association, beyond which storage root yield will decline severely due to shading in a number of cultivars.

Varieties differed significantly in the total (Fig. 10) and commercial (Fig. 11) storage root production per hectare. Naspot 9 had significantly ($p \leq 0.05$) higher total (8.3 and 12.9 t ha^{-1}) and commercial (6.2 and 11.0 t ha^{-1}) storage root yields than Ejumula in the two seasons. Kapinga *et al.* (2010) achieved similar results for the two varieties. Intercropping maize with sweetpotato cultivars in increasing maize populations caused a yield decline in all cultivars although the degree of response was different among the cultivars. Oswald *et al.* (1995a) noted that the effect of shade densities on sweetpotato varied with varieties and shade densities. The outstanding yield of Naspot 9 over Ejumula in sole and intercrops implies that the former is inherently more productive and more tolerant to shading than the latter. Ejumula may also not be well adapted to this environment. Tumwegamire *et al.* (2011) reported that the storage root yield of Ejumula varied greatly across environments in Uganda.

Total Biomass production

Biomass production of sweetpotato varied significantly ($p \leq 0.05$) with density of associated maize both in the first and second seasons (Fig. 12). Generally, sole sweetpotato produced the highest biomass (40.9 and 43.0 t ha^{-1} in first and second seasons, respectively). The intercrops were not different but in the second season, density 3 was significantly lower than the rest (18.5 t ha^{-1}) (Fig. 12b). Reduction in total biomass in intercrops implies that intercropping could have reduced photosynthetic efficiency of the sweetpotato. Biomass production among densities follows the same trend as the total storage root yield. The low root:shoot ratio (Fig. 15b) indicated that the increase was higher in the shoot than the roots which suggests a higher

partitioning of the photosynthate/assimilate to the shoot than to the root. Valenzuela *et al.* (1991) reported that increased shading in cocoyam resulted in an increase in plant top:corm ratio.

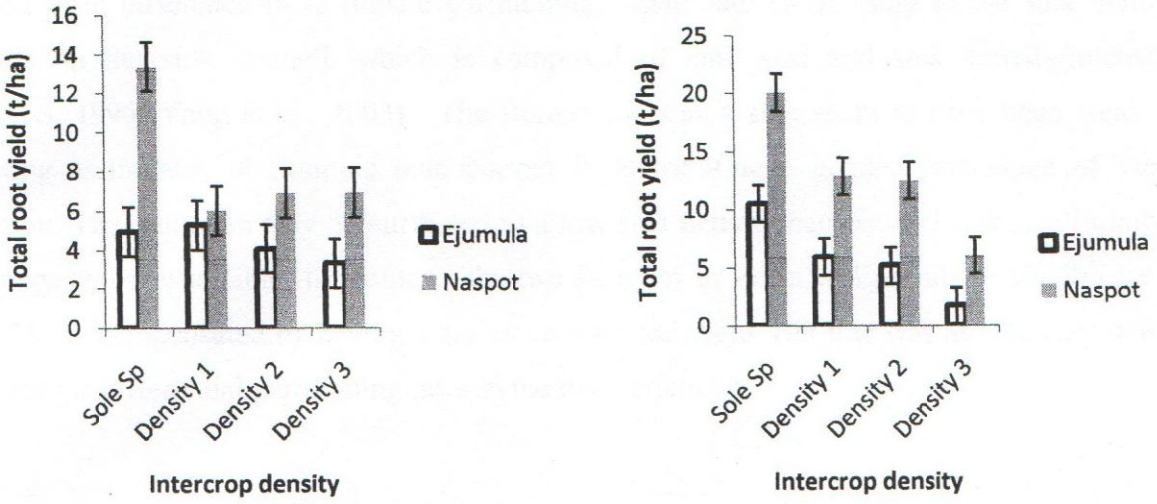


Figure 10. Effect of intercropping and maize density on the commercial storage root yield (t ha^{-1}) during the first (a) and second (b) seasons

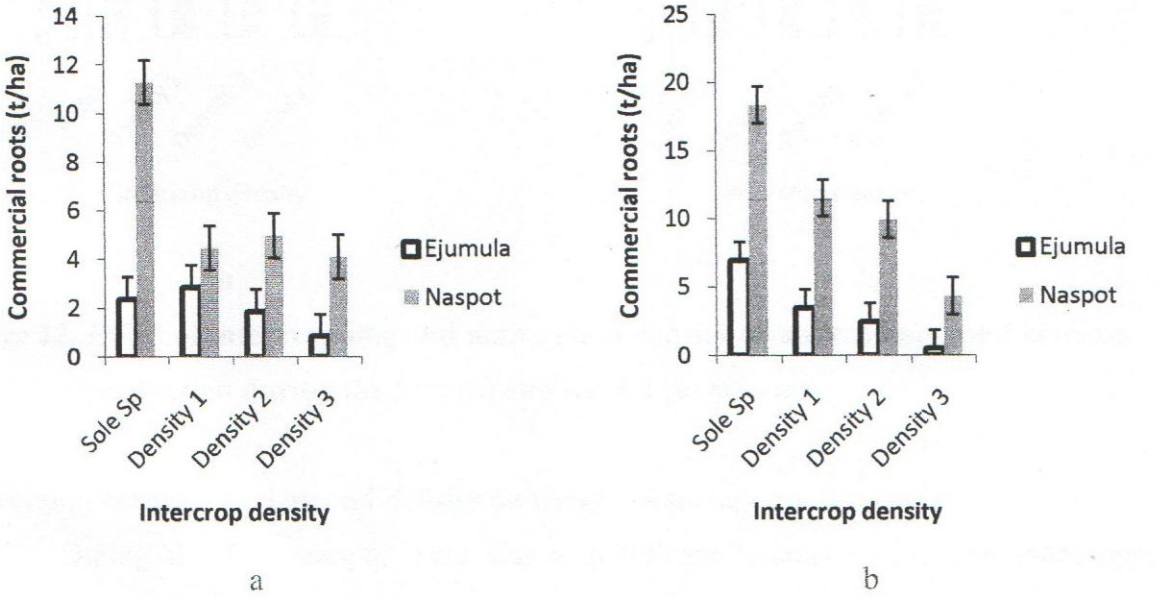


Figure 11. Effect of intercropping and maize density on the commercial storage root yield (t ha^{-1}) during the first (a) and second (b) seasons

The total biomass in the two varieties was however not different in the two seasons. The difference in the commercial and total storage root yields between the varieties could have resulted from difference in assimilate partitioning. Assimilate partitioning to the sink mainly depends on the sink strength which is composed of sink size and sink activity/intensity (Marcelis, 1996; Yang *et al.*, 2003). The storage roots as a sink seem to have been weak in attracting assimilates in Ejumula than Naspot 9 contributing a greater percentage of yield reduction. The reduction may be attributed to a low sink activity because the sink size (number of storage roots) was either the same in the two varieties or lower in Ejumula in which case it should have compensated by having a higher commercial yield. But this was not the case and it indicates the differential partitioning rates in the two varieties.

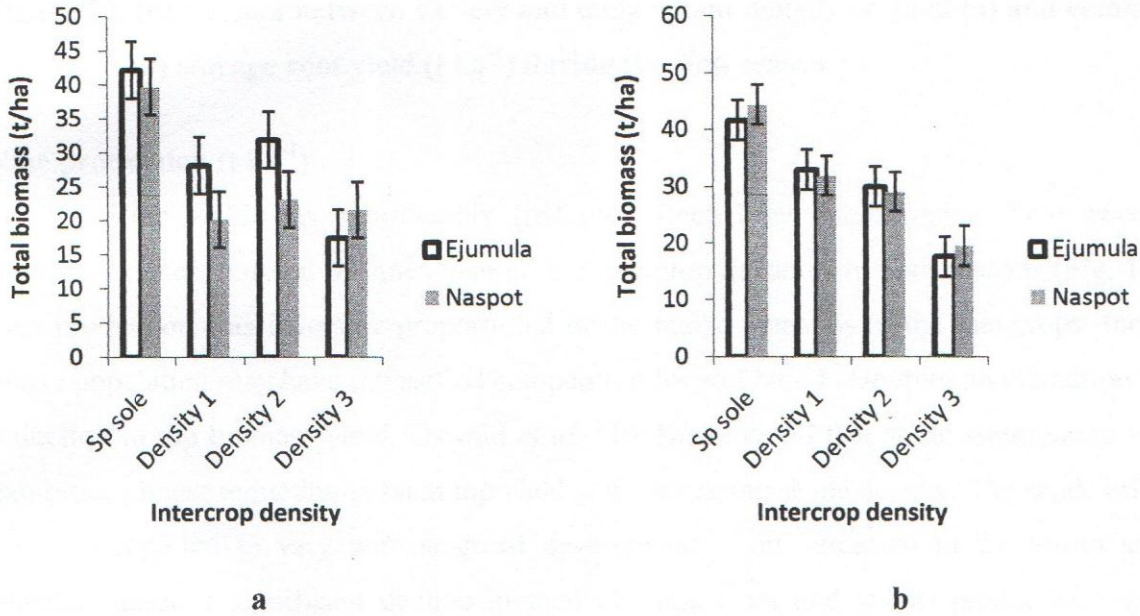


Figure 12. Effect of intercropping and maize plant density on sweetpotato total biomass production during the first (a) and second (b) seasons

Interaction between variety and density on weight of storage roots (t ha^{-1})

During the first season, there was a significant interaction between intercropping density and variety on total and commercial storage root yield (t ha^{-1}) at density 1. There was however no interaction during the second season. The interaction shows that at intercrop density 1, both varieties produced similar yields.

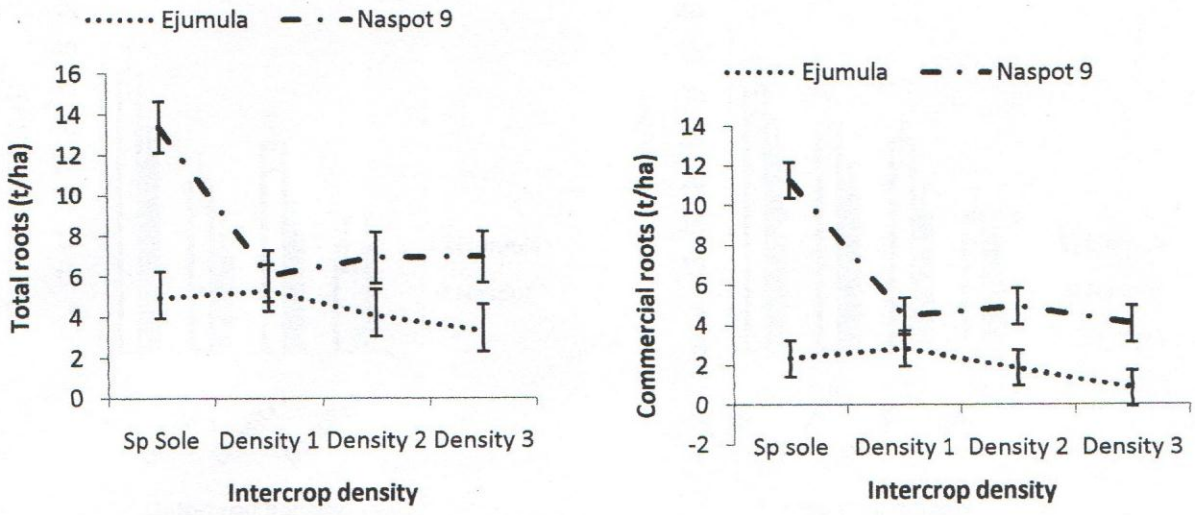


Figure 13. Interaction between variety and maize plant density on total (a) and commercial (b) storage root yield (t ha^{-1}) during the first season

Vine production (t ha^{-1})

Vine yield was significantly ($p \leq 0.05$) affected by intercropping. Sole sweetpotato produced highest amount of vines than all the intercrop densities in both seasons (Fig. 14). The vine production was inversely proportional to the maize densities in the intercrops. Increasing maize population may have intensified competition for soil based resources and radiation hence a reduction in top biomass yield. Oswald *et al.* (1995a) reported that some sweetpotato varieties exhibited a linear reduction in plant top yield with increasing shade density. The shade effect was however reported to vary with stage of development. Low radiation in the fourth and fifth months caused a significant decline in total biomass (root and shoot) production while low radiation only in the fifth month reduced shoot biomass production (Oswald *et al.*, 1995b). Foroutan-pour *et al.* (1999) found that the more the cumulative intercepted radiation, the higher the biomass production. Sole sweetpotato intercepted more total radiation and would thus be expected to have a higher biomass. Sweetpotato is a C_3 plant with a low compensation point. It grows normally in minimal shade because it is able to trap the necessary light to maintain net photosynthesis (Craine and Reich., 2005). However, as the plant population of the component crop increases, excess shading interferes with its growth.

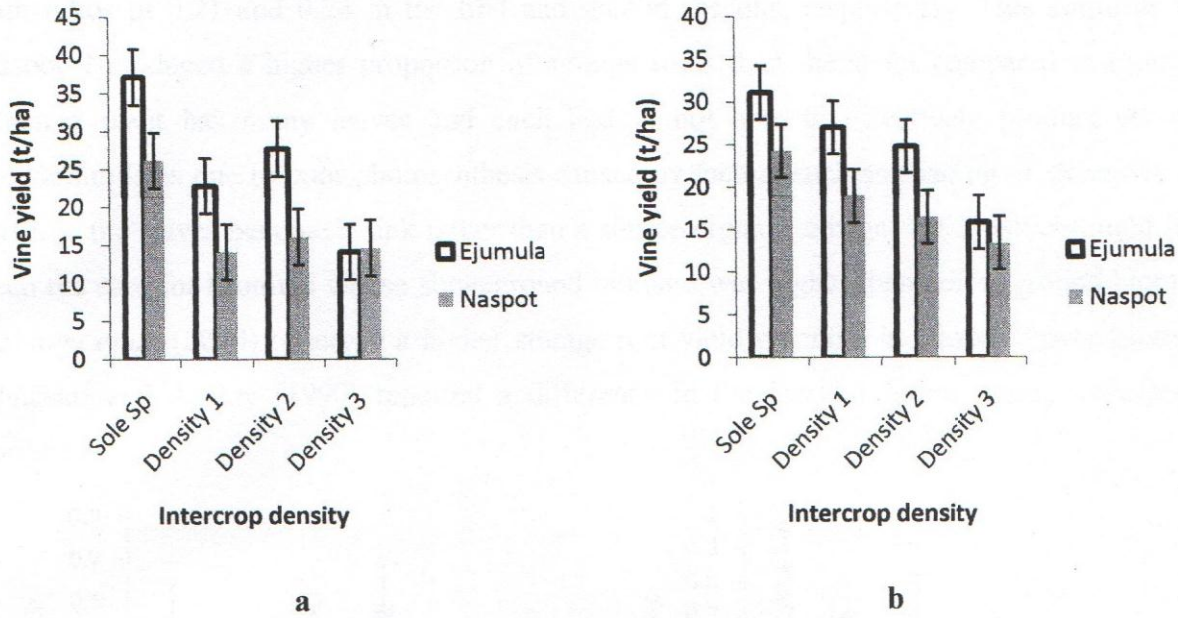


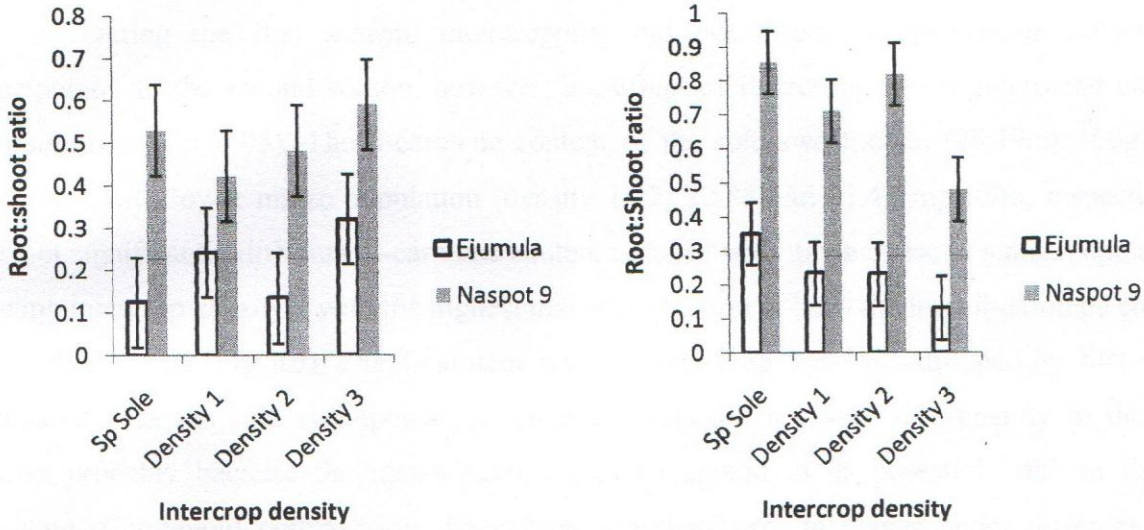
Figure 14. Vine yield (t ha^{-1}) production as affected by increasing maize densities in the intercrop during the first (a) and second (b) seasons

Varieties varied significantly in vine production (Figure 14). Variety Ejumula yielded significantly higher amounts of vines (25.5 and 24.7 t ha^{-1}) compared to Naspot 9 (17.8 and 18.3 t ha^{-1}). In intercropping sweetpotato and maize, cultivars displayed different vine yield potentials as some had significantly higher yields than the others (Oswald *et al.*, 1996).

Root:Shoot ratio

The root:shoot ratio across maize densities varied significantly in the second season but not in the first. The proportion of storage roots in reference to shoot (vines) reduced significantly ($p \leq 0.05$) in intercrop density 3 - with the highest maize population - in the second season (Fig. 15). This ratio seems to have been affected adversely by increasing the maize population rather than intercropping because the root:shoot ratio of sole sweetpotato was not significantly different from intercrops with lower maize populations. Light is a probable limiting resource that could cause such a reduction. In an air based resource stress, limitation in photosynthesis will have a severe effect on root growth more than shoot growth and vice versa (Marscher, 1995). Heuvel *et al.* (2004) further noted that the root: shoot ratio decreased with increasing shade. Naspot 9 had significantly higher ratios of 0.51 and 0.72 compared to Ejumula

with ratios of 0.21 and 0.24 in the first and second seasons, respectively. This confirms that Naspot 9 produced a higher proportion of storage roots than the shoot compared to Ejumula. When a plant has many leaves and each leaf is not able to effectively produce its own food/assimilates due to poor photosynthesis caused by factors such as shading or excessive soil fertility, the leaves become a sink rather than a source organ (Lemaga, 1992) which might have been the case for Ejumula whose aboveground biomass was higher than below ground biomass. Kapinga *et al.* (2010) observed a higher storage root yield potential in Naspot 9 over Ejumula. Bhagsari and Ashley (1990) reported a difference in the Harvest Index among sweetpotato varieties.



a **b**

Figure 15. Effect of intercropping and maize density on the root:shoot ratio of sweetpotato during the first (a) and second (b) seasons

Dry matter (%) of the storage roots

Dry matter content of storage roots was not affected by intercropping. There was no significant difference between dry matter content of sweetpotato grown as a sole crop and the intercrops during both seasons. This implies that intercropping and increasing the maize density in sweetpotato do not affect the dry matter content of the storage roots. This is however contrary to Ebwongu *et al.* (2001), who reported that intercropping reduced dry matter.

In both seasons, varieties differed significantly in dry matter content. Ejumula had significantly higher dry matter content than Naspot 9 in both seasons. Dry matter percentage values were 34.6 and 32.5 for Ejumula and 32.7 and 30.3 for Naspot 9 for the first and second seasons, respectively. Ejumula innately has a higher dry matter content than Naspot 9 (Kapinga *et al.*, 2010). During the second season however, the dry matter values were lower than in the first season and this is thought to have been caused by plenty of moisture in the soil in the later season. Dry matter of soybean and maize plants was also found to increase with limited moisture availability (Ennin *et al.*, 2002).

4.1.3 Effect of intercropping on β-carotene content

During the first season, intercropping did not affect the β-carotene content of sweetpotato. In the second season, however, the effect of intercropping on β-carotene content was significant ($p \leq 0.05$). The β-carotene content of the sole sweetpotato (25.19mg/100g) and intercrops with lower maize population (density 1&2; 22.88 and 21.42 mg/100g, respectively) was not significantly different. β-carotene content reduced with the increase in maize population, causing intercrop density 3 with the highest maize population to have the least β-carotene content of 18.98 mg/100g (Fig. 16). The β-carotene levels in intercrop density 3, dropped by 30% when compared with the sole sweetpotato. β-carotene levels did not vary significantly in the first season probably because the maize canopy did not spread to its potential due to limited moisture. Carotenoid compositions have been found to vary in leaves under different light intensities (Li *et al.*, 2002). Grumbach and Lichtenthaler (1982) reported that carotenoid biosynthesis was increased by light and Simkin *et al.* (2003a) found that in prolonged dark conditions, carotenoid biosynthesis is completely cut off. Some studies have reported varying levels of β-carotene in the storage roots of some sweetpotato varieties with varying environmental factors (Andrade *et al.*, 2009). Gruneberg *et al.* (2005) reported very low reductions of β-carotene due to environmental influence, while Kosambo *et al.* (1998) observed significant variations. The variations in β-carotene in this study could be attributed to low irradiance received by sweetpotato. A study done by Kotíková *et al.* (2007) on effect of N, P, K and Mg on total carotenoid content in potato tubers did not find any significant differences. There were no varietal differences in the levels of β-carotene over the two seasons probably because the β-carotene levels of the two varieties fall in the same range (7760 - 14370 µg/100g for Ejumula and 11030 µg/100g for Naspot 9) (Kapinga *et al.*, 2010).

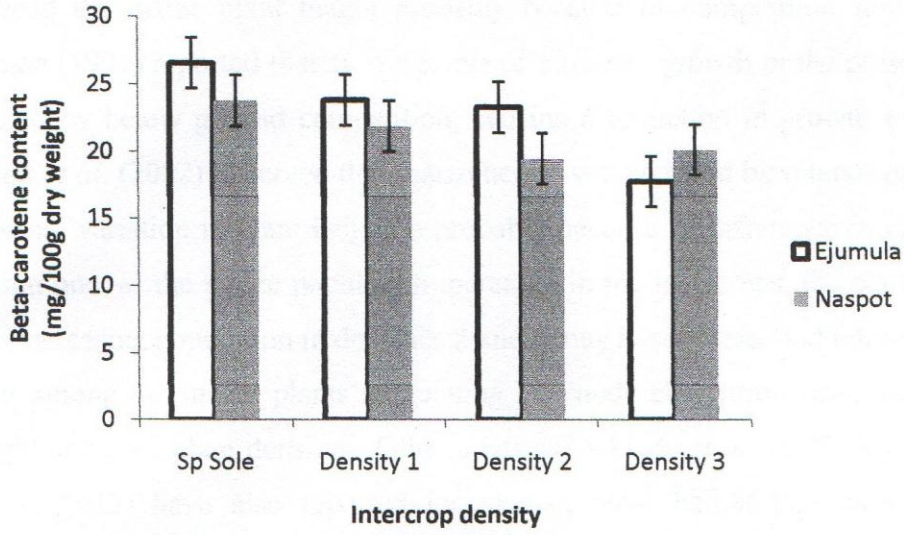


Figure 16. Effect of intercropping and maize plant density on the β-carotene content in sweetpotato during the second seasons

β-carotene in foods is an important precursor for vitamin A in the human body. The daily recommended intake of 400 μg Retinol (National Academy of Sciences, 2004) in the most vulnerable group to vitamin A deficiency is provided by 4.8 mg β-carotene. According to the β-carotene levels from both cropping systems, sole sweetpotato with the highest amount of β-carotene would provide this requirement with about 50 g of fresh storage roots while intercrop density 3 with the least amount of β-carotene would provide the 4.8 mg in about 65 g of fresh storage roots. The reduction due to intercropping in all the intercrop ratios was minimal in these varieties to cause nutrition deficiencies. Varieties were not statistically different in terms of β-carotene content in the storage roots. 45g and 52g of Ejumula, and 56g and 66g of Naspot 9 would be sufficient to provide the daily recommended intake in seasons 1 and 2, respectively.

4.2 Effect of intercropping on the growth and yield of maize

4.2.1 Effect of intercropping on maize growth

Plant height

Intercropping and increasing plant population significantly reduced the plant height (Fig. 17). Sole maize plants were the tallest (161.2cm and 194.1 cm) and intercrop density 1 had the shortest plants (148.9 cm and 169.1 cm) over the two seasons. Intercropping and population

reduced the maize plant height probably because of competition for resources. Wilson and Tilman (1991) reported that at low levels of nitrogen, growth in the presence of neighbours was limited by below ground competition, causing a reduction in growth rates and plant biomass. Ennin *et al.* (2002) observed that maize height was reduced by intercropping with soybean. The seasonal variation in plant height is probably because of difference in rainfall amounts. During season one, as the maize population increased in the intercrops, the plant height also increased. The increasing population in densities 2 and 3 may have intensified intra-specific competition for light among the maize plants stimulating internode elongation resulting into increase in plant height at higher plant densities. Other studies (Makinde *et al.*, 2009; Mukhtar *et al.*, 2012; Shafi *et al.*, 2012) have also reported increase in plant height due intraspecific competition in increasing plant densities.

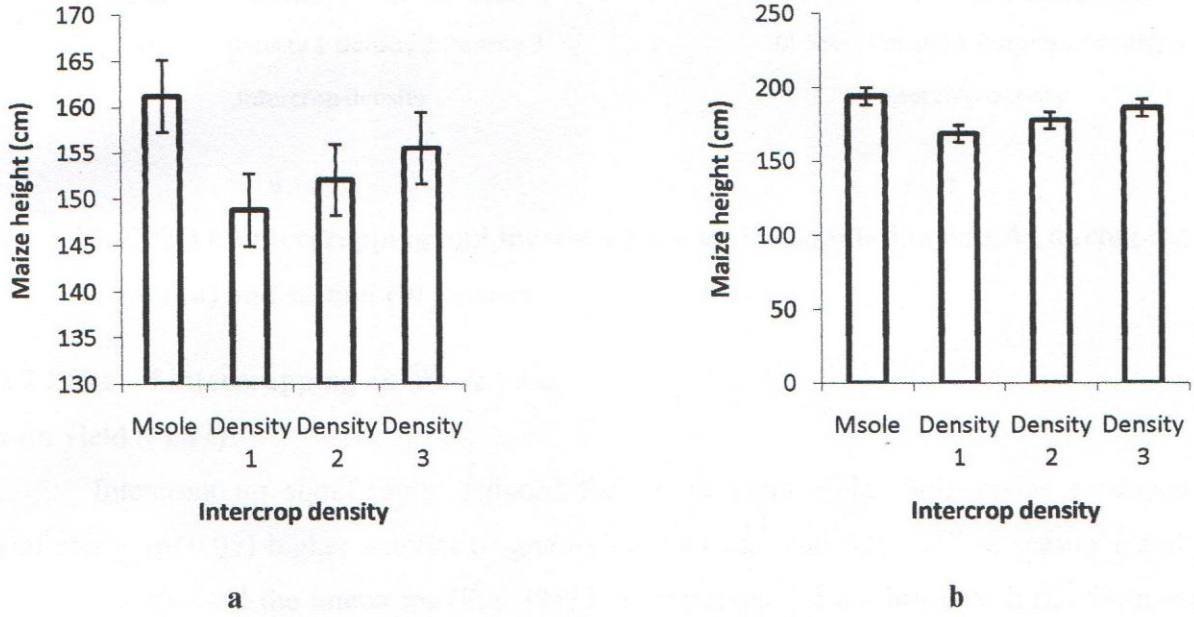
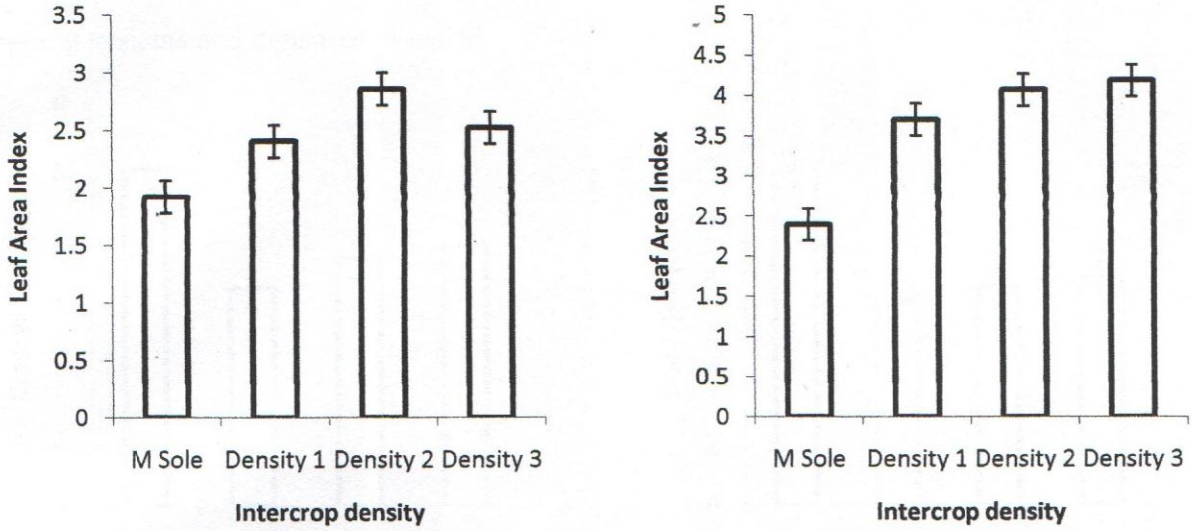


Figure 17. Effect of intecropping and increasing the maize population on the maize plant height during the first (a) and second (b) seasons

Leaf area index

The LAI was significantly ($p \leq 0.05$) higher in the intercrops than sole maize (Fig. 18). The higher LAI was because of the higher plant densities in the intercrops. During the first season, intercrop density 2 had the highest LAI of 2.86. Similarly, in season two intercropping gave a higher LAI and density 2 and 3 had the highest values (4.07 and 4.19 respectively). In

both seasons, sole maize had the least LAI, mainly because LAI in the intercrops was a collective sum of the two crops (sweetpotato and maize). Moreover, in some intercrops the maize population was higher than in sole maize.



a b

Figure 18. Effect of intercropping and increasing the maize population on LAI during the first (a) and second (b) seasons

4.2.2 Effect of intercropping on maize yield

Grain yield (t ha^{-1})

Intercropping significantly reduced the maize grain yield. Sole maize produced a significantly ($p \leq 0.05$) higher amount of grain yield (5 t ha^{-1} and 5.8 t ha^{-1} in season 1 and 2, respectively) than all the intercrops (Fig. 19). The intercrops did not however differ from each other in the two seasons.

Previous studies have also noted a reduction in maize yields because of intercropping (Ennin *et al.*, 2002; Niringiye *et al.* 2005). In a maize-bean intercrop, Willey and Osiru (1972) however observed yield increases at high plant populations. Sarlak *et al.* (2008) reported that increasing the maize plant density beyond the optimum caused the yield decline while lower plant densities exhibited higher yields. This implies that increasing the maize population to very high densities was not necessarily advantageous since it caused no grain yield difference. A

lower maize population that facilitates a higher sweetpotato yield in the intercrop would therefore be preferred.

Neither intercropping nor plant population affected 100-seed weight. Ossom (2010) in a sweetpotato-maize intercrop similarly found that the 100-seed weight did not differ with cropping systems and densities of maize.

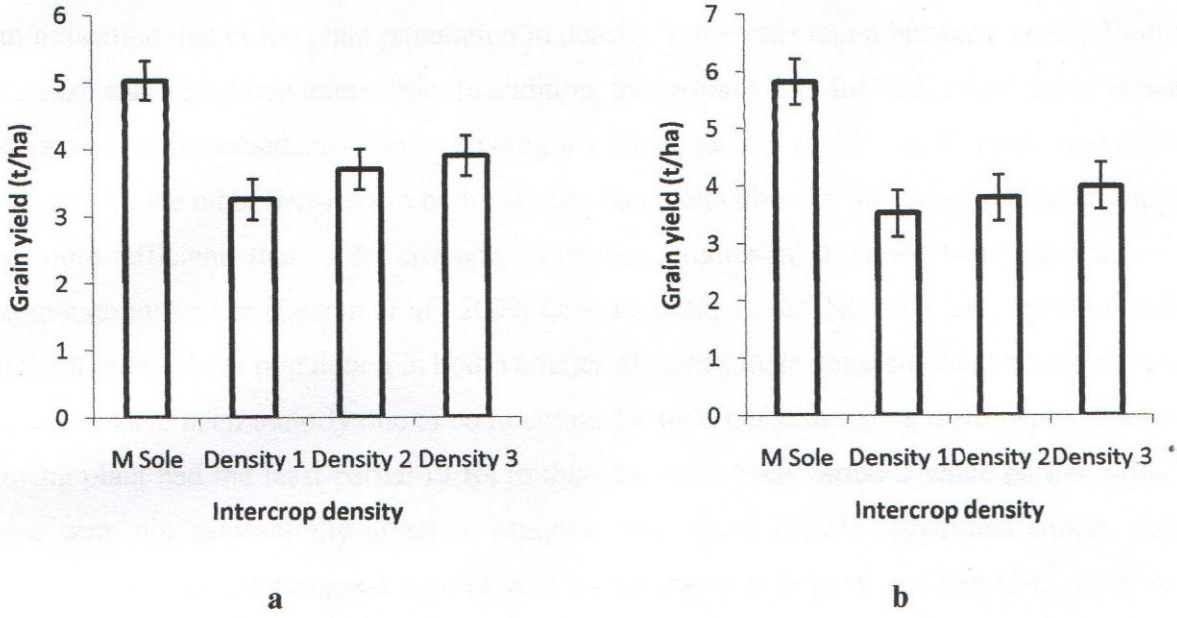


Figure 19. Effect of intercropping and increasing the maize plant population on the grain yield during the first (a) and second (b) seasons

4.3 Land Equivalent Ratio

The LER is generally used to evaluate the biological efficiency of intercropping and comparing the different treatments. The yields used to calculate the LER are shown in Table 3. The partial LERs were generally higher in maize than in sweetpotato (Table 4). The LER in both Ejumula and Naspot 9 varieties were greater than 1 except in density 3 of variety Ejumula. This is an indication that at the plant population in density 3, the interaction between variety Ejumula and maize was a negative interaction. In addition, the partial LERs for both sweetpotato varieties in density 3 were considerably low showing a yield reduction of 67% in Ejumula and 61% in Naspot 9. All the other densities in both varieties had LERs above 1 indicating that intercropping was more efficient than sole cropping. Previous studies also show yield advantages in sweetpotato intercrops (Ossom *et al.*, 2009; Oswald *et al.*, 1996). Nevertheless, density 3 which had the highest maize population in both varieties of sweetpotato generally had the lowest ratios. This could have been majorly due to competition for light because sweetpotato which is a lower growing plant had the least partial LERs in this density in both varieties while partial ratios for maize were not substantially affected. Muoneke and Mbah (2007) also found similar results where cassava was intercropped with okra at increasing okra population. The LER ratios in all the intercrops were above 1 except in the combination with the highest okra population.

Table 3. Yields of sweetpotato and maize (t ha^{-1}) in the respective treatments averaged over the two seasons

	Ejumula		Naspot	
Treatment	Sweetpotato	Maize	Sweetpotato	Maize
Sole	7.756	5.432	16.741	5.432
Density 1	5.629	3.100	9.474	3.695
Density 2	4.650	3.410	9.734	4.105
Density 3	2.530	2.707	6.523	4.018

Table 4. The LER of the two sweetpotato varieties (Ejumula and Naspot 9) intercropped with maize in the three plant densities

	Ejumula			Naspot		
Maize intercrop densities	Sweetpotato	Maize	LER	Sweetpotato	Maize	LER
Density 1	0.73	0.57	1.30	0.57	0.68	1.25
Density 2	0.60	0.63	1.23	0.58	0.76	1.34
Density 3	0.33	0.50	0.82	0.39	0.74	1.13

Considering intercrop densities 1 and 2, the area planted to sole crops would need to be greater than the area under intercrops by 30% and 23% for Ejumula and 25% and 34% for Naspot 9, respectively for the two crops to produce the same combined yields as the yields from the intercrops. The partial LERs of maize are higher than those for sweetpotato in both varieties and all densities. This implies that intercropping caused a higher yield reduction in sweetpotato than in maize probably because the competitive ability of maize over sweetpotato was higher. Maize a C_4 and taller crop in the mixture stood the advantage to trap more sunlight and was thus more aggressive. On the other hand, sweetpotato which is a C_3 plant and less efficient in carbon assimilation received less light and was dominated, causing less yields. C_4 plants have an advantage for carbon fixation at high light intensities because of the high light saturation point (Skillman, 2008). The implication of the results is that a higher maize population increases competition on sweetpotato and significantly lowers the sweetpotato yields. In a maize-bean intercropping experiment, Tsubo *et al.* (2004) did not observe reduction in maize yields and maize was a more aggressive crop in the mixture. Also, Oswald *et al.* (1996) reported that the partial LER of maize in a sweetpotato-maize intercrop contributed largely to the total LER depending on the location where the experiment was set. The partial LERs of maize were higher in intercrops with Naspot 9 than in intercrops for Ejumula. This suggests that Naspot 9 favoured maize production better than Ejumula.

Density 1 of Ejumula had the highest LER of 1.30 with sweetpotato contributing a greater partial LER than maize. The LER for intercrop density 1 of Naspot 9 was lower (1.25) with sweetpotato contributing a smaller ratio. The actual yields were however consistently lower in the sole crop and intercrops of Ejumula compared to Naspot 9. The LER in Ejumula was

therefore a product of consistently low yields in both systems such that density 1 of Naspot 9 though with a lesser total LER had better yields. This ratio (for Ejumula), however, still confirms that it was better to intercrop Ejumula than grow it as a sole crop (Mead and Willey, 1980).

4.4 Economic and calorific-yield Evaluation of OFSP and QPM intercropping

4.4.1 Partial budget analysis

The results of a partial budget analysis show that sole maize returned the highest net benefit of UGX 2,958,228 ($ 1,095.64) compared to sole sweetpotato and the intercrop treatments for Ejumula variety (Table 5). Among the intercrop treatments, intercrop density 1 had the highest net return of 2,165,420 ($802.01) followed by intercrop density 2 with net benefit of UGX 1,979, 050 ($ 732.98) and intercrop density 3 had the least net benefit of UGX 1,698,718 ($ 629.15). Over all sole Ejumula had the least net benefit compared to sole maize and intercrop treatments with Ejumula variety.

In the treatments with variety Naspot 9, the partial budget analysis shows that sole sweetpotato had the highest benefit of UGX 4,764,660 ($ 1,764.69) (Table 6). Among the intercrops, intercrop density 2 gave the highest net benefit of UGX 4,282,713 ($ 1,586.19) followed by intercrop density 1 and 3 with respective net benefits of UGX 4,254,635 ($ 1,575.79) and UGX 3,048,290 ($ 1,129). Net benefit from sole maize of UGX 2,958,228 ($ 1,095.64) was the least compared to sole Naspot 9 and intercrop densities.

The value of the harvest from Naspot 9 was higher than for Ejumula in all treatments. Total costs that vary (input costs) in the different treatments of the two varieties and sole maize resulted in notable differences in subsequent profits. General costs of production across intercrop densities in the two varieties were uniform and the profit difference was mainly due to low yields of Ejumula variety. Due to the low yields in Ejumula, net benefit for sole maize was higher than all the treatments of Ejumula variety which was contrary in Naspot 9 treatments because Naspot 9 had higher yields. Waddington *et al.* (2007) reported that the legume-maize intercrops could maintain crop productivity but not profitability compared to sole crops due to low yield achievements compared to relatively high investment costs of intercrops.

Table 5. Partial budget analysis of the Intercrop treatments with the sweetpotato variety-Ejumula

Benefit	Treatments				
	Ejumula sole	Density1	Density 2	Density 3	Msole
Sweetpotato yield ($kgha^{-1}$)	4,650	3,162	2,170	669.5	-
Maize yield ($kgha^{-1}$)	-	3100	3410	3893.5	5,431.5
Adjusted Sweetpotato yield	4,185	2,845.8	1,953	602.55	-
Adjusted maize yield	-	2,790	3,069	3,504.15	4,888.35
Sweetpotato value (400ugx/kg)	1,674,000 (620)	1,138,320 (421.6)	781,200 (289.33)	241,020 (89.27)	-
Maize value (650ugx/kg)	-	1,813,500 (671.67)	1,994,850 (738.83)	2,277,698 (843.59)	3,177,428 (1,176.83)
Gross benefit	1,674,000 (620)	2,951,820 (1,093.27)	2,776,050 (1,028.17)	2,518,718 (932.86)	3,177,428 (1,176.83)
Total labour cost	170,000 (62.96)	350,000 (129.63)	350,000 (129.63)	350,000 (129.63)	180,000 (66.67)
Total material cost	400,000 (148.15)	436,400 (16163)	447,000 (165.56)	470,000 (174.07)	39,200 (14.52)
Total costs that vary	570,000 (211.11)	786,400 (291.26)	797,000 (295.19)	820,000 (303.70)	219,200 (81.19)
Net benefit	1,104,000 (408.89)	2,165,420 (802.01)	1,979,050 (732.98)	1,698,718 (629.15)	2,958,228 (1095.64)

The indicated maize and sweetpotato yields are the averages for two seasons

Values in parentheses are the US Dollars ($) equivalents of Ugandan Shillings (UGX) at the rate of 1USD ($) = 2,700 UGX

Table 6. Partial budget analysis of the Intercrop treatments with the sweetpotato variety-Naspot 9

Benefit	Treatments				
	Naspot sole	Density 1	Density 2	Density 3	Msole
Sweetpotato yield ($kgha^{-1}$)	14,818.5	7998.5	7,440.5	4,216	-
Maize yield ($kgha^{-1}$)	-	3695	4104.5	4018	5,431.5
Adjusted Sweetpotato yield	13,336.65	7,198.65	6,696.45	3,794.4	-
Adjusted maize yield	-	3,325.5	3,694.05	3,616.2	4,888.35
Sweetpotato value (400ugx/kg)	5,334,660 (1,975.8)	2,879,460 (1066.47)	2,678,580 (992.07)	1,517,760 (562.13)	-
Maize value (650ugx/kg)	-	2,161,575 (800.58)	2,401,133 (889.31)	2,350,530 (870.57)	3,177,428 (1,176.83)
Gross benefit	5,334,660 (1,975.8)	5,041,035 (1,867.05)	5,079,713 (1,881.38)	3,868,290 (1,432.7)	3,177,428 (1,176.83)
Total labour cost	170,000 (62.96)	350,000 (129.63)	350,000 (129.63)	350,000 (129.63)	180000 (66.67)
Total material cost	400,000 (148.15)	436,400 (161.63)	447,000 (165.56)	470,000 (174.07)	39,200 (14.52)
Total costs that vary	570,000 (211.11)	786,400 (291.26)	797,000 (295.19)	820,000 (303.70)	219,200 (81.19)
Net benefit	4,764,660 (1,765)	4,254635 (1,575.79)	4,282,713 (1,586.19)	3,048,290 (1,129)	2,958,228 (1,095.64)

The indicated maize and sweetpotato yields are the averages for two seasons

Values in parentheses are the US Dollars ($) equivalents of Ugandan Shillings (UGX) at the rate of 1USD ($) = 2,700 UGX

In the dominance analysis of sole maize and Ejumula treatments, only Sole maize passed as a treatment that would be economically viable compared to the intercrops (Table 7). All the other treatments are excluded on a rationale that for an economic investment, one will choose a treatment with a lower cost and a high benefit. The dominated treatments had low net benefits but high costs of production.

Only sole Naspot 9 and sole maize qualified for further consideration in the dominance analysis on Naspot 9 treatments and sole maize (Table 8). All the intercrops were dominated having lower net benefits and higher costs. The marginal rate of return of changing from growing sole maize to sole Naspot 9 was 515% which is above the 50% benchmark. This implies that in changing from growing sole maize; for every UGX 100 invested in growing sole Naspot 9 sweetpotato, a farmer recovers UGX 100 and an extra UGX 515 in net benefit.

Table 7. Dominance analysis of the sole and intercrop treatments with the sweetpotato variety – Ejumula

Treatments	Costs	Benefit	Dominance
Maize sole	219,200 (81.19)	2,958,228 (1095.64)	Undominated
Ejumula sole	570,000 (211.11)	1,104,000 (408.89)	Dominated
Density 1	786,400 (291.26)	2,165,420 (802.01)	Dominated
Density 2	797,000 (295.19)	1,979,050 (732.98)	Dominated
Density 3	820,000 (303.70)	1,698,718 (629.15)	Dominated

Values in parentheses are the US Dollars ($) equivalents of Ugandan Shillings (UGX) at the rate of 1USD ($) = 2,700 UGX

Table 8. Dominance and marginal rate of return analysis of the sole and intercrop treatments with the sweetpotato variety - Naspot 9

Treatments	Costs	Benefit	Dominance	Incremental cost	Incremental benefit	MRR (%)
Maize sole	219,200 (81.19)	2,958,228 (1,095.64)	Undominated	-	-	-
Naspot sole	570,000 (211.11)	4,764,660 (1,764.69)	Undominated	350,800	1,806,433	514.9466
Density 1	786,400 (291.26)	4,254,635 (1,575.79)	Dominated	-	-	-
Density 2	797,000 (295.19)	4,282,713 (1,586.19)	Dominated	-	-	-
Density 3	820,000 (303.70)	3,048,290 (1,129)	Dominated	-	-	-

Values in parentheses are the US Dollars ($) equivalents of Ugandan Shillings (UGX) at the rate of 1USD ($) = 2,700 UGX

4.4.2 Minimum returns analysis

A minimum returns analysis on treatments with Ejumula and sole maize (Table 9) shows that in a situation of the worst yields; sole maize would give the highest net benefit of UGX 2,263,475 ($ 838.32) followed by intercrop densities 3, 1 and 2 with net benefits of UGX 921,025 ($ 341.12), 905,025 ($ 335.19) and UGX 755,675 (279.88) respectively. In this environment (since Ejumula yields well in other parts of the country), sole Ejumula would not be a viable investment in a situation of risky factors as the total benefits would not be sufficient to write off the total costs. However, a dominance analysis eliminates all the other treatments except maize (Table 11). Sole maize production has a high net benefit at a low cost under minimum returns analysis while the other treatments have high costs of production with low net benefits which would not attract an interested investor. Waddington *et al.* (2007) noted that farmers will opt to grow sole crops if they anticipate loss due to labor costs.

A minimum returns analysis for treatments of Naspot 9 indicates that in a situation of the worst crop performance, density 2 would have the highest net benefit followed by sole sweetpotato, densities 1,3 and lastly sole maize (Table 10). A dominance analysis under minimum returns for Naspot 9 treatments and sole maize eliminated densities 1 and 3 basing on their low net benefit and yet high costs; leaving sole maize, sole sweetpotato and density 2 (Table 12). A marginal analysis shows that shifting from sole maize production to sole Naspot 9 production gives a 323% MRR, while changing from production of sole Naspot 9 to intercrop density 2 returns 50%. Thus, a farmer will regain UGX 100 and an extra benefit of UGX 323 and UGX 50 on changing from sole maize to sole Naspot 9 and from sole Naspot 9 to density 2, respectively. An economically driven farmer would therefore consider sole Naspot 9 while a farmer who produces for subsistence purposes would consider intercrop density 2 to diversify produce for food security since maize can be stored for a longer time.

Table 9. Minimum returns analysis with the sweetpotato variety – Ejumula

	Treatments				
Minimum returns analysis	Ejumula sole	Density 1	Density 2	Density 3	Msole
Sweetpotato yield(worst)	0	1,488	0	0	-
Sweetpotato yield(2nd worst)	1,984	1,488	992	0	-
Average yield	992	1,488	496	0	-
Maize yield(worst)	-	1,885	2,381	2,976	3,671
Maize yield(2nd worst)	-	1,488	1,786	2,381	3,968
Average yield	-	1,686.5	2,083.5	2,678.5	3,819.5
Benefits					
Sweetpotato value (400ugx/kg)	396,800 (146.96)	595,200 (220.44)	198,400 (73.48)	0	-
Maize value (650ugx/kg)	-	1,096,225 (406.01)	1,354,275 (501.58)	1,741,025 (644.82)	2,482,675 (919.51)
Gross benefit	396,800 (146.96)	1,691,425 (626.45)	1,552,675 (575.06)	1,741,025 (644.82)	2,482,675 (919.51)
Total variable costs	570,000 (211.11)	786,400 (291.26)	797,000 (295.19)	820,000 (303.70)	219,200 (81.19)
Net benefit	-173,200 (-64.15)	905,025 (335.19)	755,675 (279.88)	921,025 (341.12)	2,263,475 (838.32)

Values in parentheses are the US Dollars ($) equivalents of Ugandan Shillings (UGX) at the rate of 1USD ($) = 2,700 UGX

Table 10. Minimum returns analysis with the sweetpotato variety - Naspot 9

Minimum returns analysis	Treatments				
	Naspot sole	Density 1	Density 2	Density 3	Msole
Sweetpotato yield(worst)	8,929	2,976	3,472	2,976	-
Sweetpotato yield(2nd worst)	10,913	7,440	6,944	3,472	-
Average yield	9,921	5,208	5,208	3,224	-
Maize yield(worst)	-	2,282	3,175	3,274	3,671
Maize yield(2nd worst)	-	2,778	3,671	3,274	3,968
Average yield	-	2,530	3,423	3,274	3,819.5
Benefits					
Sweetpotato value (400ugx/kg)	3,968,400 (1,469.78)	2,083,200 (771.56)	2,083,200 (771.56)	1,289,600 (477.63)	-
Maize value (650ugx/kg)	-	1,644,500 (609.07)	2,224,950 (824.06)	2,128,100 (788.19)	2,482,675 (919.51)
Gross benefit	3,968,400 (1,469.78)	3,727,700 (1,380.63)	4,308,150 (1,595.61)	3,417,700 (1,265.82)	2,482,675 (919.51)
Total variable costs	570,000 (211.11)	786,400 (291.26)	797,000 (295.19)	820,000 (303.70)	219,200 (81.19)
Net benefit	3,398,400 (1,258.67)	2,941,300 (1,089.37)	3,511,150 (1,300.43)	2,597,700 (962.11)	2,263,475 (838.32)

Values in parentheses are the US Dollars ($) equivalents of Ugandan Shillings (UGX) at the rate of 1USD ($) = 2,700 UGX

Table 11. Dominance analysis under minimum returns with the sweetpotato variety – Ejumula

Treatments	Costs	Benefit	Dominance
Maize sole	219,200 (81.19)	2,263,475 (838.32)	Undomiated
Ejumula sole	570,000 (211.11)	-173,200 (-64.15)	Dominated
Density 1	786,400 (291.26)	905,025 (335.19)	Dominated
Density 2	797,000 (295.19)	755,675 (279.88)	Dominated
Density 3	820,000 (303.70)	921,025 (341.12)	Dominated

Values in parentheses are the US Dollars ($) equivalents of Ugandan Shillings (UGX) at the rate of 1USD ($) = 2,700 UGX

Table 12. Marginal analysis of the treatments under minimum returns with the sweetpotato variety - Naspot 9

Treatments	Costs	Benefit	Dominance	Incremental cost	Incremental benefit	MRR (%)
Maize sole	219,200(81.19)	2,263,475(838.32)	Undominated	-	-	-
Naspot sole	570,000(211.11)	3,398,400(1,258.67)	Undominated	350,800	1,134,925	323.5248
Density 1	786,400(291.26)	2,941,300(1,089.37)	Dominated	-	-	-
Density 2	797,000(295.19)	3,511,150(1,300.43)	Undominated	227,000	112,750	49.6696
Density 3	820,000(303.70)	2,597,700(962.11)	Dominated	-	-	-

Values in parentheses are the US Dollars ($) equivalents of Ugandan Shillings (UGX) at the rate of 1USD ($) = 2,700 UGX

Generally, the analysis highlights Naspot 9 variety and its intercrop treatments to have economically performed better than Ejumula and its intercrops, respectively. The results of a partial budget analysis show varying figures of net benefits but the higher figures do not necessarily imply that that particular treatment is more lucrative. The economic advantage of a treatment is proved in a dominance analysis which compares the net benefit and the cost of production.

Treatments with Ejumula did not measure up to the sole maize performance and as such it would be economically advantageous to grow sole maize rather than Ejumula or any of its intercrop treatments. Only Sole Naspot 9 among the treatments with Naspot 9 performed better than sole maize. All the intercrops were dominated and less advantageous to invest in.

A minimum returns analysis shows that among sole maize and Ejumula treatments, still sole maize would be the most beneficial in an event that other factors such as drought resulted in lowest yields. In a similar situation, sole Naspot 9 and density 2 would be economically advantageous treatments. However, switching from production of sole Naspot 9 to intercrop density 2 gives less marginal rate of return.

Over all, the analysis illustrates that sole crops would fetch better benefits than the intercrops. Sole maize would profit more compared to sole Ejumula and its intercrop treatments while sole Naspot 9 would profit more compared to sole maize and other intercrop treatments of Naspot 9. However, under unpredictable situations, intercrop density 2 of Naspot 9 would reduce the risks of total economic loss.

4.4.3 Evaluation of the calorific yield in sole crops and the intercrops

The calorific value of sole maize (19,825,149 K cal) was not different from all the intercrop treatments of Ejumula but significantly ($p \leq 0.05$) different from sole Ejumula (9,533,110 K cal) (Fig. 20a). The lower calorific value of Ejumula was majorly because of its poor yields. A comparison between sole maize and Naspot 9 treatments shows that intercrop density 2 (26,955,605 K cal) had the highest energy value and was not significantly different from the other intercrop treatments (Fig. 20b). However, sole maize and sole Naspot 9 had the least (19,825,149 K cal and 20,591,518 K cal) energy yields, respectively. Intercropping is sometimes practiced to diversify the farm produce with the aim of improving nutrition. Diangar *et al.* (2004) stated that farmers may prefer intercropping to ensure food security. Besides the intercrops providing energy, they become a source of a range of nutrients. Intercrops for variety Ejumula yielded lower energy equivalents compared to intercrops for Naspot 9 which is mainly because of the low yield of Ejumula in this experiment (Fig. 21).

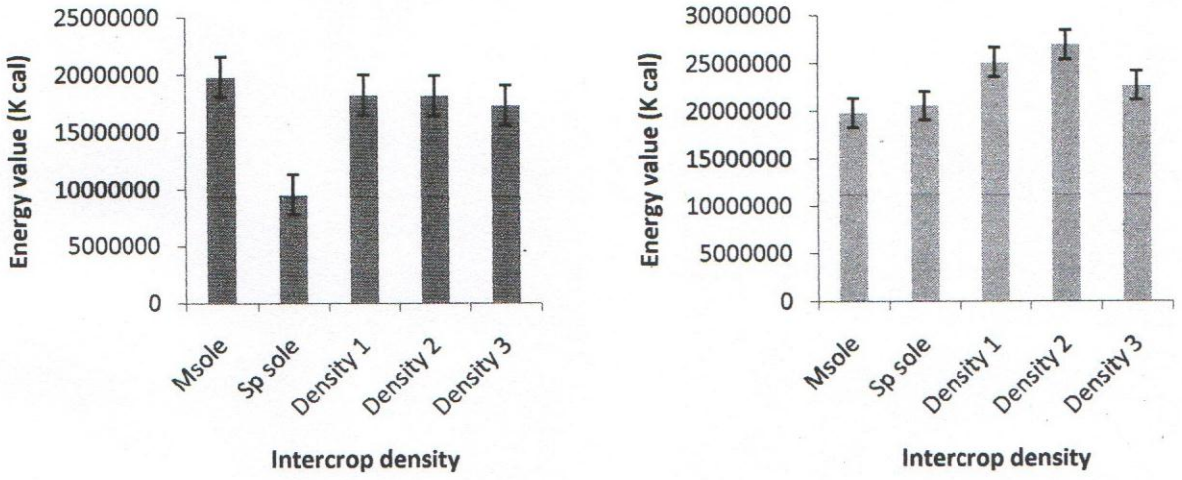


Figure 20. Calorific yield of sweetpotato and maize sole crops and their intercrops for sweetpotato varieties Ejumula (a) and Naspot 9 (b), calculated from average yields of two seasons

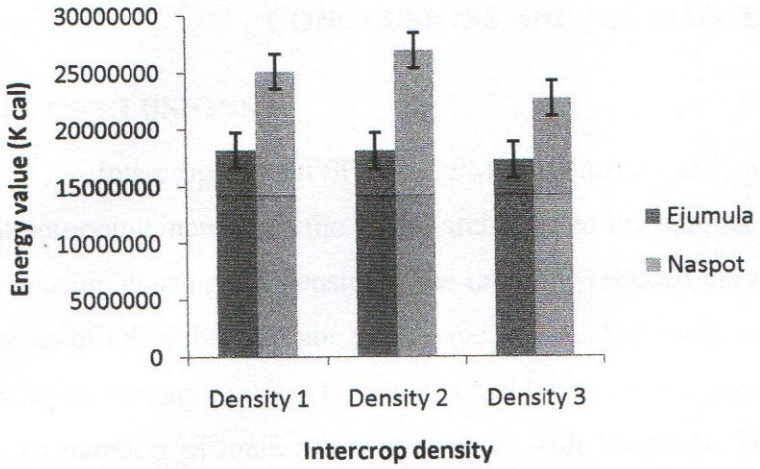


Figure 21. Calorific yield in intercrops of sweetpotato varieties Ejumula and Naspot 9 in the respective intercrop densities

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Intercropping OFSP and QPM significantly affected growth and yield of sweetpotato. Intercropping increased vine length and reduced the number of main stems, branches and leaves. Increasing maize plant density in the intercrop reduced the number of main stems, branches and leaves of OFSP but did not affect vine length. The sweetpotato varieties varied in performance under intercropping. Variety Ejumula had longer stems, higher number of branches but relatively equal numbers of main stems and leaves with Naspot 9. The LAI was higher in intercops than sole sweetpotato. Maize contributed a greater ratio of the LAI in the intercrops because the number of sweetpotato leaves declined in the intercrops.

Intercropping significantly reduced the total and commercial storage root numbers and yield (t ha^{-1}). Sole sweetpotato yielded better in total and commercial storage root numbers and yields (t ha^{-1}) while the intercrops were not significantly different among themselves. Variety Naspot 9 yielded better than Ejumula in total and commercial storage root numbers and yields (t ha^{-1}). Biomass and vine yields were highest in sole sweetpotato and reduced in the intercrops with increasing maize density. In high maize densities which reduced sweetpotato biomass production, storage root yield declined more than vine yield. The dry matter content of the storage roots did not vary in the sole and intercrops but varieties differed and Ejumula had higher dry matter content.

Intercropping caused a reduction in the β-carotene content in sweetpotato storage roots. The β-carotene content reduced with increasing maize density in the intercrops.

Maize plant height reduced due to intercropping but increased with increasing maize plant population probably because of intensified competition for light. Intercropping increased overall LAI but reduced grain yield (t ha^{-1}). Intercrop densities 1 and 2 consistently had high LERs in both seasons denoting the advantage of intercropping in the two densities.

Economically, sole crops fetched better benefits than the intercrops. Sole maize performed better compared to Ejumula treatments and sole Naspot 9 performed better compared to sole maize and other treatments of Naspot 9. Under unpredictable situations, sole Naspot 9

and intercrop density 2 appear to minimize risks of total economic loss among treatments with Naspot 9.

Unlike in the economic analysis where intercrops had less value, calorific yield analysis shows that intercrops had high calorific (energy) value depending on the sweetpotato variety. Intercrop densities 2, 1 and 3 of variety Naspot 9 had the highest energy yields, respectively compared to sole crops. Sole maize had the highest energy yield in comparison with Ejumula and all its treatment.

5.2 RECOMMENDATIONS

1. Other varieties of Orange-fleshed sweetpotato need to be tested to establish the physiologically suitable ones for intercropping.
2. Further work should be carried out to establish the exact level of mixture at which shading will not cause a significant reduction in the β-carotene content.
3. Varieties with low levels of β-carotene should not be grown under intense shading. In case of intercropping, it is advisable to avoid mixing with high levels of the component crop especially the tall and aggressive ones.
4. The same experiment should be conducted in different agro-ecologies to determine the causes for the seasonal effects.

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APPENDICES

Appendix 1. Temperature and rainfall data for the year 2011

	Months												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Mean
Temp (°C)	28.1	27.7	27.5	27.0	25.7	25.7	24.4	24.3	24.3	27.4	25.3	23.2	25.9
Rainfall (mm)	13.5	5.4	80	146	194.8	164.1	130.3	236.5	220	181.8	203.5	46.9	135.2

Appendix 2. Anova with P-values for vine length at different weeks after planting for season 1 and season 2

		Vine length								
		Season 1				Season 2				
		Time(Weeks after planting)				Time(Weeks after planting)				
Source	DF	9	12	15	18	9	11	13	15	17
Variety	1	0.0932	0.0111	0.0011	0.0027	<.0001	<.0001	<.0001	<.0001	<.0001
Density	3	0.4285	0.2786	0.2506	0.3238	0.0172	0.0745	0.096	0.1464	0.1601
Replication	3	0.242	0.8852	0.4802	0.2823	0.2781	0.3899	0.3822	0.4367	0.1018
Variety*Density	3	0.5796	0.3283	0.6525	0.7924	0.0799	0.2629	0.317	0.4345	0.2952

Appendix 3. Anova with P-values for number of main stems at different weeks after planting for season 1 and season 2

		Number of main stems								
		Season 1				Season 2				
		Time(Weeks after planting)				Time(Weeks after planting)				
Source	DF	9	12	15	18	9	11	13	15	17
Variety	1	0.3741	0.4303	0.0692	0.0692	0.2205	0.8258	0.7022	0.829	0.829
Density	3	0.4027	0.9674	0.5898	0.5898	0.0705	0.0612	0.0132	0.0003	0.0003
Replication	3	0.0195	0.0162	0.017	0.017	0.1163	0.0143	0.0609	0.0275	0.0275
Variety*Density	3	0.9786	0.9252	0.7849	0.7849	0.5248	0.6997	0.7194	0.8902	0.8902

Appendix 4. Anova with P-values for number of branches at different weeks after planting for season 1 and season 2

		Number of branches								
		Season 1				Season 2				
		Time(Weeks after planting)				Time(Weeks after planting)				
Source	DF	9	12	15	18	9	11	13	15	17
Variety	1	0.4044	0.0232	0.377	0.377	<.0001	0.0002	0.0002	0.048	0.048
Density	3	0.0169	0.0059	0.0375	0.0375	0.0008	0.0006	<.0001	<.0001	<.0001
Replication	3	0.241	0.1245	0.3196	0.3196	0.7356	0.8782	0.3622	0.5498	0.5498
Variety*Density	3	0.493	0.7682	0.4549	0.4549	0.2839	0.2562	0.1966	0.7497	0.7497

Appendix 5. Anova with P-values for number of leaves at different weeks after planting for season 1 and season 2

		Number of leaves							
		Season 1			Season 2				
		Time(Weeks after planting)			Time(Weeks after planting)				
Source	DF	12	15	18	9	11	13	15	17
Variety	1	0.3881	0.0188	0.0622	0.0616	0.9607	0.1903	0.1117	0.0041
Density	3	0.0384	0.0004	0.004	0.0062	<.0001	<.0001	<.0001	<.0001
Replication	3	0.6319	0.0148	0.0027	0.5401	0.0469	0.2534	0.2309	0.0481
Variety*Density	3	0.5893	0.1751	0.31	0.4775	0.3347	0.1851	0.4673	0.063

Appendix 6. Anova with P-values for sweetpotato yield parameters and Leaf area index for season 1 and season 2

		Parameters																	
		Number of commercial roots		Total number of roots		Commercial root weight (t ha^{-1})		Total root weight (t ha^{-1})		Vine yield (t ha^{-1})		Dry matter (%)		Beta-carotene content (mg/100)		Leaf Area Index		Root:shoot ratio	
Source	DF	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2
Variety	1	<.0001	0.0137	0.023	0.4466	<.0001	<.0001	0.0003	<.0001	0.0073	0.0085	<.0001	<.0001	0.3814	0.2598	0.0012	<.0001	0.0007	<.0001
Density	3	0.0032	0.0593	0.0227	0.0072	0.0006	<.0001	0.0148	<.0001	0.0008	0.0039	0.3568	0.4871	0.3739	0.0256	0.0529	0.0007	0.5122	0.0278
Replication	3	0.1283	0.4733	0.0677	0.5631	0.5841	0.0294	0.4603	0.0727	0.2132	0.5199	0.258	0.7004	0.8307	0.2107	0.0236	0.1922	0.5008	0.1218
Variety*Density	3	0.0197	0.6365	0.0981	0.5142	0.0033	0.0758	0.0403	0.4554	0.353	0.7724	0.8614	0.5306	0.3865	0.3951	0.658	0.6506	0.7432	0.6432

Appendix 7. Anova with P-values for maize growth and yield parameters for season 1 and season 2

		Parameters							
		Plant height		Leaf Area Index		Grain yield		100 seed weight	
Source	DF	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2
Density	3	0.1651	0.0284	0.0011	<.0001	0.0029	0.0017	0.7286	0.1566
Replication	3	0.0431	0.5516	0.0434	0.4906	0.3399	0.4159	0.867	0.5121