OPTIMIZATION OF LAND PRODUCTIVITY IN ZANZIBAR THROUGH INTERCROPPING OF CASSAVA (*Manihot esculenta* Crantz) AND SWEET POTATO (*Ipomoea batatas* L.Lam)

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A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN CROP SCIENCE OF SOKOINE UNIVERSITY OF AGRICULTURE. MOROGORO, TANZANIA.

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ABSTRACT

Two field experiments were conducted during the growing season of 2018/2019 at Zanzibar Agricultural Research Institute (ZARI) Unguja and Pemba. The objective of the experiment was to explore the potentiality of optimizing land productivity through intercropping cassava with sweet potato on limited land available. The experiment was a split-split plot laid out in a randomized complete block design (RCBD) with four replications. Improved cassava variety 'Kizimbani' was intercropped with improved sweet potato variety 'Mayai'. The main plot was intercropping time of sweet potato. Fertilizer application was a sub plot and sweet potato intercrop plant density of 10 000, 20 000 and 30 000 plants ha^{-1}was a sub-sub plot. There were 48 intercropped plots and 32 sole-cropped plots. Data on crop establishment, plant height, canopy dimension, foliage cover, vine vigour, root/tuber yields and number of roots/tubers were collected and subjected to analysis of variance (ANOVA). The results revealed that there were significant differences between treatments in crop yields, vine vigor, plant height, foliage cover, canopy length, thickness and number of marketable roots/tubers. Furthermore, there were significant differences in the two sites in most of the observed characteristics. Matangatuani gave the highest yield of cassava (17.63tha^{-1}) in intercropping compared with Kizimbani (13.15tha^{-1}). However, for sweet potato, Kizimbanirecorded14.67tha^{-1} and Matangatuani13.75tha^{-1}.In addition, intercropping of cassava with sweet potato gave the highest land equivalent ratio (LER) of 1.75 in combined site analysis. This indicated that the greatest productivity per unit area was achieved by growing the two crops together.

Keywords: Cassava, fertilizer, intercropping, planting time, spacing, sweet potato

DECLARATION

I, Ally Hamad Ally, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my original work done during the period of my registration and has neither been submitted nor concurrently being submitted for degree award in any other Institution.

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DEDICATION

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LIST OF ABBREVIATIONS AND SYMBOLS

%	-	Percentage
<	-	Less than
≤	-	Less than or equal to
>	-	Greater than
^{0}C	-	Degree Celsius
ACAI	-	African Cassava Agronomy Initiative (Project)
ANOVA	-	Analysis of Variance
CIP	-	Centro International de la Papa (International Potato Centre)
cm	-	Centimeter
cm^3	-	cubic centimeter
CV	-	Coefficient of variation
Df	-	Degree of freedom
DMRT	-	Duncan’s multiple range test
DTPA	-	Di-ethylene-tri-amine penta acetic acid
E	-	East
e.g	-	For example
FAO	-	Food Agricultural Organization of the United Nation
FAO STAT	-	Food and Agriculture Organization Corporate Statistical Data Base
g	-	Gram
ha	-	Hectare
i.e.	-	That is
IAEA	-	International Atomic Energy Agency
IITA	-	International Institute of Tropical Agriculture
LER	-	Land Equivalent Ratio
LSD	-	Least Significance Differences
MAP	-	Month After Planting
m.a.s.l.	-	Meter above sea level
mm	-	Millimeters
m^2	-	Square Metre
MS	-	Mean Square
RCBD	-	Randomized Complete Block Design
S	-	South
SD	-	Standard Deviation
Se_x	-	Standard Error of Mean
SOV	-	Source of Variation
SPVD	-	Sweet Potato Virus Disease
SPW	-	Sweet Potato Weevil
SS	-	Sum of Square
SSA	-	Sub-Saharan Africa
SUA	-	Sokoine University of Agriculture
VAD	-	Vitamin A Deficiency
WAP	-	Week after planting
ZARI	-	Zanzibar Agricultural Research Institute
ZATI	-	Zanzibar Agricultural Transformation Initiative
ZFSNP	-	Zanzibar Food Security and Nutrition Programme

CHAPTER ONE

1.0 INTRODUCTION

1.1 Back Ground and Rationale

1.1.1 Cassava

Cassava (*Manihot esculenta* Crantz) is a perennial shrub which belongs to the family Euphorbiaceae. It is the seventh most important staple food crop in the world and fourth in Sub-Saharan Africa (Howeler, 2014). On average cassava is a staple food for over 800 million people across the world (El-Sharkawy, 2012).It is a major food crop in Africa, and both dry root chips and leaf silage are excellent feed for animals (FAO/IAEA, 2018). The crop is the third largest source of carbohydrates for humans and animals in the tropics, after rice and maize (FAO/IAEA, 2018). People consume the cassava roots as a source of calories. Cassava produces high starch with levels of up to 90% of its total storage root dry mass (Jansson *et al.,* 2009). The high starch content (20-40%) makes cassava a desirable energy source for both human and industrial use (Kanju *et al.,* 2019).

The crop has spread throughout the tropical world to such an extent that today more cassava is grown outside than within its areas of origin and domestication. In Tanzania cassava is a major staple food crop after maize and rice with an estimated annual production of 5.4 million tonnes (FAOSTAT, 2012). The potential areas for cassava production in the mainland Tanzania are Northwestern regions (Mwanza, Shinyanga, Mara and Kigoma), Southern regions (Mtwara and Lindi).

According to FAOSTAT (2012) Tanzania is the12th largest cassava producer in the world and the 6th largest in Africa after Nigeria (top producer in the word), Democratic Republic of Congo (DRC), Ghana, Angola and Mozambique. The average cassava productivity in Tanzania is 8tha^{-1}, which is below its potential yield of 20tha^{-1} (FAOSTAT, 2012).

Moreover, cassava is believed to be highly resilient to future climatic changes compared to other staples such as maize, sorghum and millet, which could provide Africa with options for adaptation (Jarvis *et al*., 2012). The crop has numerous agronomic traits that confer comparative advantages in adverse environments where farmers often lack the resources to improve income-generating capacity of their land through purchased inputs. It is a hardy crop as it tolerates infertile soils, periodic and extended droughts, and biotic stresses (Calle *et al.,* 2005; El-Sharkawy, 2007).

Cassava is highly suited to intercropping with many types of crops and its time of harvest is flexible. It has a wide variety of food, feed and industrial uses (Westby, 2002; Jansson *et al.,* 2009). These attributes make cassava an important crop in food production and income generation, in particular benefitting the poor in the tropical regions of the world (Henry and Hershey, 2002). Due to its tolerance to poor soils and harsh climatic conditions, cassava is generally cultivated by smallholder farmers as a subsistence crop in a diverse range of agricultural and food systems (Alves, 2002).

1.1.2 Sweet potato

Sweet potato (*Ipomoea batata* L. Lam) is a perennial root crop belonging to the family Convolvulaceae (Cuminging *et al.,* 2009). It is a herbaceous dicot crop widely grown throughout the tropics and warm temperate regions of the world. The crop is commonly cultivated for its root tubers and vines on annual basis. Sweet potatoes are grown for food and feed in many developing countries (Low *et al*., 2009). It is an important food security crop, often crucial during famine periods because of its excellent drought tolerance and rapid production of storage roots (Mukhopadhyay *et al*., 2011). It is an important crop grown by subsistence farmers for food security in Tanzania (Kulembeka *et al*., 2005; Masumba *et al.,* 2005). It contributes significantly to livelihoods of many households. In

Tanzania the average sweet potato yield has been reported to be 4.5 tha^{-1} (FAOSTAT, 2012). Sweet potato is almost entirely used for human consumption (Tumwegamwire *et al.*, 2011). The International Sweet potato Centre (CIP) and its partner organizations have taken up a food – based options to combat the vitamin A deficiency (VAD) in the sub-Saharan Africa through increased consumption of orange fleshed sweet potato. It is estimated that 60% of the total cultivated land in Zanzibar is planted to food crops. Cassava and sweet potato are the main root crops grown by the majority of smallholder farmers. Out of the total arable land of 130 000 ha in Zanzibar, sweet potato occupies a total areas of 5230 ha. Sweet potato is the most important food crops in Zanzibar and ranks fourth after rice, cassava and bananas (ZATI, 2010).

1.1.3 Intercropping

Intercropping is a practice of growing two or more crops in the same field during the same year or season (Leihner, 1983; Musa *et al.,* 2012).The most widespread intercropping system in the humid and sub-humid tropics is cassava-based (Amanullah *et al.,* 2007). Cassava is usually intercropped with short duration crops because of its slow initial growth (3–4 months) which allows the farmer to exploit the niche between the cassava stands by smothering weeds and increasing economic returns of the system (Salau *et al.,* 2012). It involves planting on the same piece of land, crops that differ in productivity, growth habit and morphological characteristics.

The intercropping practices widely common among small-scale farmers as a strategy for increasing crop yields and diversity of crop production (Adeniyan *et al.,* 2014). Cassava is intercropped either with legumes or non-legume crops (Lazzaro *et al.,* 2007; Musa *et al.,* 2012; Matata *et al*., 2017). Intercropping is an effective way of intensifying agricultural production through the more efficient use of land resources. Cassava as an important root crop of the tropics and sub-tropics has been intercropped with variety of other crops such as legumes and cereals. This is because cassava does not impose much competition at the beginning of its growth cycle (Leihner, 1983).

In Tanzania cassava is largely intercropped with other crops rather than sole crop (Lazzaro *et al.,* 2007). Both in the mainland and the islands of Tanzania, cassava is intercropped with either cereals (maize and sorghum) or legumes (beans and cowpeas. Cassava is often found in mixed stands together with a variety of other food or cash crops. From personal experience, traditional farmers adopt intercropping as a production system in order to reduce the risk of crop failure, obtain production at different times during the year, make the best use of the available land, labour, resources and provide the family with a balanced diet. However, intercropping cassava with short duration crops is very common because the crop has a slow initial growth at 3-4 months after planting allowing the intercrop to optimize growth resources (Adekunle *et al.,* 2014).

There are many known roles of intercropping; it increases the productivity per unit area of the land (Silva *et al.,* 2016) and allowing efficient use of both space and time to optimize beneficial effects. Intercropping also promotes diversification and allows greater flexibility in adjusting to short- and long-term changes in the production and marketing situations (Musa *et al.,* 2012). It has been noted that intercropping improves moisture conservation and weed suppression, thus can ensure nutrient availability to the particular crop. It also reduces production costs by decreasing weeding regimes (IITA, 2001).

Moreover, intercropping plays a significant role in integrated pest management; reducing weed, pests and diseases (Ibeawuchi *et al.*, 2007). The association of crops with different growth durations results in a gain in total yield through better utilization of two dimensions, space and time (Leihner, 1983). Cassava and sweet potato have different morphology, time to maturity and growth habit that allow relay intercropping as sweet potato is harvested earlier (4MAP) and cassava is allowed to complete its growing cycle. The growth duration of cassava depends on environmental conditions and varieties, but the period from planting to harvest is about 9-12 months in hot regions and 2 years in cooler regions.

Intercropping assures the farmer a more lucrative crop with lower risks especially in adverse conditions (Silva *et al.*, 2016). It helps to minimize the threat of losing whole crops in a season because if one crop failed the other could survive. Thus, improving crop management and cropping systems by intercropping using appropriate plant populations ensures optimum use of land that would allow farmers to harvest more than one crop in a year, and these results into improved land potentiality, increase food availability as well as income generation. This study was, therefore; aimed at evaluating productivity of cassava-sweet potato intercropping and ultimately extends the technology more on the best timing, density and fertilizer application levels in the study areas.

1.2 Problem Statements and Justification

Cassava and sweet potato are the main root crops grown by the majority of small holder farmers in Zanzibar. However, the crops are commonly grown on small pieces of land due to shortage of arable land. Overall, domestic production of staple foods has remained at rather low and unstable levels, which is largely dependent on small holder farming (ZFSNP, 2008). Consequently, imported foods constitute a large proportion of the food available and consumed in Zanzibar (ZFSNP, 2008). In order to optimize production and diversify risks, farmers grow more than one crop in their small farms. Besides, the low crop yields under poor agronomic practices (Saleh and Zahor, 2007) and limited access to land in Zanzibar; proper crop intercropping practice to optimize land area and crop yield is of paramount importance. Intercropping cassava with short-duration crops is a common practice in many tropical countries. These intercrops are useful because they supply either food or additional income, especially at times when cassava crop is not ready to be harvested. Also, the intercrops protect the soil from the direct impact of rainfall, and reduce the speed of runoff water when cassava canopy is not yet closed, thus reducing soil erosion. Furthermore, intercrops reduce weed growth during the early stages of cassava development (Howeler, 2017).

It is usually practiced by small-holder farmers who have only small areas of land from which to feed or sustain a family. These farmers have to maximize the total productivity of the land by optimizing the growth factors such as light, water and nutrients. However, intercrops need to be carefully managed in order to reduce competition with cassava for light, water and nutrients. This is usually done through modifications of plant spacing or planting pattern of both crops, by adjusting the relative time of planting and by fertilizing each crop adequately to maximize yields (Howeler, 2017).

Some farmers plant cassava in a relatively wide spacing, above the recommended practice of 1 x 1m, hence establishing very low plant populations, which expose large open spaces for weed growth. Similarly, most farmers in Zanzibar rarely use mineral fertilizers in cassava and sweet potato production; with the concept that cassava is tolerant to low soil fertility. However, both cassava and sweet potato are heavy feeder crops with high capacity of utilizing much of the soil nutrients. Due to limited information on intercropping system, most cassava growers in Zanzibar use traditional cultivation knowledge and experiences, especially on the intercropping aspect. As a matter of fact, productivity of cassava-based intercropping systems in Zanzibar is not fully understood in terms of its relative importance under varying cropping density and fertilizer application. Hence the basis for conducting this study.

1.3 Objectives

1.3.1 Overall objective

Improve food availability in Zanzibar through production of cassava and sweet potato crops from the same piece of land in a year.

1.3.2 Specific objectives

The specific objectives of this study were to;

i. Assess the effect of intercropping time and plant density on growth and yield of sweet potato and cassava under intercropping.

ii. Evaluate the effect of fertilizer application on growth, yield and quality of cassava and sweet potato under intercropping.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Crop Origin and Distribution

2.1.1 Cassava

Cassava originated from Central and Southern America and has since then spread to various parts of the world (FAO, 2001). The crop was first domesticated in South America and it is now grown in tropical and subtropical areas of the world between latitude 30°N and 30°S of the equator under various ecological conditions (El-Sharkawy, 2012). It is grown from sea level to 2000 meters above sea level under annual precipitation from 500 to >2000 mm. The crop requires a warm moist climate with mean temperature range of 24 to 30°C.

Cassava tolerates soil acidity, infertile soils, periodic and extended droughts, and biotic stresses (El-Sharkawy, 2012). It thrives in a pH range 4.5 to 8.0 (FAO/IAEA, 2018) but does not tolerate excess soil moisture, high salinity or temperatures of ≤10°C (IITA, 2001). The physical properties of surface soils are very important in determining its productivity potential (Asmar, 2011). Soil pH reflects the overall chemical status of the soil and influence a whole range of chemical and biological processes of the soil (Jaillard *et al.,* 2005). The highest yields of cassava occur on well-drained, medium to heavy textured soils with medium fertility and a pH of about 5.5 – 7. The crop is highly suited to intercropping with many types of crops.

Cassava has a wide variety of uses as a staple food, feed and industrial purposes (Jansson *et al.*, 2009). Propagation of cassava is possible either through true seed or through cuttings. Propagation by cuttings is the common practice for commercial production while seed propagation is suited in the breeding purpose. Cassava cuttings for planting is normally 20-30 cm length and preferably taken from the middle of the stems due to hormonal balance. Roots are the main economic and storage organs in cassava. Most roots are concentrated on the top soil depth of 30 cm with some as far down as 140 cm. Depending on the cultivars and growing conditions, these large storage roots are harvested 6 to 24 months after planting [MAP] (Alves, 2002) and can remain in the soil for 1 to 2 years without decaying particularly under drought conditions (Nweke *et al*., 2002). During its growth, cassava develops alternating periods of vegetative growth and carbohydrate storage in its roots (Alves, 2002).

Under favourable conditions, the photosynthesis process can participate in plant growth after true leaf appears at about 1 MAP. Most of the leaves and stems develop during 3 to 6 MAP. Since the leaves can intercept most of light during the first 3 MAP, maximum canopy size may reach at 6 MAP (Hillocks, 2002). The fibrous roots can absorb water and nutrients in the soil at 1 MAP and storage roots may initiate when few fibrous root become storage roots from 2 to 6 MAP (Howeler, 2002). The storage root number (SRN) in cassava is determined during the first 3 months after planting (MAP). Cassava has low requirement for N compared to other crops and high N application may lead to excessive top growth and a reduction of starch synthesis (Howeler, 1981).

Cassava varieties may differ in their growth habits, some having vigorous early growth and early branching, while others are more erect with medium- to late-branching. Cassava is often found in mixed stands together with a variety of other food or cash crops. When small farmers adopt intercropping as the production system, a relatively small plot is sufficient to provide the family with the basic dietary elements (Leihner, 1983). The optimum sole crop planting density can also be used when cassava is grown in association with other crops without causing a serious yield reduction of the associated crop. However, if the cassava variety is very vigorous, it may be necessary to reduce its plant density in order to maximize yields. With late-branching and less vigorous cassava varieties the best yields were achieved with an intermediate plant density of about 10 000 plants ha^{-1} (Howeler, 2017). The choice of spatial arrangement of each crop is important in reducing competition and maximizing total yield, as different arrangements affect the efficiency of utilization of light and space. However, to favor the growth of intercrops, a wider inter-row spacing of cassava and shorter interplant spacing within the row is often preferred.

2.1.2 Sweet potato

Sweet potato is a root crop which originated from North America (Zhang *et al*., 2000). It was spread by local traders to South America by 2500 BC and widely spread by Portuguese explorers to Africa, India and the East Indies in the 16th century (Zhang *et al.,* 2000). Currently, sweet potato is an important crop in many places of sub-Saharan Africa (SSA). It is cultivated worldwide in more than 100 countries, including Central America, South America, North America, Pacific Islands, Asia, India, Africa, Australia, the Caribbean, and the Mediterranean basin.

The crop grows well at an average temperature of 24^{o}C; however, below 10^{o}C growth is severely retarded. It is usually planted as sole or intercropped with other crops such as maize, cassava, yam or okra in different countries. In Zanzibar, sweet potato is grown almost in all agro ecological zones, both in plantation zones where soils are rich and moisture is adequate and at the semi coral rag zone where soils are poor and moisture stress dominates (Saleh and Zahor, 2007). The major production regions in Zanzibar include Urban West, Northern and Southern regions of Unguja and Northern region of Pemba.

Sweet potato effectively suppresses weed growth in a field cultivated (Eneji *et al.*, 1995). In most cases sweet potato is vegetatively propagated by vine cuttings or rooted shoots. Vines grow quickly and may reach full canopy in 6 weeks with effective coverage of the ground surface. The edible storage roots of sweet potato are important food for resource-poor farmers in many countries (Woolfe, 1992). The tubers are rich in vitamins A, B, and C; and minerals such as K, Na, Cl, P and Ca (Onwueme and Sinha, 1991).

2.1.3 Fertilizer application

Although cassava has been traditionally grown without fertilizers; studies show that it responds to fertilizer application. According to Howeler (1981) adequate nutrients should be added in order to achieve high cassava root growth and yield. Balanced fertilizer application is critical not only to increase crop yield but also to increase starch content in roots. In most soils cassava responds well to potassium, nitrogen and phosphorus applied in the following order of magnitude: K >N >P (FAO/IAEA, 2018). Thus, application of fertilizers plays an important role in improving production and maintaining a positive nutrient balance. Cassava is well adapted to very acidic and infertile soils but may require high level of fertilizer application to obtain maximum yield (Howeler, 1981).

However, the crop is sensitive to over fertilization, which causes excessive top growth and little root growth. Therefore, there is no doubt that responses of cassava to mineral fertilizers are substantial. On top of that high amount of potassium (K), nitrogen (N) and phosphorus (P) are needed for high root yield (Nguyen *et al.*, 2002). Previous studies (Fermont *et al.*, 2010; Pypers *et al.*, 2011; 2012; Uwah *et al.*, 2013) reported that cassava responds to good soil fertility and mineral fertilizer application. The study conducted by Pypers *et al.* (2012) in western Democratic Republic of the Congo (DRC) showed that application of NPK fertilizer to cassava increased root yield from 42 to 212 %. Gregory and Bump (2006) reported that during the last 30 years an average of 660 kg N ha^{-1}, 75 kg P ha^{-1}, and 450 kg K ha^{-1} had been depleted from about 200 million ha of cultivated land in 37 African countries. Therefore, traditional soil fertility maintenance strategies, such as land fallow, cereal-legume intercropping and mixed crop-livestock farming were not capable of adjusting quickly enough to rapid population growth combined with reducing farm size and soil fertility (Bationo *et al.*, 2006). Thus, soil fertility replenishment in small-holder farms should be considered as an investment in SSA (Sanchez and Jama, 2002).

Small-holder farmers often consider cassava as suitable for poor soils and not requiring fertilizers; although cassava shows response to fertilizer application (Fermont *et al.,* 2010; Pypers *et al*., 2011). As a result of the limited use of nutrient inputs, soil fertility is a main cause of decreasing cassava production (CIALCA, 2006). Although cassava withstands harsh conditions and grows well on acidic soils where other crops cannot grow satisfactorily, application of fertilizers in cassava fields appears to be more profitable. Generally, farmers do not evaluate crop loss in terms of nutrients deficiency. According to Mokwunye and Bationo (2002), application of nutrient inputs is required for improvement and sustainability of agricultural production in Sub-Saharan Africa.

Cassava extracts large amount of K from the soil and may cause depletion of this element if grown continuously without adequate K fertilizer application. Howeler (1981) concluded that, on the average; each tonne of fresh cassava roots removes 2.3 kg N, 0.5 kg P, 4.1 kg K, 0.6 kg Ca, and 0.3 kg Mg. On the other hand, 2.24 kg N, 0.7 kg P and 3.97 kg K are removed for each tonne of sweet potato harvested. On average, intercropping cassava with sweet potato reduced N uptake of cassava by 35%, P by 36% and K by 38%. On other hand intercropping with cassava, reduced N uptake of sweet potato by 15%, P by 17% and K by 28% (Kapinga *et al*., 1994). This shows that although cassava and sweet potato competed for the same nutrients, sweet potato being more aggressive in intercropping and the dominant competitor by which its nutrient uptake are less affected by intercropping. From this scenario the total nutrients uptake of cassava /sweet potato intercrops are greater than that in their respective sole cultures and this suggesting that soil N, P and K reserves will be depleted faster in intercropping. Therefore a sound fertilizer application practice in cassava/sweet potato association should be put in place to ensure soil fertility maintenance (Kapinga *et al*., 1994). Low to poor soil fertility conditions are among the major constraints that limit effective sweet potato production in Tanzania (Ndunguru *et al*., 2009).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Location

The study was conducted in Zanzibar, Tanzania, in the 2018/2019 cropping season. Two sites were selected and experiments established under the Research management section. Both sites were of different in soil types and composition. One site was set at Kizimbani Agricultural Research Institute, West District, Unguja located at 6^{o}.13’33’’ S and39^{o}.31’67’’ E (72 m.a.s.l) and the other site at Matangatuani Agricultural Research Station, Micheweni District Pemba, located at 5^{o}.16’67’’ S and39^{o}.78’33’’ E (26 m.a.s.l). Kizimbani is characterized by sand clay loam soil, with a pH ranging from 4.9 to 5.7 and average annual rainfall ranging from 1720 – 1850 mm. Matangatuani has sandy loam textured soil, a pH range from 5.4 to 5.7 and average annual rainfall of 1088 mm. Generally Zanzibar experiences bimodal rainfall, the long rains (Masika) usually starts in middle March to May and the short rains (Vuli) begin in September to November. The average minimum and maximum temperatures are 23.8^{o}C and 30.2^{o}C, respectively.

3.2 Fertilizer and Varieties of Plants

Urea 46%N, triple supper phosphate (TSP) 46%$P_2O_5$and muriate of potash (MOP) 60%K_2O, were used in the study. **S**imilarly, improved cassava and sweet potato planting materials obtained from ZARI were used. Cassava variety “Kizimbani” and sweet potato variety “Mayai” were used at each site. Kizimbani variety is a popular and high yielding cultivar. This variety is also tolerant to cassava brown streak (CBSD) and cassava mosaic virus (CMV) diseases, which are the most important diseases of cassava in Zanzibar. Mayai variety of sweet potato is a bush type, high yielding and tolerant to sweet potato virus diseases (SPVDs) and leaf and stem scab disease, which are the most important diseases affecting sweet potato production in Zanzibar.

3.3 Methods

3.3.1 Experimental design and treatment allocation

The experiments were established in split-split plot design and laid out in Randomized Complete Block design (RCBD). Intercropping time of sweet potato was the main plots, recommended fertilizer application rate for intercropping and sole cropping of cassava and sweet potato was the sub-plots and sweet potato plant density was the sub-sub plots. Sweet potato intercropping was carried out in two planting intervals. The first planting was done simultaneously with cassava at 0- Week after planting (0WAP) as control and the second planting was at 2 weeks later. Similarly, fertilizer application had two levels; without fertilizer as a control and with fertilizer.

Sweet potato plant density was at three levels; low density as a control (10 000 plants ha^{-1}), medium density (20 000 plants ha^{-1}) and high density (33 333 plants ha^{-1}). Each experiment was composed of 20 treatments replicated four times. In both established experiments, there were 48 intercropped plots and 32 sole-cropped plots. The plot size was 8 x7m equivalent to $56m^2$. Both cassava and sweet potato sole crops without fertilizer were used as control. For every experiment the allocation of main plots within replicate blocks, as well as the allocation of the subplots were randomized separately. The experimental field lay out is shown on (Appendix 2).

3.3.2 Land preparation

Soil sampling was done at a depth of 0 -30cm before land preparation and ridging at both sites for physical and chemical analysis. Experimental fields were first ploughed two times mechanically to pulverize the soil and facilitate ridge formation. Thereafter, ridges of 8m length, 0.6m height and a distance of 1m between them were prepared.

3.3.3 Planting

During planting, eight cassava cuttings, 20 – 30cm length were planted in slant angles (45°) on top of the ridge at a spacing of 1 x 1m. Sweet potato vines of 30cm length were planted (intercropped) on top of the ridge between two cassava cuttings at 0 weeks and 2 weeks after the first planting of cassava and sweet potato (WAP). The sweet potato intercropping was planted at 1 x 1m, 1 x 0.5m and 1 x 0.33m. Cassava sole-crop was spaced 1m apart (square) and sweet potato sole- crop was also planted on a spacing of 1 x 0.33m (30 000 plants ha^{-1}). Both sweet potato and cassava sole crops were integrated into the main plots with sweet potato planted concurrently or same time with cassava.

3.3.4 Weeding

Weeding was done by hand hoeing in all plots 1 month after planting. The experiments were weeded two times before sweet potato harvest and one time weeding later for cassava after sweet potato harvest.

3.3.5 Fertilizer applied

The N, P and K fertilizers were applied at the rates of 75, 20 and 90kg/ha, respectively, as recommended by IITA. Phosphorus was applied 100% as basal dressing at planting of cassava. In contrast, N and K were applied as top dressing in two splits, depending on the planting time of the sweet potato intercropping. Moreover, in the sweet potato planted the same day with cassava first split of N and K was done 2 weeks after planting, since sweet potato rooted and sprouted earlier than cassava. Second split was applied 2 weeks later. For sweet potato planted after 2 weeks, the first split application of N and K was done 2 weeks after planting the sweet potato and repeated 2 weeks later. In sweet potato and cassava sole cropping, the first split application of N and K was done 2 WAP and the second split 8 WAP. For cassava that was intercropped with, the second split of N and K were applied after harvest of sweet potato (4MAP). Furthermore, during application, fertilizers were banded around the plants at about10-15cm away from the plant at a depth of 1cm beneath the soil and covered with soil.

3.4 Data Collection

3.4.1 Weather data collection

Weather data, mainly rainfall (mm), were collected daily and the average data summarized on monthly basis. The data was recorded from the day of planting to final sweet potato harvest. Soil moisture content was determined on a weekly basis using oven dry method as described by Zein (2002). The samples were taken from the representative experimental plots. This was done by taking the weight of wet soils (W_2) filled in soil core of $100cm^3$. The weights of all empty cores (W_1) were measured and labeled before sample collection. The soil samples were then oven dried at 105ºC for 24 hours. After that dry weight (W_3) was recorded. Therefore soil moisture content (%) was calculated as shown in Eqn.1.

$$\textit{Soil moisture content (\%)} = \frac{W2 - W3}{W2 - W1} x\,100 \quad \text{...} \textit{Eqn. 1}$$

The percent soil moisture results are shown as (Appendix 1).

3.4.2 Growth characteristics

Agronomic data such as canopy dimension, plant height, percent establishment and economic yield were collected. The canopy dimensions on cassava were determined when the crop attained full canopy stage at 6 MAP. This was done by measuring length, height and width of canopy using hand hold tape measures. Plant height was taken prior to crop harvest by measuring the plant from the above ground level to the apex of the highest terminal shoot using tape measure. Furthermore, sweet potato vigour and coverage was recorded by observing the status of the vine cover above the ground by which a scale of 1-5 was used, where 1 was very bad and 5 was very good ground coverage as described by IITA (1990).

3.4.3 Pests and diseases scoring

Cassava brown streak disease (CBSD) and Cassava mosaic disease (CMD) as well as sweet potato virus disease (SPVD) and sweet potato weevil (SPW) severity were scored at three months after planting and during harvesting. This was done by recording the number of plants showing symptoms by assessing subjectively on a scale of 1-5 where, 1= no visible symptoms, 2= slight foliar mosaic, 3= foliar mosaic with stunted growth, 4= severe roots mosaic and stunted growth, general reduction of leaf size and 5= severe mosaic and stunted growth, twisted and miss-shaped leaves. SPW severities were scored at two and four months after planting.

3.4.4 Yields and yield components

During harvesting 12 months after planting for cassava and 4 months for sweet potato, yield assessment was undertaken. Total number of plants in the net plot and weight of storage roots were taken into account. Number of unmarketable roots per plot was determined as all tuberous roots with less than 2 cm in diameter, rotten roots, diseased and pest infested roots/tubers. Number of marketable tuberous roots per plot was recorded as all roots with greater than 2.5cm in diameter. On addition the weight of marketable and unmarketable root yields was assessed and expressed in tonnes per hectare (t ha^{-1}).

3.4.5 Land equivalent ratio (LER)

Land equivalent ratio (LER) is used to compare different combinations of crops in intercropping systems. Mathematically, the LER is the sum of two or more quotients according to the number of crops in the association (Leihner, 1983). Thus, LER was calculated as indicated in Eqn. 2.

LER = $Lx + Ly$ ¿ $\frac{Ax}{Px} + \frac{Ay}{Py}$ ……………………………………………………………*Eqn. 2*

Where *Lx* and *Ly* are the individual LER’s of two crops *X* and *Y. Lx* is obtained by dividing the yield of crop *X* in association *(Ax)* by the yield of the same crop in pure stand *(Px). Ly* is the result of dividing the yield of crop *Y* in association *(Ay)* by the yield of that same crop in pure stand *(Py)* (Leihner, 1983).With respect to Eqn. 2, the crop *X* can be taken as cassava and *Y* as sweet potato; whereby *(Ax)* is a yield obtained from cassava intercropped and *(Px)* is the yield of cassava in sole crop. Similarly, *Ay* is the yield obtained from sweet potato intercropped and *Py* is the yield from sweet potato in sole crop.

Normally, due to competition among crops in association, the yield of each component crop is greater in pure stand than when intercropped. Therefore, less area is required for a single crop to attain the same production in pure stand than in association. This is reflected by *A/P* values normally smaller than unity.

3.5 Data Analysis

The agronomic data were subjected to Analysis of variance (ANOVA). A single and combined sites analysis was done using Gen-Stat computer software package v.15. Duncan's multiple range test (DMRT) at 0.05 probability level was used for mean comparisons. According to split-split plot design, the following statistical model was used to assess mean and interaction effects:

$Y_{ijkl} = \mu+\beta_i +A_j +\delta_{ij} +B_k+AB_{ik}+\omega_{ijk}+C_m+AC_{im}+BC_{km}+ABC_{jkm}+\varepsilon_{ijkm}$ *Eqn.3*

Where, Y_{ijkm}=Response level, μ=General error mean, β_i =block effect, A_j =Main plot effect, δ_{ij} =the main plot random error (error a), B_k =Sub-plot effect, AB_{ik}=Interaction effect between the main-plot and the subject, ω_{ijk}=subject error (error b), C_m =Sub-sub plot effect, AC_{im}= Interaction effect between main-plot and the subject I. BC_{km}= Interaction effect between the sub-plot and the subject I. ABC_{jkm}=the three way (factors A*B*C) and ε_{ijk} = Sub-sub plot random error effect.

CHAPTER FOUR

4.0 RESULTS

4.1 Weather Condition in the Experimental Sites

4.1.1 Rainfall and temperature

Weather conditions did not vary much over the cropping season in both sites, although there were slight differences in rainfall distribution. In both sites mean maximum rainfall was recorded in May. Whereas 591.9mm of rainfall was recorded at Kizimbani and 500.8mm reported at Matangatuani. The mean minimum rainfall was received in August; 40 mm was reported at Kizimbani and 11.8 mm at Matangatuani (Table 1).

The mean maximum and minimum temperature for both sites were almost the same during the seasons from April to August, which ranged from 22.8-33.4°C. The annual average maximum temperature (30.2ºC) and average annual minimum temperature of 23.8ºC, difference between annual maximum and minimum was 6.4ºC. November to February was a very hot period (31 – 33ºC). Average humidity was 71.5% and average evaporation was 5.72 mm day^{-1}. Sunshine duration ranged from 7 – 9 h day^{-1}.

Table 1: Weather data at the experimental sites, 2018

Site		**Rainfall**	**Temperature**	
	Month	**mm**	**Min ^{0}C**	**Max ^{0}C**
Kizimbani	April	425.3	23.8	32.3
	May	591.9	23.6	31.2
	June	45	21.9	29.8
	July	78.8	21.4	29.6
	August	40	23.5	33.4
Matangatuani	April	450.2	23.7	32.4
	May	500.8	23.6	31.2
	June	121.7	21.8	29.9
	July	89.8	21.5	29.5
	August	11.8	23.4	33.6

Sources; Kizimbani and Matangatuani meteorological stations

4.1.2 Soils properties

The soil physic-chemical properties for Kizimbani and Matangatuani are described in Table 2. Generally, the soil organic carbon at both sites was very low. According to Sahrawat (2010) soil organic carbon content of >2% would be rated as medium and be adequate for normal growth and yield. Based on soil organic carbon content for Kizimbani (0.83%) and Matangatuani (0.75%), these values are very low. Low percentage organic carbon content translates to low organic matter content in soils (Sahrawat, 2010).

Table 2: Physical and chemical properties of the top soils (0-30 cm) at the experimental sites (Kizimbani and Matangatuani)

Properties	Kizimbani-Unguja		Matangatuani – Pemba	
Particle size distribution (%)	Value	General rating	Value	General rating
Sand	57		71	
Silt	16		13	
Clay	27		16	
Textural class (USDA)		Sand clay loam		Sandy loam
pH (H_2O) (1:2.5)	5.7	Sufficient	5.4	Sufficient
O.C. (%)	0.83	Very low	0.75	Very low
O.M. (%)	1.93	Low	1.63	Low
P (mg kg^{-1})	6.8	Low	7.1	Medium
Total N (%)	0.11	Medium	0.08	Low
CEC (cmolc$_{(+)}$ kg^{-1})	18.75	Medium	20.3	High
Exchangeable base (cmolc$_{(+)}$ kg^{-1})				
Ca^{2+}	5.1	Medium	6.48	Medium
Mg^{2+}	1.83	Medium	0.2	Very low
K^{+}	0.72	High	0.71	High
DTPA Extractable (mg kg^{-1})				
Zn	0.75	Low	0.71	Low
Cu	0.7	Low	0.89	Medium
Fe	102	High	96	High

Rating according to Landon (1991, 2014); Howeler (1996).

4.2 Description of Crop Growth Characteristics, Yield and Yield Components Results under Intercropping

4.2.1 ANOVA results summary for cassava growth and yield characteristics under intercropping at Kizimbani and Matangatuani

Most of cassava characteristics except CMD, CBSD and CAW for Kizimbani site showed significant differences among the treatments; i.e. time of intercropping, fertilizer application and plant spacing. Highly significant difference was observed only on plant height with fertilizer treatment (P<0.001) (Table 3). Cassava root yield, plant height and canopy thickness were significantly different (P<0.01) due to fertilizers, time of intercropping and plant spacing. Cassava marketable roots and canopy thickness were significantly different (P<0.05) due to intercropping time of sweet potato and plant spacing. On the other hand, interaction of fertilizers and intercropping time showed also significant differences on cassava marketable roots and canopy thickness, respectively.

At Matangatuani, significant differences were also encountered in most characteristics except for CMD, CBSD and un-marketable cassava roots. Plant height and cassava root yield had greater significant differences on fertilizer and plant spacing (P<0.001) (Table 4). There were significant differences among spacings in canopy width and canopy length (P<0.01). In addition, significant differences also occurred on cassava marketable roots for fertilizer and plant spacing (P<0.05). Difference in canopy thickness was observed only on plant spacing while in crop establishment and plant height significant differences were noted on the interaction of fertilizers and time of intercropping.

Table 3: Summary of mean square (MS) and probability levels on cassava growth characteristics, yield and yield components at Kizimbani- Unguja

		Mean squares									
SOV	**DF**	**ESTB**	**PLANTH**	**CAL**	**CAW**	**CATH**	**CBSD**	**CMD**	**CASRY**	**MAKR**	**UN-MAKR**
REP	3	89.77	142.25	172.36	41.24	22.98	0.13	0.13	6.09	2695.90	2815.96*
TIME OF INTERCROPPING	1	59.27	5376.33**	2.80	0.18	9.01	0.18	0.02	35.67	9436.02*	438.02
ERROR A	3	30.86	151.39	43.49	12.98	9.21	0.02	0.24	5.45	881.24	145.46
FERTILIZER	1	3.71	3852.08***	846.72*	42.94	252.08**	0.02	0.02	63.74**	31.68	682.52
FERT x TIME	1	23.13	3.0	354.25	20.54	137.36*	0.18	0.02	1.16	414.18	229.68
ERROR B	6	20.20	48.49	76.40	54.89	15.89	0.15	0.24	4.18	470.93	361.99
SPACING	2	162.68**	423.15**	141.24	39.16	49.89	0.02	0.25	29.48**	1911.89*	347.27
SPA x TM	2	16.90	118.90	167.81	3.15	0.34	0.06	0.08	0.45	153.77	138.27
SPA x FERT	2	7.17	70.65	119.88	52.66	19.77	0.02	0.08	2.62	201.56	200.39
SPA x TM x F	2	3.01	1.56	137.03	38.10	47.72	0.06	0.08	3.84	43.93	15.06
ERROR C	24	18.74	59.42	51.93	28.09	22.98	0.09	0.15	3.83	422.40	249.33
TOTAL	47	29.76	277.83	99.75	31.83	29.30	0.095	0.16	6.92	812.74	421.11

***$P \leq 0.001$, **$P \leq 0.01$ and *$P \leq 0.05$

CASRY = Cassava root yield, CMD = Cassava mosaic disease severity, CBSD = Cassava brown streak disease severity, CAL = Canopy length, CAW = Canopy width, CATH = Canopy thickness, ESTB = Crop establishment, PLANTH = Plant height, MAKR = Marketable roots, UN-MAKR = Un-marketable roots

Table 4: Summary of mean square (MS) and probability levels on cassava growth characteristics, yield and yield components at Matangatuani - Pemba

		Mean squares									
SOV	**DF**	**ESTB**	**PLANTH**	**CAL**	**CAW**	**CATH**	**CBSD**	**CMD**	**CASRY**	**MAKR**	**UN-MAKR**
REP	3	114.52	142.25	55.74	90.69	6.83	0.020	0.076	11.57	1233.63	219.46
TIME OF INTERCROPPING	1	133.27	5376.33**	13.86	14.08	0.85	0.020	0.020	21.42	3536.33	595.02
ERROR A	3	13.56	151.39	91.90	40.87	18.81	0.187	0.076	5.12	3568.33	266.63
FERTILIZER	1	14.83	3852.08***	617.76**	133.33	241.20*	0.020	0.020	252.09***	8910.75*	475.02
FERT x TIME	1	408.33*	3.0	138.04	2.08	71.05	0.020	0.187	8.17	320.33	58.52
ERROR B	6	45.52	48.49	44.07	40.23	29.69	0.076	0.104	5.32	1254.65	98.99
SPACING	2	70.34	423.15**	236.94**	117.27**	90.81*	0.083	0.250	57.4*	2396.52*	117.00
SPA x TM	2	77.73	118.90	66.61	4.23	31.34	0.083	0.083	27.30	1081.02	121.08
SPA x FERT	2	28.68	70.65	60.19	48.38	42.29	0.083	0.083	28.56	3187.56**	69.08
SPA x TM x F	2	52.79	1.56	38.17	49.01	36.34	0.083	0.250	3.45	451.89	30.08
ERROR C	24	53.39	59.42	30.79	18.36	19.78	0.111	0.194	11.27	471.80	48.64
TOTAL	47	62.86	277.83	64.25	35.40	30.73	0.095	0.155	18.46	1282.08	106.86

****P≤ 0.001*, ***P≤0.01* and **P ≤0.05*

CASRY = Cassava root yield, CMD = Cassava mosaic disease severity, CBSD = Cassava brown streak disease severity, CAL = Canopy length, CAW = Canopy width, CATH = Canopy thickness, ESTB = Crop establishment, PLANTH = Plant height, MAKR = Marketable roots, UN-MAKR = Un-marketable roots

4.2.2 ANOVA results summary for effects of intercropped sweet potato growth and yield characteristics at Kizimbani and Matangatuani

With the exception of SPVD, the remaining sweet potato characteristics at Kizimbani showed significant differences at various probability levels (Table 5). Highly significant differences ($P<0.001$) were obtained from sweet potato yields, LER and plant vigour due to effect of plant spacing. Regarding sweet potato marketable and un-marketable tubers, significant differences were observed ($P<0.01$) on plant spacing.

The fertilizer treatments showed significantly differences in foliar cover and vigour. Significant differences were also observed on interaction between time of intercropping and spacing, and on the three ways interactions (time of intercropping x fertilizer x plant spacing) in sweet potato tuber yield and vigour ($P < 0.01$). Furthermore, sweet potato yields, marketable tubers, LER, plant establishment and foliage coverage showed significant differences among time of intercropping, fertilizers and plant spacings ($P<0.05$), whereas the interaction of spacing and planting time also showed significant differences ($P<0.05$).

At Matangatuani, all observed characteristics were significantly different at various probability levels and treatments as well as interactions. Sweet potato yield and LER were highly significantly different on plant spacing ($P<0.001$) (Table 6). Foliage cover and un-marketable tubers were significantly different between times of intercropping ($P<0.01$). In addition, interaction of fertilizers and plant spacing showed significant differences on sweet potato vigour and un-marketable tubers, while three way interactions (intercropping time x fertilizers and plant spacing) were significantly different on marketable root tubers and sweet potato weevils ($P < 0.01$). Furthermore, significant differences were observed ($P < 0.05$) on marketable and un-marketable tubers, crop establishment, foliage coverage, SPVD and LER due to the effects of intercropping time, spacing and fertilizer application.

Table 5: Summary of mean square (MS) and probability levels on sweet potato growth characteristics, yield and yield components at Kizimbani - Unguja

		Mean squares								
SOV	**DF**	**ESTB**	**FOLI**	**VIGO**	**SPVD**	**SPWE**	**SPY**	**MAKT**	**UNMAT**	**LER**
REP	3	4.19	0.90	0.68	0.61	0.55	3.63	8033	81.27	0.164
TIME OF INTERCROPPING	1	196.87*	6.02*	0.52	0.33	3.00	151.94*	42721.33	1518.75	0.050
ERROR A	3	11.74	0.18	0.35	0.16	0.55	12.39	6532.66	331.25	0.022
FERTILIZER	1	13.05	9.18**	11.02**	0.08	0.17	0.14	990.08*	75	0.103*
FERT x TIME	1	1.44	0.02	0.02	0.08	0.06	2.22	140.08	44.08	0.002
ERROR B	6	15.67	0.32	0.68	0.02	0.07	1.18	125.63	173.81	0.009
SPACING	2	11.14	0.52	2.25***	0.56	0.43*	19.10***	5057.89**	1106.89**	0.241***
SPA x TM	2	8.96	0.39	0.08	0.14	0.43*	8.29**	1038.52	57.93	0.022
SPA x FERT	2	7.45	0.18	0.08	0.27	0.06	0.92	573.89	148.56	0.006
SPA x TM x F	2	2.83	0.14	0.58**	0.02	0.06	0.99	1734.52	115.77	0.019
ERROR C	24	11.55	0.22	0.08	0.16	0.11	1.04	763.23	185.04	0.018
TOTAL	47	14.70	0.60	0.57	0.19	0.23	6.19	2626.16	238.67	0.038

****P≤ 0.001*, ***P≤0.01* and **P ≤0.05*

ESTB = Crop establishment, FOLI = Foliage cover, LER = Land equivalent ratio, MAKT = Marketable tubers, UNMAT = Un-marketable tubers, SPVD= Sweet potato virus diseases severity, SPWE = Sweet potato weevil severity, SPY = Sweet potato yield, VIGO = Plant vigour

Table 6: Summary of mean square (MS) and probability levels on sweet potato growth characteristics, yield and yield components at Matangatuani - Pemba

		Mean squares								
SOV	**DF**	**ESTB**	**FOLI**	**VIGO**	**SPVD**	**SPWE**	**SPY**	**MAKT**	**UNMAT**	**LER**
REP	3	12.98	0.31	0.11	0.08	0.24	1.06	134.27	30.57	0.008
TIME OF INTERCROPPING	1	83.53*	5.33**	3	0.75	0.52	14.31	901.33*	2200.52**	0.003
ERROR A	3	4.64	0.11	0.33	0.08	0.41	3.05	80.72	22.07	0.017
FERTILIZER	1	0.02	1.33*	8.33**	1.33	0.52	1.78	2.08	927.52*	0.092*
FERT x TIME	1	10.28	0.08	1.17	7.48	0.19	2.87	0.08	981.02*	0.001
ERROR B	6	30.43	0.21	0.28	0.67	0.19	2.52	32.36	80.93	0.009
SPACING	2	6.28	0.89*	1.02**	2.08*	0.25	11.70***	175.18*	33.39	0.269***
SPA x TM	2	22.46	0.65*	0.06	0.25	0.33	1.39	48.77	88.27*	0.033
SPA x FERT	2	9.75	0.02	0.02	0.33	0.08	0.02	26.39	211.39**	0.068
SPA x TM x F	2	25.12*	0.52	0.06	0.25	1.75**	1.55	215.89**	73.77	0.011
ERROR C	24	7.31	0.19	0.13	0.48	0.22	0.86	34.95	23.40	0.023
TOTAL	47	13.44	0.38	0.42	0.50	0.31	2.05	74.77	130.38	0.033

***$P \leq 0.001$, **$P \leq 0.01$ and *$P \leq 0.05$

ESTB = Crop establishment, FOLI = Foliage cover, LER = Land equivalent ratio, MAKT =Number of marketable tubers, UNMAT = Number of Un-marketable tubers, SPVD= Sweet potato virus diseases severity, SPWE = Sweet potato weevil severity, SPY = Sweet potato yield, VIGO = Plant vigour

4.2.3 Summary of combined analysis results for intercropped cassava plant growth and yield characteristics at Kizimbani and Matangatuani

Results of combined analysis of cassava revealed that plant spacing and fertilizer application contributed to highly significant differences on cassava root yield and plant height (P<0.001)(Table 7), whereas time of intercropping slightly influenced plant height (P<0.01). Also, marketable roots, canopy length and plant height showed significant differences, also due to fertilizer effects (P<0.01). Crop establishment in both sites were not significantly different probably indicating moisture availability for crop establishment and development. Furthermore, significant differences were not revealed in canopy width, CMD, CBSD and un-marketable roots for all treatments.

4.2.4 Summary of combined analysis results for intercropped sweet potato on growth and yield characteristics at Kizimbani and Matangatuani

From the results plant spacing increased significantly (P< 0.001). Higher significant differences were in sweet potato yields and land LER (Table 8). Similarly, to fertilizer effects on foliage cover. The SPVD, vine vigour, marketable and un-marketable tubers indicated significant differences due to plant spacing (P<0.01). Also fertilizer application showed significant differences on LER (P<0.01) and sweet potato plant vigour (P<0.05). Additionally, there were significant interactions (P < 0.01) between plant spacing and intercropping time on sweet potato yield. At 5% probability level, fertilizer treatments contributed significantly to variation in marketable and un-marketable root tubers. Similarly, sweet potato weevils and foliage cover were significantly affected by plant spacing at the same probability level. The interactions between plant spacing and intercropping time as well as fertilizer and plant spacing had significant effects on crop establishment and un-marketable tubers (P<0.05). In addition, intercropping time had significant effects on sweet potato yield and crop establishment (P<0.05) (Table 8).

Table 7: Summary of mean square (MS) and probability levels of the combined analysis for the two sites on cassava growth characteristics, yield and yield components

SOV	DF	ESTB	PLANTH	CAL	CAW	CATH	CBSD	CMD	CASRY	MAKR	UN-MAKR
	Mean squares										
REP	3	176.50**	35.73	114.85	100.16	22.10	0.069	0.153	9.183	2973.9	1550.1
TIME OF INTERCROPPING	1	7.39	10147.59**	14.57	8.76	7.71	0.042	0.000	56.192	12262.8	6.0
Residual	3	3.70	222.45	56.41	36.53	20.51	0.069	0.0056	9.794	3083.2	178.7
FERTILIZER	1	1.85	6851.26**	1455.48**	163.80	493.23*	0.042	0.042	284.684***	5002.6**	1148.2
FERT x TIME	1	118.55	11.34	467.28	17.85	203.00	0.042	0.167	1.581	3.0	260.0
Residual	6	34.86	37.39	97.25	72.48	42.08	0.069	0.076	6.604	313.7	262.4
SPACING	2	16.99	1087.70***	370.69*	87.85	125.12*	0.073	0.000	83.812***	3726.4**	58.1
SPA x TM	2	73.69	4.59	217.13	0.87	12.68	0.073	0.000	12.377	324.3	213.8
SPA x FERT	2	20.93	43.45	103.70	88.28	59.41	0.010	0.042	20.191	2295.5*	17.3
SPA x TM x F	2	32.76	6.84	157.63	86.61	70.91	0.010	0.292	7.284	119.0	2.6
Residual	24	33.33	55.52	67.75	33.63	36.25	0.111	0.153	7.689	437.9	125.8
SITE	1	90.75	3838.01***	1057.35***	148.50**	301.04***	0.000	0.000	482.770***	36231.5***	32.7
RESIDUAL	47	50.78	40.52	28.70	16.82	7.05	0.104	0.192	6.849	802.0	277.4
TOTAL	95	46.774	288.097	92.267	34.827	32.873	0.094	0.154	17.637	1417.77	261.558

****P≤ 0.001*, ***P≤0.01* and **P ≤0.05*

CASRY = Cassava root yield, CMD = Cassava mosaic disease severity, CBSD = Cassava brown streak disease severity, CAL = Canopy length, CAW = Canopy width, CATH = Canopy thickness, ESTB = Crop establishment, PLANTH = Plant height, MAKR = Marketable roots, UN-MAKR = Un-marketable roots

Table 8: Summary of mean square (MS) and probability levels of the combined analysis for the two sites on sweet potato growth characteristics, yield and yield components

		Mean squares								
SOV	**DF**	**ESTB**	**FOLI**	**VIGO**	**SPVD**	**SPWE**	**SPY**	**MAKT**	**UNMAT**	**LER**
REP	3	11.92	0.566	29.1	0.403	0.594	1.865	4591.0	29.1	0.116
TIME OF INTERCROPPING	1	268.44*	11.344**	31.5	1.042	3.010	129.758*	28017.0	31.5	0.039
Residual	3	14.22	0.177	107.8	0.125	0.955	7.365	4022.0	107.8	0.029
FERTILIZER	1	5.96	8.760***	765.0*	1.042	0.260	1.468	542.0*	765.0*	0.196**
FERT x TIME	1	2.01	0.094	720.5*	0.042	0.094	1.438	67.0	720.5*	0.000
Residual	6	2.01	0.177	91.2	0.431	0.094	1.623	49.0	91.2	0.010
SPACING	2	16.35	1.385*	667.4**	2.260**	0.594*	28.804***	2107.0**	667.4**	0.510***
SPA x TM	2	29.88*	0.031	4.8	0.385	0.510	6.984**	730.0	4.8	0.000
SPA x FERT	2	2.12	0.135	127.6	0.0.010	0.010	0.441	283.0	127.6	0.058
SPA x TM x F	2	16.61	0.281	46.9	0.135	0.594	0.554	525.0	46.9	0.025
Residual	24	8.60	0.264	92.3	0.379	0.163	0.842	340.0	92.3	0.021
SITE	1	0.72	7.594***	3208.6	1.042*	0.094	20.403**	1380.0	3208.6***	0.537***
RESIDUAL	47	10.47	0.275	233.2	0.254	0.200	2.627	1207.0	233.2	0.020
TOTAL	95	13.936	0.568	216.36	0.357	0.267	4.292	1350.779	216.36	0.041

****P≤ 0.001*, ***P≤0.01* and **P ≤0.05*

ESTB = Crop establishment, FOLI = Foliage cover, LER = Land equivalent ratio, MAKT =Number of marketable tubers, UNMAT = Number of Un-marketable tubers, SPVD= Sweet potato virus diseases severity, SPWE = Sweet potato weevil severity, SPY = Sweet potato yield, VIGO = Plant vigour

4.3 Effect of Time of Intercropped Cassava on Growth Characteristics, Yield and Yield Components at Kizimbani

The results (Table 9) indicated that time of intercropping had significant effects on plant height ($P<0.01$) and number of marketable roots ($P<0.05$). The highest value of 275.8 cm plant height was obtained from cassava planted 2 weeks (CSSP-2WAP -1-NPK1) before intercropping with sweet potato. This indicated that cassava planted earlier before sweet potato intercropping initiated vigorous plant growth before competing with its associate crop. Duncan's multiple range mean comparison test ($P<0.05$) indicated significant effects between cassava planted with sweet potato on the same day and that planted 2 weeks before sweet potato. This is because when planted simultaneously, both crops built up earlier competition, whereas sweet potato becomes more aggressive (Kapinga *et al.*, 1994).

Based on the results it could be concluded that, the more delayed the planting of sweet potato, the higher the chances for cassava to grow well. On the other hand, earlier intercropped sweet potato initiated faster vine growth than cassava and may reach full coverage of the ground surface 6 weeks after planting (Eneji *et al.,* 1995). This growth characteristic makes sweet potato more competitive than cassava and hence affects cassava growth and development. Time of intercropping had significant effects on number of marketable cassava roots (root quality and quantity), where the highest mean of 164.2 was obtained from cassava sole crop (CS 2WAP- 1- NPK 0) (Table 9). This implied that cassava got ample time to initiate growth before competing with sweet potato. Cassava planted simultaneously with sweet potato encountered low average number of marketable roots (68.2). From this observation, in order to have more quality cassava roots in intercropping with sweet potato, one to 2 weeks delay sweet potato planting will be better.

Table 9: Effect of treatment interactions on intercropped cassava growth characteristics, yield and yield components at Kizimbani

Treatments	Plant height (cm)	Canopy length (cm)	Canopy width (cm))	Canopy thickness (cm)	Cassava root yield (t/ha)	Marketable roots (no)
CSSP-0WAP-1-NPK0	237.5b	117.4cd	76.45a	70.40a	12.31ab	94.3abc
CSSP-0WAP-2-NPK0	234.8ab	103.1ab	71.80a	74.05ab	10.22a	68.2a
CSSP-0WAP-3-NPK0	225.8a	100.2a	73.25a	73.65ab	10.40a	70.2a
CSSP-0WAP-1-NPK1	260.8def	121.0cde	72.95a	83.10b	15.43bcd	97.5abc
CSSP-0WAP-2-NPK1	251.0cd	127.5def	81.65a	82.50b	13.59abc	86.8ab
CSSP-0WAP-3-NPK1	241.5bc	113.8bc	76.50a	76.40ab	11.77ab	71.0a
CSSP-2WAP-1-NPK0	253.5cd	113.2bc	74.10a	75.20ab	15.12bcd	122.5bcd
CSSP-2WAP-2-NPK0	257.5de	112.7bc	77.10a	78.60ab	12.46ab	111.0abc
CSSP-2WAP-3-NPK0	252.0cd	109.8abc	74.60a	71.85a	11.46ab	101.0abc
CSSP-2WAP-1-NPK1	275.8g	113.8bc	74.55a	76.80ab	15.50bcd	112.5abc
CSSP-2WAP-2-NPK1	271.5fg	112.8bc	78.65a	76.65ab	15.56bcd	112.0abc
CSSP-2WAP-3-NPK1	268.0efg	117.9cd	74.35a	75.80ab	13.96abcd	97.2abc
CS-0WAP-1-NPK0	251.8cd	131.2ef	99.25b	129.50c	15.53bcd	101.8abc
CS-0WAP-1-NPK1	259.5def	139.5f	115.0c	143.50d	21.48e	143.0cd
CS-2WAP-1-NPK0	239.2b	129.5def	112.50c	130.25	17.29cd	164.2d
CS-2WAP-1-NPK1	261.0 def	137.8f	125.0d	143.50d	18.22de	141.8cd
G. Mean	252.56	118.82	84.86	91.36	14.39	105.9
SEx	5.528	5.468	4.135	4.018	1.885	20.93
CV (%)	3.1	6.5	6.9	6.2	18.5	27.9
P. Value	< 0.001	< 0.001	< 0.001	<0 0.001	< 0.001	< 0.001

Means within columns with same letter (s) are not significantly different according to DMRT at $*P \leq 0.05$

CS- Cassava sole crop, CSSP - Cassava sweet potato intercrop, 0WAP- Week of planting sweet potato, NPK0- No fertilizer applied, NPK1- With recommended fertilizer applied. 1- Low plant density of sweet potato (1 x1m), 2- Medium plant density of sweet potato (1 x0.5m), 3-High plant density of sweet potato (1 x 0.33m).

4.3.1 Effect of fertilizer application on intercropped cassava plant characteristics at Kizimbani

Table 9 presents results of fertilizer application on intercropping cassava with sweet potato plant characteristics at Kizimbani site. There were significant differences among plots applied with fertilizers and those without fertilizers in terms of cassava root yields, canopy length, canopy thickness and plant height. The highest mean values were obtained from fertilizer applied plots. The highest means for intercropped cassava were 15.56 t ha^{-1}, 117.9 cm, 83.1 cm and 275.8 cm for cassava root yields, canopy length, canopy thickness and plant height, respectively. However, in cassava sole crop, the highest values were 21.48 t ha^{-1}, 139.5cm, 143.5 and 261.0 cm for cassava root yields, canopy length, canopy thickness and plant height, respectively. The differences of cassava root yield between intercropping and sole cropping both applied with fertilizers was 5.92 t ha^{-1}, greater in sole crop. On the other hand, plots without fertilizers had values lower than the grand mean.

4.3.2 Effect of sweet potato plant spacing in intercropped cassava plant characteristics at Kizimbani

The results showed that there were significant differences between plant spacing in cassava root yield. Cassava plant spacing of 1.0 x 0.5 m in intercropping had the highest mean yield of 15.56 t ha^{-1} whereas cassava sole crop (1 x 1 m) produced the highest mean yield of21.48 t ha-[1]. Regarding crop establishment, plant spacing had no significant influence; whereas mean crop establishment was 94.4% at 1 x 1 m; it was 94.58 % at 1 x 0.5 m. Similarly, plant height was significantly influenced by plant spacing. At 1 x 0.33 m plant height was the lowest with mean value of 225.8 cm below the grand mean (252.56 cm), compared with 1 x1m (275.8 cm) for intercropped and 261cm for sole crop (Table 9). Regarding number of marketable roots, significant differences were observed among plant spacings; where 1 x 1m was the highest (122.5) followed by 1 x 0.5 m (112).

4.4 Effect of Time of Intercropped Cassava on Growth Characteristics, Yield and Yield Components at Matangatuani

There were no significant differences between times of intercropping in crop characteristics with the exception of plant height. Cassava planted 2 weeks before intercropping with sweet potato gave the highest plant with mean value of268.2 cm compared with cassava intercropped simultaneously with sweet potato that had plant height of 241.5 cm; which was below grand mean (243.5 cm). Differences in plant height of cassava intercropped with sweet potato (2 weeks before sweet potato and simultaneously) were significant compared to plant height in sole cropping (Table 10).

Table 10: Effect of treatment interactions on intercropped cassava growth characteristics, yield and yield components at Matangatuani

Treatments	Crop establishment (%)	Plant height (cm)	Canopy width (cm)	Canopy thickness (cm)	Cassava root yield (t/ha)	Marketable root (no)
CSSP-0WAP-1-NPK0	95.00bcde	228.2bc	80.40a	75.60a	16.85bc	133.8abcd
CSSP-0WAP-2-NPK0	91.67abcde	221.5ab	73.20a	79.95ab	14.09ab	101.5ab
CSSP-0WAP-3-NPK0	97.50cde	218.8a	73.10a	73.85a	14.32ab	108.5abc
CSSP-0WAP-1-NPK1	85.84ab	241.5def	79.40a	89.60b	18.53cd	126.5abcd
CSSP-0WAP-2-NPK1	94.17bcde	235.5cde	83.80a	83.20ab	19.01cd	133.2abcd
CSSP-0WAP-3-NPK1	90.00abcde	233.5cd	74.75a	77.35ab	19.00cd	150.2cde
CSSP-2WAP-1-NPK0	86.67ab	249.5fgh	77.85a	79.30ab	21.19cd	166.5def
CSSP-2WAP-2-NPK0	81.67a	242.0defg	76.80a	79.65ab	13.93ab	97.8a
CSSP-2WAP-3-NPK0	88.34abcd	231.25c	76.55a	76.95ab	11.67a	115.5abc
CSSP-2WAP-1-NPK1	94.17bcde	268.2j	83.70a	81.60ab	22.52d	164.2def
CSSP-2WAP-2-NPK1	87.50abc	256.8hi	80.55a	80.30ab	20.80cd	163.2def
CSSP-2WAP-3-NPK1	95.84bcde	251.0ghi	75.70ab	80.15ab	19.69cd	149.5cde
CS-0WAP-1-NPK0	100.0e	248.5fgh	95.50b	139.50cd	19.88cd	126.5abcd
CS-0WAP-1-NPK1	97.50cde	266.2j	119.25c	156.25e	27.03e	187.2ef
CS-2WAP-1-NPK0	97.50cde	243.2efg	104.50b	133.25c	21.80d	145.5bcde
CS-2WAP-1-NPK1	98.33de	259.5ij	122.00c	146.00de	27.80e	195.5f
G. Mean	92.60	243.45	86.07	95.78	19.26	141.6
SE_X	4.433	4.157	4.842	5.455	1.968	19.24
CV (%)	6.8	2.4	8.0	8.1	14.5	19.24
P. Value	0.003	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

Means within columns with same letter (s) are not significantly different according to DMRT at *$P \leq 0.05$*

CS- Cassava sole crop, CSSP - Cassava sweet potato intercrop, WAP- Week after planting sweet potato, NPK0- No fertilizer applied, NPK1- With recommended fertilizer applied. 1- Low plant density of sweet potato (1 x1 m), 2- Medium plant density of sweet potato (1 x 0.5 m), 3-High plant density of sweet potato (1 x 0.33 m)

4.4.1 Effect of fertilizer application on intercropped cassava plant characteristics at Matangatuani

Fertilizer application (NPK1) on cassava intercropped (CSSP) led to higher mean value of plant growth characteristics, yield and components than those without fertilizer (CSSP-NPK0). The highest mean values in intercropping were 22.52 t ha^{-1} (cassava root yield), 83.8 cm (canopy width), 89.6 cm (canopy thickness) and 268.2 cm (plant height).Regarding sole cropping the highest mean yield of cassava root was (27.8 t ha^{-1}) (Table 10). In contrast, the lowest mean values for the characters were 11.67 t ha^{-1} (cassava root yield), 73.1 cm, 73.85 cm (canopy width) and 218.8 cm (plant height).

4.4.2 Effect of sweet potato plant spacing in intercropped cassava plant characteristics at Matangatuani

Results presented in Table 10 indicate that plant spacing had significant differences in cassava root yields, canopy length, canopy width, canopy thickness, plant height and number of marketable roots. Intercropping of 1 x 1m spacing gave higher and significant mean differences among the characteristics with regard to canopy thickness. There was no significant difference observed on yield between spacings of 1 x 1m and 1 x 0.5m; however, significant difference was observed with 1 x 0.33m. For cassava root yield and number of marketable roots, no significant differences were observed between 1 x 0.5 m and 1 x 0.33m plant spacing, although 1 x1m was significant ($P<0.05$). Overall, 1 x 0.33m spacing showed significantly lower mean effects, which were below the grand mean of various characteristics analyzed.

4.5 Effect of Time of Intercropped Sweet Potato on Growth Characteristics, Yield and Yield Components at Kizimbani

The results (Table 11) showed that there were significant differences between time of intercropping of sweet potato on yield, percent crop establishment and foliage cover. The highest mean in intercropping was obtained from sweet potato crop planted with cassava on the same day with mean values of 18.7 t ha^{-1}(sweet potato tuber yield), 99.17% (plant establishment) and 4.75(foliage cover).

For the sole crop, the highest mean tuber yield was 24.06 t ha^{-1}. The difference between sole and intercrop tuber yield was5.36 t ha^{-1}greater with sole crop. On other hand, the lowest mean values were observed from sweet potato planted two weeks (2WAP) after cassava with minimum mean values of 12.2 t ha^{-1}, 91.25% and 3.00, which were less than the grand means of 16.63 t ha^{-1}, 96.4% and 4.031 in sweet potato yields, crop establishment and foliage cover, respectively. Thus, the more the delay in sweet potato planting in the cassava intercrop plots, the higher the set back of sweet potato growth but room for cassava to grow was best.

Table 11: Effect of treatment interactions on intercropped sweet potato growth characteristics, yield and yield components at Kizimbani

Treatments	Crop establishment (%)	Foliage cover (1-5)	Vigour (1-5)	Sweet potato yield (t/ha)	Marketable tubers (no)	Un-markt tubers (no)
CSSP-0WAP-1-NPK0	98.34bc	3.25ab	4.00bcde	18.03de	89.3abcd	31.5ab
CSSP-0WAP-2-NPK0	98.75bc	4.00d	3.75abcd	16.56cd	136.8def	49.0abc
CSSP-0WAP-3-NPK0	98.61bc	4.25d	3.00a	14.60bc	115.0bcde	60.0cd
CSSP-0WAP-1-NPK1	99.17c	4.5d	5.00f	18.73e	91.8abcd	40.0abc
CSSP-0WAP-2-NPK1	96.25abc	4.75d	4.25cdef	15.83c	124.5cde	49.2abc
CSSP-0WAP-3-NPK1	96.11abc	4.75d	4.25cdef	14.97bc	162.2ef	49.5abc
CSSP-2WAP-1-NPK0	94.17abc	3.00a	3.50abc	13.54ab	50.2a	32.5ab
CSSP-2WAP-2-NPK0	93.33ab	3.25abc	3.25ab	12.78ab	55.0a	33.0ab
CSSP-2WAP-3-NPK0	95.00abc	3.00a	3.25ab	12.20a	67.0abc	47.0abc
CSSP-2WAP-1-NPK1	94.17abc	4.00d	4.75ef	13.10a	47.5a	24.7a
CSSP-2WAP-2-NPK1	91.25a	4.00bcd	4.50def	12.75ab	76.8abc	36.0abc
CSSP-2WAP-3-NPK1	95.00abc	4.00bd	3.75abcd	13.00ab	65.0ab	38.5abc
SP-0WAP-3-NPK0	97.22bc	4.5d	4.0bcde	20.88f	165ef	54bcd
SP-0WAP-3-NPK1	99.17c	4.75d	4.0bcde	24.06g	191f	75d
SP-2WAP-3-NPK0	97.78bc	4.0d	3.75abcd	21.15f	164.5ef	60cd
SP-2WAP-3-NPK1	98.06bc	4.5d	3.978bcde	23.87g	159.5ef	50.25abcd
G. Mean	96.4	4.031	3.936	16.63	110.1	45.6
SE_X	2.300	0.332	0.349	0.879	25.36	11.13
CV (%)	3.4	11.7	12.6	8.3	32.6	34.5
P. Value	0.025	< 0.001	< 0.001	< 0.001	< 0.001	0.005

Means within columns with same letter (s) are not significantly different according to DMRT at **P≤ 0.05*

Un-markt = Number of un-marketable tubers, CSSP - Cassava sweet potato intercrop, SP-Sweet potato sole crop, WAP- Week after planting sweet potato, NPK0- No fertilizer applied, NPK1- With recommended fertilizer applied. 1- Low plant density of sweet potato (1 x1 m), 2- Medium plant density of sweet potato (1 x 0.5 m), 3-High plant density of sweet potato (1 x 0.33 m)

4.5.1 Effect of fertilizer application on intercropped sweet potato plant characteristics at Kizimbani

The effects of fertilizer application at Kizimbani were statistically significant in terms of number of marketable tubers, foliage cover and vigour. The plots with fertilizers had higher mean values of 162.2 (number of marketable tubers), 4.75 (foliage cover) and 5 (plant vigour) (Table 11).

4.5.2 Effect of plant spacing on intercropped sweet potato plant characteristics at Kizimbani

The results (Table 11) showed that there were significant differences in sweet potato yield, marketable and un-marketable tubers and plant vigour due to the plant spacing treatments. For sweet potato yield and vigour, the highest means were obtained from 1 x 1m (CSSP SP1) spacing with values of 18.73 t ha^{-1} and 5.00 for yield and plant vigour, respectively. In addition, lowest mean values were observed from CSSP SP2 and CSSP SP3 gradually with mean values below the grand mean. However, regarding number of marketable and un-marketable tubers, the highest mean values were obtained from CSSP SP3 followed by CSSP SP2. This observation could imply that closer spacing would result into large number of root tubers but low in weight. On the other hand, whenever the vines are closely planted the numbers may increase but the tuber size decreases and thus has negative significant difference.

4.6 Effect of Time of Intercropping Cassava and Sweet Potato on Growth Characteristics, Yield and Yield Components at Matangatuani

Planting time of intercrops had significant influence ($P < 0.05$) on crop establishment and marketable tubers of sweet potato. Under CSSP-0WAP treatment, the highest number of marketable tubers was 93.5 whereas the highest mean of crop establishment was 99.17%. Highly significant effect ($P < 0.01$) was also observed from CSSP-0WAP on foliage cover (Table 12). On the other hand, the CSSP- 2WAP influenced significantly ($P < 0.01$) the number of un-marketable tubers. These observations probably mean that, late planting of intercropped sweet potato in cassava established field affects sweet potato growth and development leading to poor tuber formation. Also delayed planting caused poor foliage coverage and plant vigour.

Table 12: Effect of treatment interactions on intercropped sweet potato growth characteristics, yield and yield components at Matangatuani

Treatments	Crop establishment (%)	Foliage cover (1-5)	Vigour (1-5)	Sweet potato yield (t/ha)	Marketable tubers (no)	Un-markt tubers (no)
CSSP-0WAP-1-NPK0	97.50cd	4.50cde	4.00bcd	14.82bcd	88.00de	53.50cd
CSSP-0WAP-2-NPK0	98.33cd	5.00e	4.00bcd	14.02abc	87.50cde	37.75a
CSSP-0WAP-3-NPK0	94.72abcd	4.50cde	3.75bc	12.75a	84.50bcde	45.50abc
CSSP-0WAP-1-NPK1	99.17d	5.00e	5.00f	15.28cd	85.25cde	43.00abc
CSSP-0WAP-2-NPK1	97.08bcd	4.75de	4.75ef	15.67d	93.50ef	48.00abcd
CSSP-0WAP-3-NPK1	97.22bcd	5.00e	4.50def	13.27ab	82.25abcde	46.50abcd
CSSP-2WAP-1-NPK0	97.50cd	3.50a	3.75bc	13.73abc	77.50abcd	68.25e
CSSP-2WAP-2-NPK0	92.08a	4.00abc	3.50ab	13.64abc	84.00bcde	68.25e
CSSP-2WAP-3-NPK0	95.83abcd	4.25bcd	3.00a	12.41a	72.25a	68.00e
CSSP-2WAP-1-NPK1	92.50ab	3.75ab	4.50def	13.86abc	86.00cde	44.50abc
CSSP-2WAP-2-NPK1	94.17abc	4.75de	4.25cde	12.88a	73.50ab	50.50bcd
CSSP-2WAP-3-NPK1	96.11abcd	4.50cde	4.00bcd	12.73a	75.75abc	56.00d
SP-0WAP-3-NPK0	98.89cd	5e	4.25cde	15.83d	103.50fg	43.00abc
SP-0WAP-3-NPK1	99.17cd	5e	4.75ef	17.94e	119h	43.50abc
SP-2WAP-3-NPK0	98.89cd	5e	3.75bc	15.81d	112.25gh	51.25bcd
SP-2WAP-3-NPK1	99.17cd	5e	4bcd	18.03e	106.50g	42.75ab
G. Mean	96.77	4.594	4.109	14.54	89.45	50.64
SE_X	2.08	0.264	0.299	0.740	5.089	4.503
CV (%)	3.0	8.2	10.3	7.2	8.0	12.6
P. Value	0.008	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

Means within columns with same letter (s) are not significantly different according to DMRT at *$P \leq 0.05$*

Un-markt = Number of un-marketable tubers, CSSP - Cassava sweet potato intercrop, SP- Sweet potato sole crop, WAP- Week after planting sweet potato, NPK0- No fertilizer applied, NPK1- With recommended fertilizer applied. 1- Low plant density of sweet potato (1 x1 m), 2- Medium plant density of sweet potato (1 x 0.5 m), 3-High plant density of sweet potato (1 x 0.33 m).

4.6.1 Effect of fertilizer application on intercropped sweet potato crop characteristics at Matangatuani

Results in Table 12 showed that CSSP NPK0 treatment had greater mean value of number of un-marketable tubers (56.88). This suggests that fertilizer application had an effect on tuber quality. In view of this, it is expected that crop yield obtained from fertilizer applied sole crop exceeded that from fertilizer applied intercropped due to inter and intra-specific competition. This probably resulted into low ratio of the particular crop. On foliage cover and plant vigour, the highest mean value from fertilizer treated plots was 5.00 for both characteristics.

4.6.2 Effect of plant spacing on intercropped sweet potato plant characteristics at Matangatuani

There were significant differences among plant spacing on intercropping sweet potato with cassava plant characteristics (Table 12). Highly significant differences ($P<0.001$) were recorded from sweet potato yield. Sweet potato yield, number of marketable tubers and plant vigour were significantly influenced by plant spacing. However, low plant densities (CSSP SP1 and CSSP SP2) had no significant influence whereas high plant density (CSSP-SP3) led to low mean values of sweet potato yield (12.73 t ha^{-1}). This indicated that close intra-row spacing affect crop yield as well plant vigour. The CSSP SP1 and CSSP SP2 gave greater values of 14.82 t ha^{-1} and 15.67 t ha^{-1}, respectively, for sweet potato yield (Table 12). Significant differences were also observed on plant vigour ($P< 0.01$) with greater recorded values of 5.00 and 4.75 from CSSP SP1 and CSSPSP2.In addition, foliage cover gave the highest mean values of 5.00 with CSSP SP2 and 5.00 for CSSP SP3, which was not significantly different.

4.6.3 Effect of treatment interactions on intercropped cassava plant characteristics at Kizimbani

Table 9presents results of the three ways interactions (time of intercropping x fertilizer application x plant spacing).The findings showed the impact of treatment association on cassava growth characteristics, yield and yield components. The results from mean comparisons using Duncan's Multiple Range (DMR) revealed significant differences among treatments in various cassava growth characteristics, yield and yield components, with the exception of CBSD, CMD and un-marketable roots. Regarding cassava root yield, most treatments differed significantly based on mean ranks. Overall, CSSP-2WAP-2-NPK1, CSSP-2WAP-1-NPK1, CSSP-0WAP-1-NPK1 andCSSP-2WAP-1-NPK0 were the most highly significant with greater mean values of 15.56, 15.50, 15.43 and 15.12 t ha^{-1}, respectively. These values exceeded the grand mean of 13.15; however, treatment CSSP-0WAP-2-NPK0 had the lowest value of 10.22.Means of the remaining treatments except CSSP-2WAP-3-NPK1 (13.96) andCSSP-0WAP-2-NPK1(13.59) were also below the grand mean henceforth excluded from the acceptable level of performance (Table 3). Cassava sole crop applied with fertilizers (CS-0WAP-1-NPK1) had the highest mean (21.48 t ha^{-1}) of root yield compared with all treatments of intercropping. This indicates that cassava planted 2 weeks delay before introducing sweet potato leads to higher probability for cassava to sprout vigorously, which affects growth initiation of sweet potato.

On the other hand, the highest mean yield (15.56 t ha^{-1}) of plots applied with fertilizers (CSSP-2WAP-2-NPK1) exceeded the control value of 10.22 t ha^{-1}, which is an increase of 20.72% of cassava root yield. Plant height in half of the treatments was in the range above the grand mean (252.5 cm), but the shortest plants (225.8 cm) resulted from CSSP-0WAP-3-NPK0. In addition, the highest mean value of275.8 cm obtained from treatment CSSP-2WAP-1-NPK1was highly significant compared to the others (Table 9).

With regard to crop establishment, the CSSP-2WAP-1-NPK1and CSSP-2WAP-1-NPK0 gave highest values (96.67%) followed byCSSP-2WAP-2-NPK0 (95.84%). Three treatments, i.e. CSSP-0WAP-2-NPK1, CSSP-2WAP-2-NPK1 and CSSP-0WAP-2-NPK0 gave mean values of 95.00%, 94.17% and 93.34% within the range above the grand mean

(92.64%). These treatments indicated acceptable level of performance. The remaining treatments were below the average mean, whereby CSSP-2WAP-3-NPK1 gave the lowest mean value of 87.5% compared with the other treatments. There was no significant difference on disease infection; CBSD and CMD, as cassava variety used was tolerant to these diseases and hence no significant symptoms were detected. The number of marketable roots was highest (122.5) with CSSP-2WAP-1-NPK0; however, many treatments showed significant variations with mean values above the average mean (95.4). Regarding canopy dimensions, significant differences were observed on canopy thickness rather than canopy length and width.

The highest mean of 83.1 cm canopy thickness in intercropping was observed with CSSP - 0WAP -1`-NPK1 and the lowest (70.4 cm) was obtained from CSSP -0WAP -1-NPK0, which was below the grand mean value of 76.3 cm. Half of the remaining treatments were within the range above grand mean while the others were below (Table 9). On canopy width, most of the treatments were within the range of significant level and hence, statistically there were no differences except treatment CSSP- 0WAP - 2-NPK0, which gave the lowest value (71.8 cm) below the grand mean (75.5 cm) and CSSP - 0WAP-2- NPK1 accounted for the highest mean (81.7 cm). Similarly, regarding canopy length, the treatments were mostly found within the same mean ranks, although some showed statistical significance. Greater mean value (127.4 cm) was recorded with CSSP- 0WAP-2-NPK1 and the lowest (100.2 cm) was with CSSP - 0WAP-3- NPK0, which was below the grand mean of 118.82 cm (Table 9).

4.6.4 Effect of treatment interactions on intercropped cassava plant characteristics at Matangatuani

The results (Table 10) indicate that there were significant differences among the treatments on cassava characteristics and other components. With regard to disease infections (CMD and CBSD), there were no significant differences. Cassava root yield showed large variations among treatments with the highest yield of 22.52 t ha^{-1} in CSSP-2WAP-1-NPK1 and sole crop (27.03 t $ha-^{1}$) from CS-0WAP-1-NPK1. The lowest root yield was 11.67 t ha^{-1} obtained from CSSP- 2WAP-3-NPK0, which was below the grand mean (17.63 t ha^{-1}). There was an increase of 31.74% in cassava root yield following application of fertilizers, which gave the highest compared with the lowest yield from plots without fertilizers.

Overall, most fertilizer applied plots showed significant differences. Similarly, the highest mean of 268.3 cm for plant height was recorded with CSSP-2WAP-1-NPK1 and the lowest (221.5 cm) with CSSP-0WAP-2-NPK0. From the observations, it is obvious that fertilizer application not only increased root yield but also plant height compared with without fertilizers. Regarding number of marketable roots in intercropping system, the highest yield (166.5) was observed with CSSP-2WAP-1- NPK0 and lowest (97.8) with CSSP-2WAP-2-NPK0 (Table 10). The number of un-marketable roots, lowest was with CSSP-2WAP-1-NPK1 (26.5), which indicated that applying fertilizer always increased root quantity. On the other hand, the highest number (48.5) of un-marketable roots was observed with CSSP-0WAP-3-NPK0. This observation might mean that, there was insufficient nutrients availability in the soil. In addition, significant difference was also observed from crop establishment. Although six out of 12treatments were below the grand mean (90.70%).

There were also significantly different means through others e.g. CSSP-2WAP-2-NPK0 gave the lowest value of 81.7% whereas CSSP-0WAP-3-NPK0 had the highest mean value of 97.5%. However, most treatments were well established based on treatment mean ranks. There were no significant differences with regard to canopy dimensions, particularly canopy width and thickness. The highest mean of 89.6 cm for canopy thickness in intercropping was from CSSP-0WAP-1-NPK1, whereas for sole crop the highest was 156.25 cm. The lowest value of canopy thickness (73.85 cm) was from CSSP - 0WAP-3-NPK0 (Table 10).

4.6.5 Effect of treatment interactions on intercropped sweet potato plant characteristics at Kizimbani

Treatment interactions on sweet potato characteristics and other components were observed to be significant in almost all treatments. Sweet potato tuber yield in intercropping was highest (18.73 t ha^{-1}) under CSSP- 0WAP-1-NPK1. Sweet potato sole crop with fertilizer application (SP-0WAP-1-NPK1) gave higher tuber yield (24.06 t ha^{-1}) compared with intercropping. The lowest value of 12.20 t ha^{-1} was from without fertilizer applied and under high plant density planted 2 weeks after first intercropping (CSSP-2WAP-3- NPK0).

The differences between the highest and lowest yield was 21.11% (Table 11). This result highlighted fertilizer application as an important management option in sweet potato cropping system. The effect of planting density and intercropping time was reduced yield in high plant density (33 333 plants ha^{-1}) established 2 weeks after cassava. The highest performance was from low plant density (10 000 plants ha^{-1}) planted same time as cassava .Higher plant density reduces tuber yield due to intra-specific competition for growth resources including nutrients, water and light. Overall, seven treatments out of twelve based on sweet potato tuber yield were below the grand mean.

Regarding the number of marketable tubers, CSSP-0WAP-3-NPK1 had higher mean value of 162.2 and CSSP-2WAP-1-NPK1 the lowest value of 47.5(Table 11). The lowest mean yield was probably due to intercropping time since fertilizers were applied with low plant density, which gave higher yield than the higher plant densities.

Highest LER of 1.69 was recorded with CSSP-0WAP-1-NPK0 and the lowest (1.19) was from CSSP-0WAP- 3- NPK1 (Table 17). This low LER might be due to the effect of high plant density on tuber yield. The treatment interactions on crop establishment had no marked significant effects and nearly all means were closely related. Although the highest mean value of 99.17% was observed from CSSP-0WAP-1-NPK1 and lowest of 91.25% was from CSSP- 2WAP-2-NPK1. The other treatments mostly were in a range acceptable within or above the grand mean of 96.4% (Table 11).

On plant vigour, CSSP-0WAP- 1-NPK1 got a greater score of 5.00 while CSSP - 0WAP-3- NPK0 had lowest value of 3.00 below the grand mean (3.94). These results also gave evidence that significant effects of fertilizer application on plant growth characteristics, including vigour, hence the highest values obtained from fertilizer application. Other sweet potato characteristics, including foliage cover, were significantly influenced by fertilizer application and planting densities.

4.6.6 Effect of treatment interactions in intercropped sweet potato plant characteristics at Matangatuani

The results (Table 12) indicate that treatment interactions had significant effects on sweet potato growth characteristics and yield components. Regarding sweet potato tuber yield under intercropping, the highest mean (15.67 t ha^{-1}) and the highest number of marketable tubers (93.5) were obtained from CSSP-0WAP-2-NPK1. The lowest tuber mean yield (12.41tha^{-1}) and number of marketable tubers (72.25) were recorded from CSSP-2WAP-3-NPK0. However, tuber yield from sweet potato sole cropping was relatively higher (18.03 t ha^{-1}) compared with intercropping.

From these results the highest sweet potato tuber yields differed by 11.61%i.e. increased tuber yield under fertilizer application, particularly with medium plant density (20 000 plants ha^{-1}). The number of un-marketable tubers was highest (68.3) from CSSP-2WAP-1-NPK0 and CSSP-2WAP-2-NPK0. The lowest unmarketable tubers (37.5) were recorded from CSSP-0WAP-2-NPK0 (Table 12). The highest LER (1.85) was obtained from CSSP-2WAP-1-NPK0 in the contrary; at Kizimbani with a value of 1.69was from CSSP-0WAP-1-NPK0.

4.6.7 Combined site analysis for cassava crop characteristics under intercropping

The results from combined analysis for cassava crop (Table 13) indicated significant differences in some of the cassava characteristics, yield and related components excluding crop establishment, CBSD, CMD and un-marketable roots. However, number of marketable roots and canopy thickness were not significantly affected. Based on cassava root yield, there were large and significant differences among treatments. The highest mean value (19.01t ha^{-1}) was from CSSP-2WAP- 2-NPK1 and the lowest (11.57 t ha^{-1}) was from CSSP - 2WAP-3-NPK0

The low yield obtained from CSSP - 2WAP-3-NPK0 might be caused by either high plant density or lack of fertilizers since cassava was planted 2 weeks before sweet potato intercropping. With respect to plant height there were significant differences among

treatments. The highest mean of272.00 cm obtained from CSSP-2WAP- 2-NPK1 was highly significant compared to the others (Table 13). These findings indicate good response of cassava to fertilizer applied since the highest value was recorded from plots with fertilizer (NPK1). In addition, the lowest mean of 222.25cm was observed from CSSP - 0WAP-3-NPK0treatment i.e. high plant density, no fertilizers applied and cassava intercropped with sweet potato planted at the same planting time (0WAP).
Regarding number of marketable roots, there were only slight differences among treatments. Although there were no fertilizers applied, the number of quality roots was not affected either because of low plant density or due to 2 weeks delay in sweet potato intercropping.

On the other hand, the lowest mean marketable roots (84.9) were obtained with CSSP-0WAP-2-NPK0. This could be due to the effect of planting time (0WAP) buildup of earlier growth factor's competition or lack of fertilizer application (NPK0). Significant differences were also observed on canopy dimensions whereby CSSP-0WAP-2-NPK1 gave the highest mean of 127.27cm for canopy length and the lowest mean value of 103.8 cm was obtained from CSSP-0WAP-3-NPK0.

For canopy width and canopy thickness, significant differences were observed, although most treatments had closely related mean ranks of their significant levels (Table 13). However, CSSP-0WAP-2-NPK1 gave the highest mean of 82.73 cm for canopy width whereas the least mean value of 72.5 cm was below the grand mean (76.74 cm) from CSSP-0WAP-2-NPK0.

Furthermore, highest mean of 86.35 cm for canopy thickness was recorded with CSSP-0WAP-1-NPK1 and the lowest value (73.00 cm) fromCSSP-0WAP-1-NPK0, which was below the grand mean of 78.02 cm (Table 13). In view of these results, it might be concluded that; for good cassava-sweet potato intercrop crop results, low plant density and fertilizer application should be emphasized.

Table 13: Effect of treatment interactions in combined sites on cassava growth characteristics, yield and yield components at Kizimbani and Matangatuani

Treatments	Plant height (cm)	Canopy length (cm))	Canopy width (cm))	Canopy thickness (cm)	Cassava root yield (t/ha)	Marketable root (no)
CSSP-0WAP-1-NPK0	232.88bc	120.10cde	78.43abcd	73.00a	14.58abcd	114.0ab
CSSP-0WAP-2-NPK0	228.12ab	109.70ab	72.50a	77.00ab	12.16a	84.9a
CSSP-0WAP-3-NPK0	222.25a	103.8a	73.18ab	73.75ab	12.36ab	89.4a
CSSP-0WAP-1-NPK1	251.12de	125.15de	76.18abc	86.35d	16.98cde	112.0ab
CSSP-0WAP-2-NPK1	243.25cd	127.27e	82.73d	82.85cd	16.30bcde	110.0ab
CSSP-0WAP-3-NPK1	237.50bc	117.17bcd	75.63abc	76.88ab	15.38abcde	110.6ab
CSSP-2WAP-1-NPK0	251.50de	115.65bc	75.98abc	77.25ab	18.16de	144.5b
CSSP-2WAP-2-NPK0	249.75de	117.45bcd	76.95abcd	79.12bc	13.19abc	104.4ab
CSSP-2WAP-3-NPK0	241.62cd	111.40abc	75.58abc	74.40ab	11.57a	108.2ab
CSSP-2WAP-1-NPK1	272.00g	118.65cd	79.13bcd	79.20bc	19.01e	138.4b
CSSP-2WAP-2-NPK1	264.12fg	116.15bc	79.60cd	78.47bc	18.18de	137.6b
CSSP-2WAP-3-NPK1	259.50ef	119.82cde	75.03abc	77.97abc	16.82cde	123.4ab
G. Mean	246.14	116.91	76.74	78.02	15.39	114.8
SE_X	6.366	5.358	4.101	2.655	2.617	28.32
CV (%)	2.6	4.6	5.3	3.4	17.0	24.7
SD	16.97	9.606	5.901	5.734	4.200	37.65

Means within columns with same letter (s) are not significantly different according to DMRT at *$P \leq 0.05$*

CSSP - Cassava sweet potato intercrop, WAP- Week after planting sweet potato, NPK0- No fertilizer applied, NPK1- With recommended fertilizer applied. 1- Low plant density of sweet potato (1 x1 m), 2- Medium plant density of sweet potato (1 x 0.5 m), 3-High plant density of sweet potato (1 x 0.33 m)

4.6.8 Effect of combined site analysis on intercropped sweet potato characteristics

The results (Table 14) indicate the occurrence of significant differences among almost all observed sweet potato growth characteristics and other related components, on treatment interaction as well as combined analysis. Highly significant effects were revealed from sweet potato tuber yield and vigour. Regarding sweet potato tuber yield, crop establishment and plant vigour, CSSP-0WAP-1-NPK1 gave the highest values of 17.00 t ha^{-1}, 99.17% and 5.00, respectively.

On the other hand, CSSP-2WAP-3-NPK0, CSSP-2WAP-1-NPK1 and CSSP-2WAP-3-NPK0 gave the lowest values of 12.31 t ha^{-1}, 92.71% and 3.13 for sweet potato tuber yield, crop establishment and plant vigour, respectively. The high yield recorded in sweet potato tubers might be due to fertilizer application, time of planting as well as low plant density. A similar scenario was observed in cassava. Crop establishment was not affected by most treatments as crop had sufficient moisture during establishment. Regarding foliage cover, all treatments indicated good coverage except those planted 2WAP, which had medium coverage. However, highest score of 4.88 was recorded from high plant density planted earlier (0WAP) and fertilizer applied i.e.CSSP-0WAP 3-NPK1.

Significant difference was also observed among treatments with regard to SPVD, although the highest mean of 1.875 was recorded with CSSP- 2WAP-3-NPK0 and CSSP- 2WAP-3-NPK1. This observation showed that close spacing influenced disease contamination in the crop. In addition, significant difference was also observed on the number of un-marketable tubers in which CSSP -2WAP -3-NPK0 gave the highest number of poor quality tubers (Table 14).

Table 14: Effect of treatment interactions in combined sites on sweet potato growth characteristics, yield and yield components at Kizimbani and Matangatuani

Treatments	**Crop establishment (%)**	**Foliage cover (1-5)**	**Vigour (1-5)**	**Sweet potato yield (t/ha)**	**Marketable tubers (no)**	**Un-markt tubers (no)**
CSSP-0WAP-1-NPK0	97.92c	3.875abc	4.00defg	16.42de	88.6abc	42.5ab
CSSP-0WAP-2-NPK0	98.54c	4.50cd	3.875de	15.29cd	112.1c	43.4a
CSSP-0WAP-3-NPK0	96.67bc	4.375cd	3.375ab	13.68abc	99.8abc	52.8b
CSSP-0WAP-1-NPK1	99.17c	4.75d	5.00i	17.00e	88.5abc	41.5ab
CSSP-0WAP-2-NPK1	96.67bc	4.75d	4.5h	15.75de	109.0bc	48.6ab
CSSP-0WAP-3-NPK1	97.67bc	4.88d	4.375hg	14.12bc	122.3c	48.0ab
CSSP-2WAP-1-NPK0	95.84abc	3.25a	3.625bcd	13.63abc	63.9a	50.4ab
CSSP-2WAP-2-NPK0	92.71a	3.625ab	3.375abc	13.21ab	69.5a	50.6ab
CSSP-2WAP-3-NPK0	95.42abc	3.625ab	3.13a	12.31a	69.6a	57.5b
CSSP-2WAP-1-NPK1	93.33ab	3.875abc	4.625hi	13.48ab	66.8a	34.6a
CSSP-2WAP-2-NPK1	92.71a	4.375cd	4.375egh	12.81ab	75.1ab	43.2ab
CSSP-2WAP-3-NPK1	95.56abc	4.25bcd	3.875bdef	12.86ab	70.4a	47.2ab
G. Mean	95.93	4.177	4.01	14.21	86.3	46.7
SE_X	3.236	0.524	0.437	1.621	34.75	15.27
CV (%)	3.4	12.5	10.9	11.4	40.3	32.7
SD	3.733	0.754	0.703	2.072	36.75	14.71

Means within columns with same letter (s) are not significantly different according to DMRT at *$P \leq 0.05$*

Un-markt= Number of un-marketable tubers, CSSP - Cassava sweet potato intercrop, SP- Sweet potato sole crop, WAP- Week after planting sweet potato, NPK0- No fertilizer applied, NPK1- With recommended fertilizer applied. 1- Low plant density of sweet potato (1 x1 m), 2- Medium plant density of sweet potato (1 x 0.5 m), 3-High plant density of sweet potato (1 x 0.33 m)

4.7 Mean Comparison Between The Two Sites

4.7.1 Effect of location on intercropped cassava growth characteristics, yield and yield components

Significant differences were observed between locations on cassava root yield, canopy length, width, thickness, plant height and marketable roots. This indicated suitable site for the studied cassava characteristics and related components. Matangatuani yielded highest cassava roots (17.63 t ha^{-1}) compared with Kizimbani (13.15 t ha^{-1}). From these results, cassava root yield increased by 14.56% for Matangatuani from the total root yield compared with Kizimbani (Table 15). A large number (134.2) of marketable roots was obtained from Matangatuani, whereby Kizimbani gave 95.4 marketable roots. The lengthiness, wideness, and thickness of canopy dimensions were recorded at Matangatuani with the values of 120.23 cm, 77.98 cm and 79.79 cm, respectively (Table 15). The lowest canopy length, width and thickness were obtained at Kizimbani with values of 113.59 cm, 75.5 cm and 76.25 cm, respectively. Overall, all tested cassava characteristics and other components, Matangatuani gave the highest values for almost all characters except plant height in which Kizimbani gave the highest value of252.46 cm compared with Matangatuani with 239.81cm (Table 15).

Table 15: Means of intercropped cassava characteristics which showed effects on location under combined analysis

Site	Plant height (cm)	Canopy length (cm)	Canop y width (cm)	Canopy thickness (cm)	C assava root yield (t/ha)	Makr (no)
1- Kizimbani	252.46	113.59	75.5	76.25	13.15	95.4
2-Matangatuani	239.81	120.23	77.98	79.79	17.63	134.2
G. Mean	246.14	116.91	76.74	78.02	15.39	114.8
SE_X	2.496	6.826	5.174	4.352	2.682	27.23
CV (%)	1	5.8	6.7	5.6	17.4	23.7

P. Value	< 0.001	< 0.001	0.021	< 0.001	< 0.001	< 0.001
$LSD_{0.05}$	9.732	2.773	2.102	1.768	1.089	11.06

4.7.2 Effect of location on intercropped sweet potato growth characteristics, yield and yield components

There were significant differences between the sites on sweet potato yields and growth characteristics as well as other crop components. However, Matangatuani indicated higher performance in most characteristics except sweet potato yields in which Kizimbani site gave greater value of 14.67 t ha^{-1} indicating an increase of yield by 3.24% as compared with tuber yield at Matangatuani (13.75 t ha^{-1}). Significant differences were observed in SPVD, LER, foliage cover, number of un-marketed tubers and sweet potato yield. The highest sweet potato yield at Kizimbani might be due to sufficiency of available soil moisture for the crops during establishment and development, since the amount of rainfall was higher at Kizimbani (591.9 mm) than Matangatuani (500.8mm) (Table 1). Also, soil physical characteristics at Kizimbani (sand clay loam) influenced water holding capacity due high clay content compared with Matangatuani with sandy loam textured soil with moderate water holding capacity (Table 2).

Based on the values for LER as an accumulation of ratios from cassava yield and that of sweet potato was highest at Matangatuani (1.55) and lowest at Kizimbani with a value (1.40).Thus, the higher the LER the more productive the intercropping system was compared with sole cropping. This indicate that the area planted with sole crop would need 55% more land at Matangatuani and 40 % at Kizimbaniin comparison with the area planted to intercropping system to produce the combined yield. In addition, SPVD severity gave higher mean of 1.458 at Matangatuani than Kizimbani (1.25). This indicated more disease infection at Matangatuani than Kizimbani. Good coverage of sweet potato was more at Matangatuani with a value of 4.458 than Kizimbani (3.898) based on a scoring scale (1-5). Furthermore, Matangatuani produced greater number (52.5) of small tubers than Kizimbani (40.9). Overall, based on the objective and strategic functions of the intercropping, harvesting more than one crop field in the same season, it might be concluded that the practice is more promising and advantageous particularly in areas with shortage of land for crop production. In addition, regarding the yield comparison between sole cropping and intercropping indicated that in totaling higher crop yield per unit area was observed in intercropping rather than sole cropping (Table 16).

Table 16: Summary of crop mean yields comparison under intercropping system

		MATANGATUANI			KIZIMBANI		
		Cassava tha^{-1}	**Sweet potato $t\ ha^{-1}$**	**Total Yield $t\ ha^{-1}$**	**Cassava tha^{-1}**	**Sweet potato tha^{-1}**	**Total Yield $t\ ha^{-1}$**
CSSP-0WAP-1-NPK0	Intercropping	16.85	14.82	31.67	12.31	18.03	30.34
CSSP-0WAP-2-NPK0		14.09	14.02	28.11	10.22	16.56	26.78
CSSP-0WAP-3-NPK0		14.32	12.75	27.07	10.4	14.6	25
CSSP-0WAP-1-NPK1		18.53	15.28	33.81	15.43	18.73	34.16
CSSP-0WAP-2-NPK1		19.01	15.67	34.68	13.59	15.83	29.42
CSSP-0WAP-3-NPK1		19	13.27	32.27	11.77	14.97	26.74
CSSP-2WAP-1-NPK0		21.19	13.73	34.92	15.12	13.54	28.66
CSSP-2WAP-2-NPK0		13.93	13.64	27.57	12.46	12.78	25.24
CSSP-2WAP-3-NPK0		11.67	12.41	24.08	11.46	12.2	23.66
CSSP-2WAP-1-NPK1		22.52	13.86	36.38	15.5	13.1	28.6
CSSP-2WAP-2-NPK1		20.8	12.88	33.68	15.56	12.75	28.31
CSSP-2WAP-3-NPK1		19.69	12.73	32.42	13.96	13	26.96
CS-0WAP-1-NPK0	Sole cropping	19.88			15.53		
CS-0WAP-1-NPK1		27.03			21.48		
CS-2WAP-1-NPK0		21.8			17.29		
CS-2WAP-1-NPK1		27.8			18.22		
SP-0WAP-3-NPK0		15.83			20.88		
SP-0WAP-3-NPK1		17.94			24.06		
SP-2WAP-3-NPK0		15.81			21.15		
SP-2WAP-3-NPK1		18.03			23.87		

CSSP = Cassava and sweet potato intercropping, CS = Cassava sole cropping, SP = Sweet potato sole cropping, NPK 1 = Fertilizer applied plots, NPK 0 = No fertilizer applied plots, 1 = low plant density (10 000 plants ha^{-1}), 2 = medium plant density (20 000 plants ha^{-1}), 3 = high plant density (20 000 plants ha^{-1}), WAP = week after planting.

4.7.3 Summary of land equivalent ratio (LER) for the two crops at Kizimbani and Matangatuani

The land equivalent ratio (LER) was calculated to evaluate intercropping performance according to Dariush *et al.* (2006). The LER is an important tool for evaluating intercropping systems. It is the relative land area required as a sole crop to produce the same yields as intercropping. The detailed on calculating LER in this study was explained and summarized on *Eqn*. 2. The results for both sites are summarized in Table 17.

Table 17: Summary of LER for the two sites

Sites	**Kizimbani**			**Matangatuani**		
LER **TREATMENTS**	***Lx*** **Cassava**	***Ly*** **Sweet potato**	**Total** ***Lx*** **+Ly**	***Lx*** **Cassava**	***Ly*** **Sweet potato**	**Total** ***Lx +Ly***
CSSP-0WAP-1-NPK0	0.82	0.87	1.69	0.87	0.94	1.81
CSSP-0WAP-2-NPK0	0.69	0.80	1.48	0.73	0.89	1.62
CSSP-0WAP-3-NPK0	0.70	0.70	1.40	0.74	0.80	1.54
CSSP-0WAP-1-NPK1	0.75	0.78	1.53	0.69	0.85	1.54
CSSP-0WAP-2-NPK1	0.66	0.66	1.32	0.71	0.87	1.58
CSSP-0WAP-3-NPK1	0.57	0.62	1.19	0.70	0.74	1.44
CSSP-2WAP-1-NPK0	0.88	0.64	1.52	1.98	0.87	1.85
CSSP-2WAP-2-NPK0	0.76	0.60	1.36	0.64	0.87	1.51
CSSP-2WAP-3-NPK0	0.69	0.58	1.27	0.54	0.79	1.33
CSSP-2WAP-1-NPK1	0.87	0.55	1.42	0.82	0.77	1.59
CSSP-2WAP-2-NPK1	0.87	0.57	1.44	0.75	0.71	1.46
CSSP-2WAP-3-NPK1	0.78	0.55	1.33	0.71	0.70	1.41

CHAPTER FIVE

5.0 DISCUSSION

This study has demonstrated that intercropping of sweet potato in a cassava-based cropping system has high projection and potentiality for both crops; hence sweet potato played multiple roles for earlier food availability and cash income, which contribute significantly to livelihoods of many households. The success of any intercropping system depends on proper selection of the crop species to minimize competition for light, moisture and nutrients (Fukai and Trenbath, 1993). The practice is useful in cassava based intercropping system since it takes a long time to harvest maturity. Benefits of intercropping include protect the soil from direct impact of rain drops, speed of water runoff before cassava canopy is fully closed. Thus, intercropping reduces soil erosion and may also suppress weed growth during the early stages of cassava development (Howeler, 2017).

According to Michael *et al*. (2012) the greatest intercrop yields of cassava and sweet potato were obtained when cassava cuttings length of 30 cm were intercropped. Although the lowest competitive pressure was recorded from cassava with short cutting of 20 cm intercropped with sweet potato, however; intercropping sweet potato and cassava with cutting length of 30 cm gave the highest land equivalent ratio value of 2.15, indicating that the greatest productivity was achieved through growing the two crops together (Michael *et al*., 2012). From the current study, it has been observed that all treatments had significant effects on most of the assessed plant characteristics. The plant spacing and fertilizer treatments had high and direct effects on many growth characteristics, yields and yield components of both crops. According to Samuel *et al.* (2004) the planting density in sweet potato affects some important plant traits such as total yield, tuber size distribution and tuber quality. High plant densities decreased yield per plant and decreasing plant densities increased the number of large-sized tubers (Szarvas *et al.*, 2017). It was also reported that maximum weight of tubers per hill was produced from plants having more sparsely planted and the highest yield of tubers per area was obtained from the highest density and the lowest from the sparsely planted (Sultana and Siddique, 1991). In addition, the time of intercropping also revealed significant effects on cassava performance.

5.1 Effect of Time of Intercropping on Cassava Growth, Yield and Yield Components

The relative time of planting of the intercrop components (before, at the same time as, or after cassava) may have both biological and practical implications since cassava does not impose much competition early in the growth cycle. However, it does not tolerate much competition either (Leihner, 1983). As a result, cassava yields can be drastically reduced if the intercrop components are planted earlier than cassava, imposing competition for light and other growth factors. On the other hand, if cassava was planted earlier than the intercrop, growth and yield of the intercrop can be affected through shading and competition for other growth factors. Thung and Cock (1979) found that trials conducted with cassava and common beans gave the greatest total yields when both crops were planted at the same time or with a difference in planting time of less than 1 week. The effect of time of intercropping in this study could be attributed basically by sweet potato, which was planted at two different times.

5.1.1 Plant height

The major effect of time of intercropping that was observed in this study, particularly in the combined analysis, was in cassava growth and development, which indicated significant differences between planting times of intercropping (Table 13). The highest mean of 272.00cm was observed from cassava plot in which sweet potato was planted 2 weeks later. This indicates that planting cassava and sweet potato on the same day may affect cassava establishment and growth; hence sweet potato has greater ability for faster sprouting and ground coverage, which may result in over-crowding on the cassava during early growth stages. Howeler (2017) suggested that the intercrops could be planted at the same time or one or more weeks before or after planting cassava, depending on the vigor of each crop, as well as on the relative income expected from each. According to Kapinga *et al*. (1995), in a cassava sweet potato intercropping, the crops competed for soil N, P and K. Apparently, sweet potato competes more than cassava and dominated the mixture. In addition, Howeler (2017) reported that cassava and sweet potato both tend to require mainly K for root formation.

5. 2 Effect of Fertilizer Application on Intercropped Cassava Growth, Yield and Yield Components

Fertilizer application played important roles on plant growth and development. In this study fertilizer application was among the major causes of significant variations in many researched crop characteristics. Both cassava and sweet potato crop characteristics indicated diverse effects due to fertilizer application. These include; cassava root yields, plant height, canopy length, canopy thickness, marketable and un-marketable roots/tubers. Sophearith *et al*. (2015) reported that cassava root yield was significantly increased by fertilizer application compared with controls (non-fertilizer applied). Thus, application of properly balanced fertilizers, with adequate levels of potassium (K) in particular, is needed for high root high yields. Fresh tuber yield increased from 22.8 to 29.2 t ha^{-1} with inorganic fertilizer application (Leo and Vernon, 2015), also significant effects on branches per plant, tubers per plant and tuber length. Normally, complimentary use of resources occurs when the component species of an intercrop use quantitatively different times (Tofinga *et al*., 1993). Fertilizer application exposed positive effects in all significant plant characteristics whereby the highest responses were observed from fertilizer treated plots at both sites. Although cassava can grow better than other crops in poor soils, the crop does respond well to fertilizer application and realizing the full benefits (Howeler, 2002; Lovely *et al.,* 2018). Continuous cropping of cassava without balanced fertilizer application can lead to soil nutrient depletion and yield decline over time (Lovely *et al.,* 2018). A study conducted in Philippines to compare yields of fertilizer applied and without fertilizer cassava, results showed that cassava yield can be increased significantly through fertilizer application (Lovely *et al.,* 2018). Similar results were observed in studies conducted in Thailand and Indonesia (Howeler, 2002).

5. 2.1 Plant height

In cassava, a wide range of growth habits exist with respect to branching and vigor. Both characteristics may influence the quantity of light intercepted during early growth stages. Varieties with an erect growth habit (late branching) and medium vigor are most suitable for intercropping since they impose relatively little competition on the intercrop initially and also have high yield potential (Leihner, 1983). High initial vigour and early branching cause reduction in yield of the intercrops compared with varieties with medium vigour and late branching (Leihner, 1983). It is of no doubt that nitrogen fertilizers improved vegetative growth of the plant, which included plant height (Table 13). According to Howeler (2002) many studies observed N application to increase vegetative growth.

5. 2.2 Canopy length and thickness

The canopy length and canopy thickness showed significant difference due to fertilizer application ($P<0.05$) (Table 9). According to Leo and Vernon (2015) inorganic fertilizers have main effects on growth parameters of stem diameter, canopy width and plant height. Canopy diameter of 100 cm reflects full canopy closure, as plants were planted in rows 100 cm apart and between plants.

These results are similar to those of plant height, indicating that they depended not only on genetic constitution of the plant but also on the environment that favored vegetative growth. Canopy diameter in cassava ensures large surface area for solar radiation interception and photosynthesis (Lebot, 2009). Plants are thus more likely to suppress weeds. However, excessive foliage may lead to shedding of lower leave sand thus serving as net users of photosynthates. Large bulk of foliage created within cassava plants was by the action of nitrogen and consequently an extensive assimilating area (Howeler and Cadavid, 1990). Therefore, fertilizer application improves not only plant height but also affects cassava growth and yield. From this observation, fertilizer application influences vegetative growth and surface area of the plant canopy.

5. 2.3 Cassava root yield

The major expected crop response to applied fertilizer in the recommended dose was an increase in economic yields and sustained land productivity. Kapinga *et al.* (1995) reported that cassava and sweet potato removed tremendous amounts of soil N and K relative to soil P. This indicates that soil N and K depleted faster than P under cassava and sweet potato cropping system. Similarly, total nutrient uptake by cassava and sweet potato intercrop was greater than that of their respective sole cultures. However, the response of cassava root yield to fertilizer with those elements was frequently not significant, except under prolonged and continuous cassava production. Under these circumstances, response to potassium maybe more accentuated (Leihner, 1983).

In this study the effect of fertilizer application revealed positive responses with highly significant differences ($P<0.001$) in cassava root yield. The highest root yield recorded from fertilizer applied plots (19.01t ha^{-1}) and lowest (11.57 t ha^{-1}) from without fertilizer plots (Table 9). Consequently, there was an increase in root yield (24.33%) due to fertilizer application. Pypers *et al*. (2012) observed that cassava yields were increased by 42 to 212 % following application of NPK fertilizer in Western Democratic Republic of the Congo. Veronica *et al.* (2016) suggested that cassava should be intercropped first with green gram to improve cassava yield. Uwah *et al*. (2013) reported that N fertilizer application at the rate of 120 kg N ha^{-1} increased tuber weight and yield of cassava by 48 % and 36 %, respectively.

In a series of on-farm experiments in Uganda and Western Kenya, Fermont (2009) demonstrated that cassava was significantly responsive to N fertilizer application. NPK fertilizer application improved tuber yields on local and improved varieties by about 123 % over the control (Thandar, 2014). The results of this study together with other studies conducted; for instance, tuber yields were increased by 49 to 110 % in West Africa and 60 % in East Africa (Howeler, 2002).

5. 2.4 Marketable roots

The results of the current study showed that there are significant differences in the number of marketable roots (P<0.01) (Table 9). As reported by Kapinga e*t al.* (1994) fertilizer application at the rate of 60kgN, 30kgP, and 30kgK/ha increased sole crop and intercropped sweet potato yields by 25% and 32%, respectively. On the other hand, yields of sole and intercropped cassava were increased by 27% and thus, fertilizer increased land use efficiency. Positive response with NPK application might be associated with better photosynthesis rate leading to more photo-synthates being produced and trans-located to the sink (storage root) (Bagali *et al*., 2012). Usually, fertilizer influences root formation and thus, cassava utilizes much N and K with better photosynthesis. It is obvious that increased yield was due to either increase in root size or number of roots per area. It has been reported by Aina *et al.* (2007) that the number of roots and their sizes play an important role in determining crop yields, hence selection should be concentrated on producing large size storage roots as well as increased number of roots produced. Therefore, root weight can be affected by the number of roots or size of roots. On the contrary, Tsegaye *et al.* (2006) reported that storage root number was negatively and significantly correlated with storage root girth.

5.3 Effect of Spacing on Intercropped Cassava Growth, Yield and Yield Components

5.3.1 Plant height

Spacing influences much the plant height, particularly for light interception and photosynthesis process. This is common and well known scientific evidence that plants require light for energy synthesis. The current study showed that, there were highly significant differences in plant height ($P<0.001$) among spacings (Table 9). It is suggested to use the recommended spacing of 1 x 1 m so as to reduce inter-specific and intra-specific competition for growth resources such as light, moisture and nutrients. Nereu *et al*. (2014) observed that competition between cassava plants caused differences in the average number of lateral shoots from the main stem. Wider spacing gave the highest number of shoots since cassava plants grew and developed under reduced competition for environmental resources, especially light. In turn, by reducing plant spacing, plants showed a stronger apical dominance in search of solar radiation, thus producing fewer lateral shoots. Tsay *et al*. (1987) reported that in sole crop light penetrated in the inter-row space for a longer period more than 50% full sunlight reaching soil level. This light environment would be available for an intercrop if cassava growth was not affected by the intercrop.

5.3.2 Canopy length and thickness

In cassava, a wide range of growth habits exist with respect to branching and vigour. Both characteristics may influence the quantity of light intercepted during early growth stages. Varieties with an erect growth habit (late branching) and medium vigor possibly cause less shade to an intercrop than those with early branching and high initial vigor (Leihner, 1983). Similar to plant height, crop canopy is affected much by spacing as closer spacing may cause intermingling of branches, which not only affects canopy but also growth and development of the associated crop. In addition, close spacing could reduce the number of leaves; hence causing greater length of internodes (Nereu *et al.,* 2014). This might also affect canopy thickness due to abnormal height caused by closer spacing. Result from the current study (Table 9) revealed significant differences on crop canopy due to the effect of plant spacing ($P < 0.05$).

5.3.3 Cassava roots yield

Cassava root is the major economic value in cassava production. Most studies in the literature have quantified effects of plant spacing on production of tuberous roots (Aguiar *et al*., 2011). According to Howeler (2017) the optimum sole crop planting density can also be used when cassava is grown in association with other crops without causing serious yield reductions of the associated intercrop. However, if a cassava variety is very vigorous, it may be necessary to reduce its plant density in order to maximize combined yields. With late-branching and less vigorous cassava varieties, the best yields were achieved with an intermediate plant density of about 10 000 plants ha^{-1} (Howeler, 2017). The current study revealed that plant density had direct effect on cassava roots yield ($P<0.001$) (Table 9). Following these results, there was a gradual decrease in root yield (17.18, 14.96 and 14.06) for 1 x 1m, 1 x 0.5 m and 1 x 0.33 m, respectively. This suggests that 1 x 1 m spacing was more profitable than the other spacings. Kapinga *et al.* (1994) reported that, cassava plant density of 10 000 and 13 333 plants ha^{-1} could be recommended for intercropping with a constant density of sweet potato of 33 333 plants ha^{-1} without detrimental effects to either cassava or sweet potato yields in the arid areas of Tanzania. Plant density has large effect on the growth of individual plants (Austin and Aung, 1973). Amount of light, moisture, nutrients and other growth resources available to each plant can be affected by final plant spacing. The planting pattern of cassava and sweet potato association in 1 x 1 m with both row and intercropping being practiced (Leihner, 1983).

In intercrops of species with different growth durations, the yield advantage stems from low intercrop competition in space and time for the rapidly growing short-duration crop and from a lower intra-crop competition in space and time for the slow-growing, long-duration component (Andrews and Kassam, 1976). The reduced planting density, along with the competition imposed by one or more of the intercrops, may partially explain the low productivity of cassava in traditional intercropping systems (Leihner, 1983).

5.4 Effect of Time of Intercropping on Sweet potato Growth, Yield and Yield Components

5.4.1 Percent crop establishment

This study found that even though the climatic condition was favourable for crop growth and development within the first 2 months (Table 1), the percentage establishment of sweet potato planted after 2 weeks (CSSP-2WAP) had significant effect on crop establishment, with the lowest establishment (92.71%) was obtained. Similarly, differences were observed within single site analyses ($P< 0.05$).However, both sites recorded low crop percentage establishment in sweet potato planted after cassava (Table 10). This indicates that the more delayed the planting of sweet potato after cassava the more was the cassava establishment and yield. Good results were mostly obtained from all sweet potato vines planted at the same time with cassava (CSSP-0WAP). In contrast, Kapinga *et al.* (1994) found that, intercropping reduced yields of cassava and sweet potato by 32% and 23%, respectively, when the associations were planted at the same time. In addition, delayed planting might be faced with various constrains, including moisture stress. When land had been prepared it influences air circulation and increases water loss, hence, slow down vine sprouting and root initiation.

However, the main reason for this was delayed planting, as rainfall availability for crop establishment was high and sufficient. Presence of sufficient moisture in the soil at planting is very crucial for development of sweet potato tubers. Many adventitious roots, which are important for absorption of minerals and nutrients are developed during this period and hence, increased plant stand with numerous storage roots. Overall, the earlier stages of crop establishment and growth were sufficient with the available soil moisture, thus, the crops were not affected by drought. However, in July, i.e. before harvesting of sweet potato, there were showers which resulted into moisture stress, which opened up room for entrance of sweet potato weevils and accounted slightly for weevil attack at both sites. According to Skoglund and Smit (1994) drought condition influences sweet potato weevils infestation.

5.4.2 Foliage cover

Sweet potato is a short day plant that needs light for maximum development. Delayed planting of sweet potato in cassava field caused sluggish foliage coverage of the soil compared with sweet potato vines planted on the same day with cassava. All sweet potatoes planted at the same time with cassava had faster growth, good flushing of new shoots and earlier soil coverage as well as ability to compete with cassava during growth. Idoke *et al.* (2018) observed that sweet potato intercropped with cassava produced the highest vine length and high number of leaves in sweet potato varieties. The second planting of sweet potato occurred at the time at which weed emergence had started and cassava sprouted, initiated roots and growth as well as soil nutrient uptake. In addition, when the second planting of sweet potato was done, the first split of nitrogen fertilizer was applied in all sweet potato plants planted on the same day with cassava, which influenced crop growth.

5.4.3 Sweet potato yield

In contrast to cassava, the time of planting indicated significant differences ($P< 0.05$). Yield from sweet potato planted 2weeks after cassava was lower than that planted 1 week after cassava planting (Table 10 and 12). This implies that when sweet potato is planted later after cassava has established, the cassava grew and withstood competition for nutrients uptake. These results are similar to those reported by Kapinga *et al.* (1995) in which a reduction of root yield was observed. Leihner (1983) found out thatwhen sweet potato was simultaneously planted with cassava; sweet potato extracts nutrients more rapidly than cassava due to faster growth. Hence this affects cassava growth. This is because intra-specific competition is higher than inter-specific competition in the intercrop as well as in the sole crops.

Trenbath (1974) stated that yields of the main crop and its intercrop were not affected by their association where there was a competition gap between the periods when each of the component crops had critical demands for growth resources. Thandar (2014) reported that the relative planting time of cassava had influence on the root yields in a cassava-groundnut intercrop. Cassava planted 3 weeks after groundnut significantly decreased cassava root yields as compared to that planted at the same time. This might be due to the inter-specific competition for growth resources (light, water and nutrients) between the two crops (Thandar, 2014). In addition, Leihner (2002) also found out that cassava yields could be considerably decreased if the intercrop was planted earlier than cassava, creating strong inter-specific competition for growth resources at a time when cassava was still a weak competitor.

5.5 Effect of Fertilizer Application on Intercropped Sweet Potato Growth, Yield and Yield Components

5.5.1 Foliage cover and plant vigour

Fertilizer application showed significant differences in sweet potato foliage cover and plant vigour. Highly significant differences were observed on foliage cover ($P < 0.001$) and plant vigour ($P < 0.05$) (Table 10 and 12). This is a positive response to improved vegetative growth due fertilizer application. According to Howeler (2017) crops grown in association tend to cause less loss of nutrients through erosion and leaching but more loss of nutrients removed in the harvested products. These imply efficient use of nutrients by the crops and so the plants grow vigorously with good coverage.

Intercropping represents an intensification of demand for nutrients, particularly when each associated crop is planted at its normal density. Leihner (2002) reported that, in most sequences of intercropping cassava with legumes or cereals, cassava is grown as the last crop before changing the site. This is probably due to the fact that in the still widely practiced system of shifting cultivation, soil fertility is exhausted after producing several crops on the same land, and only cassava with its ability to grow and produce on soils of low fertility yields reasonably well.

5.5.2 Marketable and un-marketable tubers

The major economic value expected in sweet potato is the root tubers, particularly marketable ones. From the results of this study (Table 12), it was observed that there were significant effects ($P<0.05$) on number of sweet potato tubers following fertilizer application but highly significant values were obtained from cassava. These results indicated that when there was an increase in one of the associated crop, may affect performance of relatives, particularly if there was intra-specific competition.

According to Tsuno and Fujise (1965) K is important in the development of tubers as high concentration in leaves (above 4%) promotes translocation of photosynthates from leaves to the tubers. Sokoto *et al.* (2007) reported that application of potassium had no significant effect on all the growth parameters but significantly increased the marketable tubers and fresh tuber yield. In addition, since fertilizer improves root growth and development, the higher mean effects (122.3) on the number of marketable tubers was realized from fertilizer applied. Patrician and Bansal (1999) reported that sweet potato crop had strict requirement for a balanced fertilizer management, without which growth and development of the crop would be poor and both yield and quality of tubers would decrease.

5.6 Effect of Spacing on Intercropped Sweet Potato Growth, Yield and Yield Components

The effect of spacing on sweet potato characteristics was not much. It was not the same as that of cassava. These plant characteristics include tuber yield which was highly affected ($P<0.001$), followed by vigour, SPVD, number of marketable and un-marketable tubers ($P<0.01$) and foliage cover with sweet potato weevils ($P<0.05$) (Table 10 and 12). According to Sarkar (1985) plant population is one of the most important factors contributing to high yield of sweet potato. Farooque *et al*. (1983) reported that increase in sweet potato plant population, increased crop yield per unit area. Szarvas *et al*. (2017)

observed that increasing plant density from 3 plants m^{-2} to 6 plants m^{-2} increased the production of total storage root yield from 13.16 t $ha^{-1}$to 13.93 t ha^{-1}. However, Baker (1981) reported that intra-row spacing had no effect on total root yield or number of marketable tubers. In the current study high tuber yield (17.00 t ha^{-1}) was from low density crop intercrop. Sokoto *et al.* (2007) found that close intra-row spacing produced many tubers but comparatively of lower weight, whereas wide intra-row spacing resulted in significantly bigger tubers of greater weight.

The current study revealed that greater number of unmarketable roots was from the high plant density (Table 10). Differences in nutritional requirements and absorption efficiency are causes of competition between the components of a crop association. Competition for one nutrient at the same time may alter the ability of the component crops to compete for light, water, and other nutrients.

5.7 Land Equivalent Ratio (LER)

The Land Equivalent Ratio is a method used to assess whether growing crops in association results in higher yield as compared with growing the two or more crops in separate fields as sole crops. From the current study highly significant difference in LER was observed in relation with spacing ($P<0.001$) and fertilizer application ($P<0.01$) with a grand mean of 1.474. There was no significant difference of LER with regard to time of intercropping; although the highest LER value in the combined analysis was recorded with CSSP-2WAP-1-NPK0 (1.712). This indicated that the area planted to sole crops would need to be 71.2% greater than the area planted to intercrops to produce the combined yield. Andrews and Kassam (1976) reported that on determination of the yield, advantage obtained by growing two or more crops as intercrops. Furthermore, the higher the LER, the more productive the intercropping compared with sole cropping.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The study was conducted to establish proper agronomic techniques for intercropping cassava and sweet potato in the field to optimize land productivity in Zanzibar. The analysis of variance results revealed that a common practice of planting cassava and sweet potato on the same day is more profitable compared with late planting of sweet potato. It is obvious that whenever delay in planting of sweet potato after cassava, reduced sweet potato yield. The practices of using 1 x 1m inter and intra-row spacing is more precise than the other spacings. The use of inorganic fertilizers in sole crop and intercrops is more advantageous and has been observed to increase crop yield by 16% in sweet potato and 24.33% in cassava. In addition, the LER of 1.712 indicated that the intercrop was more profitable, with high land use efficiency of which more than 71.2% may be required for production recorded with intercrop compared with sole crop. Therefore in sole crop a larger land area is required to obtain the yield recorded with small area of intercrop.

The study also showed that close spacing of sweet potato could result in good land coverage but low tuber yield due to high intra-specific competition. In addition, it was observed that there were differences in crop yield between sites, whereby Matangatuani gave better yield for cassava and at Kizimbani it was sweet potato. In contrast, the current study took into account the importance of soil moisture availability for good crop growth and yield and keeping low level of damage of the sweet potato weevils. Furthermore, use of improved cassava and sweet potato planting materials reduced disease infestation in the field crops.

6.2 Recommendations

Based on the findings of this study the following recommendations can be made

i. To optimize productivity of cassava and sweet potato as well as maintaining sustainable land for production, application of fertilizers at the recommended rate, based on site specificity have to be put into consideration.

ii. In order to increase yields and maintain reasonable environment for both crops, and reduce competition, a1 x 1 m intercrop spacing can be adopted.

iii. Advising farmers to use high yielding, improved cassava varieties with erect branching habit to minimize shade of the intercropped sweet potato.

iv. Since there is an increase in crop yield through intercropping system and efficient use of available land resource, proper land management has to be done for sustainable crop production.

v. In the calculation of LER, each crop had given similar value thus, economic profitability or net income of the crop have to be assessed while considering the differences in production costs.

6.2.1 Areas for further research

i. The effect of long term use of inorganic fertilizers and ability of the land to produce quality product and safety for animal and human consumption.

ii. To investigate the effect of high yielding cassava and sweet potato cultivars on soil nutrient removal for late, medium and early maturing varieties so as to have specific fertilizer recommendation.

iii. To investigate the time during which cassava and sweet potato crops have greater needs for fertilizer doze for optimum yield and quality of roots/tubers.

iv. To find the possibility of using locally available materials for crop growth and development such as ash, incorporating in the soil as source of potash.

REFERENCES

Abidin, P. E., Van Eeuwijk, F. A., Stam, P., Struik, P. C., Malosetti, M., and Mwanga, R. O. M. (2005). Adaption and stability analysis of sweet potato varieties for low-input systems in Uganda.*Plant Breeding* 124(5): 491 - 497.

Adekunle, Y. A., Olowe, V. I., Olasantan, F. O., Okeleye, K. A., Adetiloye, P. O., Odedina, J. N. (2014). Mixture productivity of cassava-based cropping system and food security under humid tropical conditions. Food and Energy Security, 3(1): 46-60. DOI:10.1002/fes3.46.

Adeniyan, O. N., Aluko, O. A., Olanipekun, S. O., Olasoji, J. O. and. Aduramigba, V. O. (2014). Growth and Yield Performance of Cassava/Maize Intercrop Under Different Plant Population Density of Maize. Journal of Agricultural Science; Vol. 6, No. 8; 2014 Agriculture& Rural Development Department, World Bank, 2006.

Aguiar, E. B., Valle, T.L., Lorenzi, J.O., Kanthack, R.A.D., Miranda, F, H., Granja, N.P. (2011). Efeito da densidadepopulacional e época de colheitanaprodução de raízes de mandioca de mesa.Bragantia, v.70, p.561-569, 2011. http://dx.doi.org/10.1590/S0006-87052011000300011

Aina,O.O., Dixon, A. G. O., Akinrinde, A. E. (2007). *Genetic variability in cassava as influences storage root yield in Nigeria*, Journal of Biological Sciences 7 (5):765-770, 2007 ISSN 1727-3048. Asian Network for Scientific information, Alves, A.A.C. (2002). Cassava botany and physiology. In: R.J. Hillocks et al. (eds.), Cassava: Biology, production and utilization. CABI, Wallingford, UK.p. 67-89.

Amanullah, M. M., Somasundaram,E., Vaiyapuri, K. and Sathyamoorthi,K. (2007).Intercropping in cassava – A review.Agric.Rev. 28:179-187.

Andrews, D. J. and Kassam, A. H. (1976). The importance of multiple cropping in increasing world food supplies. In: Multiple cropping, ASA special publication no. 27. American Society of Agronomy, Madison, Wisconsin. p. 1-10.

Asmar, F. (2011).Variation in activity of root extracellular phytase between genotypes of rice. *Plant and Soil* 195: 61 – 64.

Austin, M. E. and Aung, L. H. (1973).Patterns of dry matter distribution during development of sweetpotato*(Ipomoea batatas).Journal of Horticultural Science* 48: 11 - 17.

Bagali, A.N., Patil, H.B., Chimmad, V.P., Patil, P.L. and Patil, R.V. (2012).Effect of in-organics and organics on growth and yield of onion (*Allium cepa* L.). *Karnataka J. Agric. Sci.* 25(1): 112-115.

Baker, M. A. (1981). Effect of harvest date and inter-row spacing on yield and quality of three sweet potato cultivars. Dissertation Abstract Int., B4: 4335-43-35

Bationo, A., Hartemink, A., Lungu, O., Naimi, M., Okoth, P., Smaling, E. and Thiombiano, M. (2006). African soils, their productivity and profitability of fertilizer use. Background paper prepared for the African fertilizer summit.

Bhagsari, A. S. (1994). Growth, gas exchange and harvesting Index of field-grown cassava in subtropical short season environment. Agricultural Research Station, Fort valley state college, Fort valley, GA 31030-3298,USA

Calle, F., Perez J.C., Gaitan W., Morante, N., Ceballos, H., Llano G., Alvarez, E. (2005). Diallel inheritance of relevant traits in cassava (*Manihot esculenta* Crantz) adapted to acid soil savannas. Euphytica 144:177-186.

CIALCA (2006).Consortium for Improved Agriculture-based Livelihoods in Central Africa .Technical Progress Report September 2005 - October 2006.

Cuminging, J.H.; Beatly, E.R. & Englyst, H. N. (2009). Physiological properties of improved sweet potato varieties. Journal of Nutrition, 75: 733-737.

Dariush, M. Ahad, M. and Meysam, O. (2006).Assessing the land equivalent ratio (LER).Of two corn (*Zea mays*L.) varieties intercropping at various Nitrogen Levels in KARAJ, IRAN. Journal of Central European Agriculture. 7(2) 359- 364.

El-Sharkawy, M. A. (2007). Physiological characteristics of cassava tolerance to prolonged drought in the tropics: Implications for breeding cultivars adapted to seasonally dry and semi-arid environments. Brazilian Journal of Plant Physiology 19: 257-286.

El-Sharkawy, M.A. (2012). Stress-tolerant cassava: the role of integrative eco-physiology-breeding research in crop improvement. Open Journal of Soil Science 2: 162-186.

Eneji, A. E., Agboola, A. A. and Isola, O. (1995).The weed suppressive ability of sweet potato in a cassava + maize + sweet potato intercrop. Nigerian Journal of Weed Science, 8, 18.

FAO, (2001). Production Crops: Primary and Domain, pp. 35.

FAOSTAT, (2012).Tanzania and cassava production (May 2017. http://faostat.fao.org/

FAO/IAEA, (2018). Cassava production guidelines for food security and adaptation to climate change in Asia and Africa. International Atomic Energy Agency. Division of Nuclear Techniques in food in food and Agriculture.Vienna International Centre. pp 6-78

Farooque, A.M., Rahim, M.A. and Maruf, M. G.(1983). Effect of planting methods and spacing on the growth and yield of sweet potato. Bangladesh Hortic., 11: 11-14.

Fermont, A.M. (2009). Cassava and soil fertility in intensifying smallholder farming systems in intensifying smallholder farming systems of East Africa. Ph.D thesis, Wageningen University, Wageningen, NL.ISBN 978-90-8585-399-2.

Fermont, A.M., Tittonell, P.A., Baguma, Y., Ntawuruhunga, P. and Giller, K.E. (2010). Towards understanding factors that govern fertilizer response in cassava: lessons from East Africa. Nutrient Cycling in Agro-eco-syst. 86: 133-151.

Fukai S., Trenbath, B.R. (1993). Processes determining intercropping productivity and yield of component crops. Field Crop Research 24: 247-271

Gregory, D.I. and Bumb, B. (2006). Factors affecting supply of fertilizer in Sub-Saharan Africa.

Henry, G., and Hershey, C. (2002).Cassava in South America and the Caribbean. In: R.J. Hillocks et al. (eds.), Cassava: Biology, production and utilization. CABI, Wallingford, UK.p.17-40.

Hillocks, R.J. (2002). Cassava in Africa. In: Hillocks, R.J., Thresh, J.M. and Bellotti, A. (Ed.). *Cassava: Biology, Production and Utilization*. CABI, Publishing.

Howeler, R. H. (1980). Soil related cultural practices for cassava CIAT, Cali, Columbia. 28p

Howeler, R. H. (1981). Mineral nutrition and fertilization of cassava. CIAT, Cali, Columbia. 52p.

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

Howeler, R. H. (1996a). Diagnosis of nutritional disorders and soil fertility maintenance of cassava. In: Kurup, G. T. *et al.*,(eds). Tropical Tuber crops: Problems, Prospects and Future strategies. Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi India pp18-93

Howeler, R.H. (2002). Cassava mineral nutrition and fertilization. In: Hillocks, R.J, Thresh, J.M. and Bellotti, A.C. (Ed.). *Cassava: Biology, Production and Utilization.* CABI, Wallingford, UK.

Howeler, R. H. (2014). Sustainable soil and crop management of cassava in Asia.

Howeler, R. H. (2017). Cassava agronomy intercropping system. Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia.613p chapter 23.

Ibeawuchi, I. I., Dialoke, S. A., Ogbede, K.O., Ihejirika, G.O., Nwokeji, E. M., Chigbundu, I. N., Adikuru, N. C., Obilo, O. P (2007). Influence of Yam /Cassava Based Intercropping Systems with Legumes in Weed Suppression and Disease/Pest Incidence Reduction. Journal of American Science, 3(1): 49 – 59.

Idoko, J. A, Iorlamen, T. and Offordile, A. E. (2018).Effect of intercropping some crop species with orange flesh sweet potato on the performance of orange flesh sweet potato varieties in Makurdi. *International Journal of Agricultural Policy and Research.* Vol.6 (3), pp. 28-37, March 2018 Available online at https://www.journalissues.org/IJAPR.

IITA, (1990).Cassava in Tropical Africa.A reference manual. Balding and Mansell International, Wesbech, UK.p.176.

IITA, (2001). International Institute of Tropical Agriculture: Cassava subsector analysis report Uganda. p.1-68.

Jaillard, B., Plassard, C. and Hinsinger, P. (2005).Measurement of H^+ fluxes and concentrations in the rhizosphere. In: *Handbook of Soil Acidity.* (Edited by Rengel, Z.), Marcel Dekker Inc., New York. pp. 75 - 93.

Jansson, C., A. Westerbergh, J. Zhang, X. Hu, and C. Sun. (2009).Cassava, a potential biofuel crop in (the) People’s Republic of China. Applied Energy 86:95-99.

Jarvis, A., Ramirez-Villegas, J., Herrera Campo, B. V. and Navarro-Racines, C. (2012). Is Cassava the answer to African climate change adaptation? *Tropical Plant Biology* 5:9–29. doi:10.1007/s12042-012-9096-7.

Kanju, E., Uzokwe, V.N. E., Ntawuruhunga, P., Tumwegamire, S., Yabeja, J., Pariyo, A., Kawuki, R., Varietal response of cassava root yield components and root necrosis from cassava Brown streak disease to time of harvesting in Uganda, *CropProtection*(2019), doi: https:// doi.org/10.1016/j.cropro.2019.02.013.

Kapinga, R. E., Omueti, J. A., Ekanayake, I. J. (1994). Cassava sweet potato intercropping studies in Tanzania.p.15.uploaded by Ekanayake, I.J. (2017).

Kapinga, R. E., Omueti, J. A., Ekanayake, I. J. (1995). Uptake of nitrogen (N), phosphorous (P) and potassium (K) by cassava and sweet potato intercropping in Tanzania. 41p. uploaded by Ekanayake, I.J. (2018).

Kulembeka, H., Rugutu, C., Kanju, E., Chirimi, B., Rwiza, E., Amour, R. (2005). The agronomic performance and acceptability of orange fleshed sweet potato varieties in the Lake zone of Tanzania. *African Crop Science Journal* 12: 229–240.

Landon, J. R. (1991). *Booker Tropical Soil Manual.* A handbook of soil survey and agricultural land evaluation in the tropical and subtropical.Longman. 474pp.

Landon, J. R. (Ed), (2014). Booker tropical soil manual: A hand book for soil survey and agricultural land evaluation in the tropics and subtropics. RoutledgeTylor and Francis Group.New York and Landon. 530pp

Lazaro, E. A., Lisasi, H. Assenga, A. (2007). Cassava in Tanzania: A famine or commercial reserve? Proceedings of the 13th ISTRC Symposium, 614 – 621.

Lebot, V. (2009). Tropical root and tuber crops: cassava, sweet potato, yams and aroids. Crop production science in horticulture (17th Ed), London ,UK.

Leihner, D. (1983). Management and evaluation of intercropping systems with cassava. Centro Internacional de Agricultura Tropical, Cali, Colombia.70 p.

Leihner, D. (2002). Agronomy and cropping systems. In: Hillocks, Rory J., Thresh, J.M. and Bellotti, A. (Ed.). *Cassava: Biology, production and utilization*. CABI.

Leo, M. and Vernon, H. K. (2015). Potential to increase cassava yields through cattle manure and fertilizer application.African Journal of Plant ScienceVol. 9(5), pp. 228-234, May 2015. ISSN 1996-0824

Lovely, L., Mirasol, P., Apolonio, O., Arnold, V., Dale, F. C., Thomas, O. (2018)**.**Cassava Response to Fertilizer Application.Article· May 2018 DOI: 10.24047/BC102211https://www.researchgate.net/publication/325231296

Low, J., Lynam, J., Lemaga, B., Crissman, C., Barker, I., Thiele, G., Namanda, S., Wheatley, C., Andrade, M. (2009).Sweetpotato in Sub-Saharan Africa. In*:* Loebenstein G, Thottappilly G (eds), *The sweetpotato.* Dordrecht: Springer. pp 359–390.

Manrique, K. and Hermann, M..(2002). Comparative study to determine stable performance in sweetpotato (*Ipomoea batatas* [L.] Lam.) regional traits. *Acta Horticultural*583:87-94. manual. Cali: CIAT

Masumba, E. Kapinga R., Tollano, S.M., Yongolo, M., Kitundu, D.C. (2005).Adaptability and acceptability of new orange-fleshed sweetpotatovarieties in selected areas of eastern and central zones ofTanzania. In*:* Kapinga R, Kingamkono R, Msabaha M, Ndunguru, J., Lemaga B, Tusiime G (eds), *Proceedings of the ThirteenthTriennial Symposium of the International Society for Tropical RootCrops: tropical root and tuber crops: opportunities for povertyalleviation and sustainable livelihoods in developing countries*,vol. 2. Kampala: International Society for Tropical Root Crops. pp 737–745.

Matata, P. Z., Passos, A. M. A., Masolwa, L. W., Marcolan, A. L., Ribeiro, R. da S (2017). Incorporation of Leguminous Cover Crops in Smallholder Cassava-Based Production System in Western Tanzania. American Journal of Plant Sciences, 8: 3490 – 3501. DOI: 10.4236/ajps.2017.813235.

Michael, O. I., Richard, I. B., Churchline, A. I. (2012). Productivity of Cassava-Sweet Potato Intercropping System as Influenced by Varying Lengths of Cassava Cutting at Makurdi, Nigeria. *Journal of Biology, Agriculture and Healthcare*. ISSN 2224-3208 (Paper) ISSN 2225-093X Vol 2, No.5, 2012(Online) www.iiste.org

Mokwunye, U. and Bationo, A. (2002).Meeting the Phosphorus needs of the soils and crops of West Africa: the role of indigenous phosphate rocks. In: Vanlaume, B., Diels J., Sanginga, N. and Merckx R. (Ed.). Integrated Plant Nutrient Management in sub-Saharan Africa: from concept to practice. CABI publishing in Association with the International Institute of Tropical Agriculture (IITA).

Mukhopadhyay, S. K., Chattopadhyay, A., Chakraborty, I., Bhattacharya, I. (2011). Crops that feed the world 5.Sweetpotato.Sweetpotatoes for income and food security.*Food Security* 3:283–305.

Musa, E. M., Elsheikh, E. A. E., Ahmed, I. A. M., Babiker, E. E (2012). Intercropping Sorghum (*Sorghum bicolor* L.) and Cowpea (*Vigna unguiculata* L.): Effect of Brady rhizobium Inoculation and Fertilization on Minerals Composition of Sorghum Seeds. International Scholarly Research Network ISRN Agronomy, 2012: 1 – 10. DOI:10.5402/2012/356183.

Ndunguru, J., Kapinga, R., Sseruwagi, P., Sayi, B., Mwanga, R., Tumwegamire, S.andRugutu, C.,(2009): *Assessing the Sweet Potato Virus Disease and its Associated Vectors in North-Western Tanzania and Central Uganda*. African Journal of Agricultural Research, Vol. 4 (4),pp. 334-343.

Neielsen, S. S. (2010). *Food Analysis Laboratory Manual*.Springler US Publishing, ISBN: 1572 – 0333, West Lafayette, USA. 177pp.

Nereu, A. S., Diego, G. P., Alencar, J. Z., Luana, F. G., Thiago, S. M. R., André, T. de S.,Michel, R. da S. (2014).Effect of plant spacing on growth, development and yield of cassava in a subtropical environment. Bragantia vol.73 *On-line version* ISSN 1678-4499 http://dx.doi.org/10.1590/1678-4499.0159.

Nguyen, H., Schoenau, J.J., Nguyen, D., van Rees, K. and Boehm, M. (2002).Effects of long term nitrogen, phosphorus and potassium fertilization on cassava yield and plant nutrient composition in North Vietnam. J. Plant Nutrition 25: 425-442.

Nweke, F., Spencer, D. and Lynam, J. (2002). The Cassava transformation: Africa's Best-Kept Secret. Mich. St. Univ. Press, East Lansing, USA. In: Carsky, R.J and Toukourou, M.A. (2005). Identification of nutrients limiting cassava yield maintenance on a sedimentary soil in southern Benin, West Africa. *Nutr.Cycling in Agroecosyst.*71: 151-162.

Onwueme, I. C., and Sinha, T. O. (1991). Field crop production in Tropical Africa, principles and practice (pp. 267-275).

Patricia, I. and Bansal, S.K. (1999). Potassium and integrated nutrient management in potato. Proceedings of the Global Conference on Potato, December 6-11, 1999, New Delhi, India, pp: 1-3.

Pypers, P., Bimponda, W., Lodi Lama, J., Lele, B., Mulumba, R., Kachaka, C., Boeckx, P., Merckx, R. and Vanlauwe, B. (2012). Combining mineral fertilizer and green manure for Increased, profitable cassava production. Agron. J. 104: 178-187.

Pypers, P., Sanginga, J.M., Kasereka, B., Walangululu, M. and Vanlauwe, B. (2011). Increased productivity through Integrated Soil Fertility Management in cassava–legume intercropping systems in the highlands of Sud-Kivu, DR. Congo. Field Crops Res. 120: 76-85.

Sahrawat, K. L. (2010). Nitrogen availability index for sub-emerged rice soils. *Advances in Agronomy* 36: 415 – 447.

Salau, A. W., Olasantan, F. O. and Bodunde. J. G. (2012). Effects of time of introducing okra on crop growth and yield in a cassava-okra intercrop. Nigeria J. Hortic. Soc. 17:57–67.

Saleh, H. H. and Zahor, O. T. (2007). Farmers' perception and varieties acceptability of orange fleshed sweet potato in Zanzibar.1n: *Proceedings of the 13th ISTRC Symposium.* (Edited by Kapinga, R., Kingamkono R., Msabaha M., Ndunguru, J., Lemaga B. and TusiimeG.), 10 - 14 November 2003, Arusha, Tanzania. 60 - 71 pp.

Samuel Y.C., Essah D., Holm G., Jorge, D.A. (2004). Yield and quality of two U.S. Red Potatoes: Influence of nitrogen rate and plant population. http://www. Crop science. Org.

Sanchez, P. A. and Jama, B.A. (2002). Soil fertility replenishment takes off in East and Southern Africa. In: Vanlauwe, B., Diels, J., Sanginga, N. and Merckx, R. (Ed.). Integrated Plant nutrient Management in Sub-Saharan Africa: From concept to practice. CAB International Wallingford, Oxon, UK.

Sarkar, A.K. (1985). Effect of plant density on yield of sweet potato. ARC Training, Sweet Potato, pp: 1-4. http://www.arc-avrdc.org/pdf_files/Asit (3-N).pdf.

Silva, D. V., Ferreira, E. A., Oliveira, M. C., Pereira, G. A. M., Braga, R. R., dos Santos, J. B., Aspiazu, I., Souza, M. F (2016). Productivity of cassava and other crops in an intercropping system. Cien. Inv. Agr. 43(1):159-166. DOI: 10.4067/s0718-162020160001000.1

Skoglund, L. G. and Smit, N. E.J. (1994). Major Diseases and Pests of Sweet potato in East Africa. International Potato Center (CIP). 67p.

Sokoto, M.B., Magaji, M.D. and Singh, A. (2007).Growth and Yield of Irrigated Sweet Potato (*Ipomoea batatas* (L.) Lam.) As Influenced by Intra-Row Spacing and Potassium. *Journal of Plant Sciences, 2: 54-60.*

Sophearith, S., Imran, M., Jonathan, N., Keith, F.(2015). Effect of fertilizer on growth and yield of cassava (*Manihot esculenta* Crantz). International Center for Tropical Agriculture (CIAT)

Sultana, N. and Siddique, M.A. (1991). Effects of cut seed piece and plant spacing on the yield and profitability of potato. Bangladesh Hort., 19(1): 37-43.

Szarvas, A., Evelyn H., Papp, L. and Monostori,T. (2017).The effect of planting density on the yield of sweet potato [*Ipomoea batatas (l.) lam.*] in South-east Hungary.*Research Journal of Agricultural Science, 50 (1), 2018.*

Thandar, N.Y.I (2014).Improving agronomic efficiency in cassava- based farming systems in the Democratic Republic of Congo using organic and inorganic inputs. Environmental Studies, Kenyatta University.72-124p

Thung, M. Cock, J. H. (1979). Multiple cropping cassava and field beans: status of present work at the International Center of Tropical Agriculture. In: Weber, E., Nestel, B.; and Campbell, M. (eds.), Proceedings of an international workshop on intercropping with cassava. International Development Research Centre, Ottawa, Canada.IDRC-142e. p. 7-16.

Tofinga, M. P., Paolini, R., Snaydon, R.W. (1993). A study of Root and shoot interactions between cereals and peas in mixtures. J Agronomy Science 120: 13-24.

Tonukari, N.J. (2004). Cassava and the future of starch. Electronic Journal of Biotechnology7.http://www.ejbiotechnology.info/content/vol7/issue1/ISSN: (Accessed 03 March 2012).

Trenbath, B.R. (1974). Biomass productivity of mixtures, in Brady, N.C, *Advances in agronomy. Vol. 26*, Academic Press INC. (London) LTD., pp. 177-210.

Tsay, J. S., Fukai, S., Wilson, G. L. (1987).The response of cassava (*Manihotesculenta*) to spatial arrangement and to soybean intercrop. Field Crop Research, V.16 pp19-31. https://doi.org/10.1016/0378-4290(87)90050-5

Tsuno, Y. and Fujise, K. (1965). Studies on the dry matter production of sweet potato II. Crop Sci. Soci. Japan Proc., 31: 285-288.

Tumwegamire, S., Kapinga, R. P. R., Rubaihayo, D. R., LaBonte, W. J., Gruneberg, T.Z., Felde, G., Burgos, R., Carpio, E., Pawelzik, D. and Mwanga, R.O.M. (2011). Evaluation of dry matter, protein, starch, β-carotene, iron, Zn, Ca and Magnesium in East African sweetpotato [*Ipomoea batatas* (L.) Lam] germ-plasm. *HortSci*.46 (3):1–10.

Tsegaye, E., Devakara, S.E.V and Dechassa, N. (2006). Correlation and path analysis in sweet potato and their implications for clonal selection. *Journal of Agronomy* 5 (3): 391- 395.

Ukom, A. N., Ojimelukwe, P. C., & Okpara, D. A. (2009*). Nutrient composition of selected sweet potato Ipomoea batatas* (L.) Lam*] varieties as influenced by different levels of nitrogen fertilizer application.* Pakistan Journal of Nutrition, biofuel crop in (the) People’s Republic of China. Applied Energy 86:95-99.

Uwah, D. F., Effa, E.B., Ekpenyong, L.E. and Akpan, I.E. (2013). Cassava (*Manihot esculenta* Crantz) performance as influenced by nitrogen and potassium fertilizers in Uyo, Nigeria. J. Animal and Plant Sci. 23(2): 550-555.

Veronca, N.E., Deusdedit, P. M., Habai, R. M., Edward, K., Inakwu, O. A., Joseph, O. (2016). Combating viral mosaic diseases of cassava in the lake zone of Tanzania by intercropping with legume. Crop protection journal 84(2016) 69-80

Westby, A. (2002).Cassava utilization, storage and small-scale processing. In: R.J. Hillocks et al. (eds.), Cassava: Biology, production and utilization. CABI, Wallingford, UK.p. 281-300.

Woolfe, J. A. (1992). Sweetpotato: An untapped food resource. Cambridge University Press,Cambridge, United Kingdom, New York, USA. 643pp.

ZATI, (2010). *For Agriculture Productivity, Food security and Sustainable Livelihood Annual Report.* Revolutionary Government of Zanzibar Printer. Zanzibar. 48pp.

Zein, A. K. (2002). Rapid determination of soil moisture content by the microwave oven drying method.Sudan Engineering. Soc. J, 48 (40), 43-54

ZFSNP, (2008).*Annualprogress report food security Zanzibar.*Revolutionary Government of Zanzibar. 2-84p

Zhang, D., Cervantes, J., Huamán, Z., Carey, E. and Ghislain, M. (2000).Assessing genetic diversity of sweet potato (*Ipomoea batatas* (L.) Lam.) Cultivars from tropical America using AFLP. *Genetic Resources of Crop Evolution* 47: 659-665.

APPENDICES

Appendix 1: Percent soil moisture data

SITE	KIZIMBANI				MATANGATUANI			
MONTH	APRIL	MAY	JUNE	JULY	APRIL	MAY	JUNE	JULY
TREATMENTS		MOISTURE PERCENTAGE						
CSSP-0WAP-1-NPK0	39.15	68.97	38.55	37.28	32.7	59.19	38.87	35.18
CSSP-0WAP-2-NPK0	37.31	71.04	39.82	38.07	32.96	61.74	40.45	37.89
CSSP-0WAP-3-NPK0	42.15	73.89	42.32	41.2	33.39	62.86	42.09	39.26
CSSP-0WAP-1-NPK1	43.74	72.71	43.64	42.16	33.65	61.66	39.02	36.17
CSSP-0WAP-2-NPK1	45.03	73.48	45.09	44.66	33.71	62.2	41.8	39.65
CSSP-0WAP-3-NPK1	45.8	75.22	47.78	44.66	33.71	63.73	44.53	41.17
CS-NPK 0	39.06	66.41	37.43	37.26	32.8	58.45	38.22	35.07
CS-NPK 1	40.16	68.11	38.28	37.99	33.11	59.73	38.81	36.2
SP -NPK 0	41.92	72.4	47.86	46.17	33.02	61.96	41.22	37.21
SP -NPK 1	45.26	73.35	48.73	47.44	33.81	63.26	42.6	39.29
CSSP-2WAP-1-NPK0	37.3	67.12	37.85	37.02	32.44	58.95	37.69	35.64
CSSP-2WAP-2-NPK0	37.94	70.67	41.7	40.59	32.71	59.09	38.79	34.81
CSSP-2WAP-3-NPK0	40.67	73.62	43.12	40.77	33.21	61.18	41.76	38.71
CSSP-2WAP-1-NPK1	37.63	70.83	40.32	40.16	32.91	58.99	39.04	35.24
CSSP-2WAP-2-NPK1	36.88	72.92	43.56	42.73	33.24	59.95	40.87	36.96
CSSP-2WAP-3-NPK1	40.28	74.39	44.9	43.65	33.52	60.83	42.17	39.31

CSSP = Cassava and sweet potato intercropping, CS = Cassava sole cropping, SP = Sweet potato sole cropping, NPK 1 = Fertilizer applied plots, NPK 0 = No fertilizer applied plots, 1 = low plant density (10 000 plants ha^{-1}), 2 = medium plant density (20 000 plants ha^{-1}), 3 = high plant density (20 000 plants ha^{-1}), WAP = week after planting.

REP 1		REP 2		REP 3		REP 4	
0WAP	**2WAP**	**0WAP**	**2WAP**	**2WAP**	**0WAP**	**2WAP**	**0WAP**
CSSP-2-NPK1	CSSP-1-NPK 1	CSSP-1-NPK 0	SP -3-NPK 0	CSSP-3-NPK	CS -1-NPK 1	CSSP-2-NPK 1	SP -3-NPK 0
CSSP-3-NPK1	SP -3-NPK 0	CSSP-2-NPK 1	CSSP-1-NPK1	CS -1-NPK 0	CSSP-2-NPK 0	SP -3-NPK 0	CS -1-NPK 0
CSSP-1-NPK0	CSSP-3-NPK 1	CSSP-2-NPK 0	CSSP-3-NPK0	CSSP-1-NPK1	SP -3-NPK 1	CS -1 -NPK 1	CSSP-2-NPK1
SP- 3- NPK 0	CS-1-NPK 0	CSSP-3-NPK 1	CS -1 -NPK 0	CSSP-2-NPK1	CSSP-3-NPK 1	CSSP-1-NPK 0	CS -1-NPK 1
CS -1-NPK 0	CSSP-3-NPK 0	CS -1-NPK 0	CSSP-2-NPK1	CSSP-1-NPK0	CSSP-1-NPK 0	CSSP-2-NPK 0	CSSP-3-NPK0
SP- 3-NPK 1	CSSP-2-NPK 0	CSSP-1-NPK 1	CSSP-3-NPK1	CS -1-NPK 1	SP -3-NPK 0	CSSP-1-NPK 1	SP -3-NPK 1
CSSP-2-NPK0	CSSP-1-NPK 0	CSSP-3-NPK 0	CSSP-2-NPK0	SP -3-NPK 1	CSSP-3-NPK 0	CS-1 - NPK 0	CSSP-1-NPK1
CSSP-1-NPK1	CS -1- NPK 1	SP -3-NPK 0	SP -3-NPK 1	CSSP-2-NPK0	CSSP-1-NPK 1	CSSP-3-NPK 0	CSSP-2-NPK0
CSSP-3-NPK0	SP -3-NPK 1	CS -1-NPK 1	CS -1 -NPK 1	CSSP-3-NPK0	CSSP-2-NPK 1	CSSP-3-NPK 1	CSSP-1- **N**
CS -1-NPK 1	CSSP-2-NPK 1	SP-3-NPK 1	CSSP-1-NPK0	SP -3-NPK 0	CS -1-NPK 0	SP -3-NPK 1	CSSP-3-NPK1

Appendix 2: Experimental field lay out at Kizimbani and Matangatuani

Key:

CSSP = Cassava and sweet potato intercropping, CS = Cassava sole cropping, SP = Sweet potato sole cropping, NPK 1 = Fertilizer applied plots, NPK 0 = No fertilizer applied plots, 1 = low plant density (10 000 plants $ha^{-1)}$, 2 = medium plant density (20 000 plants ha^{-1}), 3 = high plant density (20 000 plants ha^{-1}), WAP = week after planting.