FIELD EVALUATION OF YIELD AND GROUND COVERAGE OF SWEET POTATO DROUGHT TOLERANT CLONES AND ORNAMENTAL VARIETIES IN COASTAL KENYA

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Field Evaluation of Yield and Ground Coverage of Sweet Potato Drought Tolerant Clones and Ornamental Varieties in Coastal Kenya

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University

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DEDICATION

This thesis is dedicated to my children Fatuma, Mwanahamisi and Juma. Your patience, joy and laughter gave me the impetus to proceed even when things seemed to be difficult. Special dedication goes to my dear husband Bakari J.R. Tabwara for his immeasurable support. You are my beacon of hope. This thesis is also dedicated to my parents, Mwanahamisi Ndugu and my late father Abdallah Mwinyihaji, for their commitment and sacrifice in order to see their children acquire quality education.

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LIST OFABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of variance
DAP	Di-ammonium phosphate
DM	Dry matter
GLM	General linear model
KALRO	Kenya agricultural and livestock research organization
LSD	Least significant difference
LR	Long rains
SR	Short rains
M.a.s.l	Meters above sea level
RCBD	Randomized Complete Block Design
SAS	Statistical Analysis System
WAP	Weeks after planting
CL2	Coastal Lowland Agro-ecological Zone II
CL3	Coastal Lowland Agro-ecological Zone III
CL4	Coastal Lowland Agro-ecological Zone IV
CL5	Coastal Lowland Agro-ecological Zone V
SSA	Sub-Saharan Africa

DEFINITION OF TERMS

Aesthetics	-	beauty or the appreciation of beauty or pleasing in appearance
Clones	-	plants produced asexually from one stock and are genetically identical
Decoration	-	the activity of making something look more attractive by putting things on it and around it or enhancing the appearance of something by adding something unessential
Food insecurity	-	limited or uncertain access to adequate food
Food security	-	measure of the availability of food and individuals ability to access it
Ground cover plant	-	any plant that is grown to provide cover over the ground and provides protection of the topsoil from erosion and direct solar radiation
Landscape	-	beautiful or impressive area of land, a section or expanse of natural scenery, usually extensive, that can be seen from a single viewpoint
Low water stress	-	a condition which occurs when the demand for water exceeds the available amount during a certain period
On-farm research	-	research conducted on a small part of a farm, with farmer participation
Ornamental plants	-	plants that are grown for decorative purposes in gardens and landscape design projects
Ornamental sweet potato varieties	-	cultivars of the same species as edible sweet potatoes and are classic plants perfect for gardening

Storage root	-	a modified lateral root, enlarged to function as a storage organ
Sub-Saharan Africa	-	region in Africa South of the Sahara desert
Tourism	-	activities of persons travelling to and staying in places outside their usual environment for not more than one consecutive year for leisure or business
Variety	-	a taxon that falls below species and subspecies in taxonomic rank

ABSTRACT

Sweet potato is grown on a small scale in coastal Kenya due to shortage of planting material and use of varieties that are not drought tolerant. Most farmers plant their sweet potato on flat ground to avoid the labor-intensive land preparation. Some sweet potato varieties have ornamental value but this potential is yet to be exploited in coastal Kenya. This research was conducted to a) evaluate selected drought tolerant sweet potato clones under different watering regimes, b) assess the performance of conventional and ornamental sweet potato genotypes under different planting beds, c) evaluate different sweet potato clones for the production of sweet potato planting material under different vine planting methods, and d) assess the performance of selected sweet potato clones at different locations in coastal Kenya. A Randomized Complete Block Design with factorial arrangement of treatments was used in the on-station experiments. On-farm trials were conducted using a Randomized Complete Block Design. Nine drought tolerant sweet potato clones (coded 6.1A, 4.10, 7.8, 15.10, 7.6AO, 10.10B, 4.2B, 7.6B and 4.2A) and a farmer preferred variety were evaluated under four different watering regimes. Three drought tolerant clones and three planting beds were evaluated for storage root yield. Three ornamental sweet potato varieties and three planting beds were evaluated for ground coverage. Three drought tolerant clones and five methods of planting sweet potato vines were evaluated in the sweet potato planting material multiplication experiment. In the on-farm trials three drought tolerant clones and a farmer-preferred variety were evaluated. Data collected included yield, characteristics and nutritional contents of storage roots, percent ground cover and vine yield. The data were subjected to the analysis of variance using the general linear model procedure of the statistical analysis system. Storage root yield was reduced by about 70 and 50%, respectively, when water application was stopped early in the season, at two or three months after planting. Clones 7.6B and 4.10 produced higher storage root yield (5.1-11.5 t ha-1) than the rest of the clones, irrespective of the watering regime. Planting clones 4.2B and 7.6B on raised beds and ridges led to higher storage root yield (11.1-12.5 t ha-1) compared to planting the two clones on flat beds (6.9-8.3 t ha-1). Ornamental sweet potato varieties Purple heart and Green fingers gave higher percent ground coverage (68-72%), than variety Margarita (38%). In the long rains season, vine planting methods without lining produced longer vines (56.4-91.1 m m-2) than those with lining (14.8-21.8m m-2). In the on-farm trials, clone 4.2B produced higher number of marketable storage roots per plant than the other two clones (7.6B and 4.2A) and the farmer preferred variety. Planting sweet potato after the peak of the long rains season led to higher storage root yield per plant than at the start of the long rains season and during the short rains season. Clones 4.2B, 7.6B and 4.2A are recommended for further agronomic trials in coastal Kenya. It is also recommended that the crop be planted early in the planting season. Clones 4.2B and 7.6B are recommended for planting on raised beds or ridges. Ornamental sweet potato varieties Purple heart and Green fingers are recommended for evaluation in different locations in the coastal Kenya. Planting methods without lining are recommended for multiplication of planting material during the long rains season. Clone 4.2B is recommended for planting after the peak of the long rains season.

CHAPTER ONE

GENERAL INTRODUCTION

1.1 Background information

Sweet potato *(Ipomoea batatas* [L.] Lam.) is a tropical crop belonging to the family Convolvulaceae (Morning Glory family). The main edible part of a sweet potato plant is the storage root. Sweet potato is considered an "orphaned" crop, and has been given little research attention and promotion (Andea, 2012).

Sweet potato performs better in well drained soils with a pH range of between 4.5-7.0 and an annual rainfall of between 750-1,000 mm (Makini *et al.*, 2018). The crop can grow from sea level up to an altitude of about 2,500 meters above sea level (M.a.s.l) and at temperatures between 15-33°C (Stathers *et al.*, 2018). Sweet potato takes between four and seven months to mature depending on the variety and environmental conditions (Makini *et al.*, 2018).

Sweet potato is an important root crop grown in over 120 countries and is the second most important root and tuber crop, after the Irish potato in the world (FAOSTAT, 2018). The world production of sweet potato in 2018 was approximately 90M tons, from a land area of 8M hectares (FAOSTAT, 2018). According to FAOSTAT (2018) China was the largest producer of sweet potato in the world, producing approximately 53M tons, while Kenya was ranked 14^{th} with an annual production of about 0.9M tons. In Sub-Saharan Africa (SSA), sweet potato is seen as both food security and cash crop (Kivuva *et al.*, 2014a). The main sweet potato growing areas in Kenya include: Western, Nyanza, Rift Valley, Coast and Central regions (Makini *et al.*, 2018).

Sweet potato vines and storage roots have been used as human food and animal feed. The vines and leaves may be fed to livestock as fodder with zero or minimal additional input cost (Claessens *et al.*, 2009). A study by Kebede *et al.* (2011) indicated that substituting concentrate of a mixture of 78.4% wheat bran, 20.6% noug seed cake, and 1% salt with crude protein (CP) 20.5% and metabolizable energy (ME) 2.16 MJ/kg dry matter (DM) with fresh sweet potato vines in the ration of growing Arsi-Bale goats resulted to increments in DM intake. As human food, sweet potato has been a good source of essential nutrients such as carbohydrates, protein, vitamins, calcium and fiber (Mohanraj and Sivasankar, 2014). It was reported that sweet potato storage roots could be processed to produce industrial products that are used to manufacture clothe dyes, starch, noodles, alcohol and edible vaccines against diseases such as hepatitis B and Norwalk virus (Stathers *et al.,* 2018). In coastal Kenya, sweet potato is usually taken as the main meal or part of the meal during breakfast, lunch or supper. This explains the high demand for the crop in most markets in the region.

Some sweet potato varieties have ornamental potential and may be used as groundcover landscape plants for beautification in landscapes or for protecting the soil from erosion caused by wind and water. Zhang *et al.* (2020) reported beneficial effects of groundcover plants in reducing runoff and soil loss compared with bare soil. Planting of ornamental sweet potato varieties may be an effective option to limit soil erosion.

Coastal Kenya is comprised of four agro-ecological zones which include Coastal Lowland Agro-ecological Zone II (CL2), Coastal Lowland Agro-ecological Zone III (CL3), Coastal Lowland Agro-ecological Zone IV (CL4) and Coastal Lowland Agro-ecological Zone V (CL5). Sweet potato has mainly been grown in agro-ecological zones CL2 and CL3, which receive an average annual rainfall of 1,000-1400 mm (Jaetzold *et al.*, 2012).

Sweet potato has been grown in several parts of the coastal region of Kenya by smallholder farmers mainly for subsistence; where on average farmers plant 0.2

hectares of sweet potato (Makini *et al.,* 2018). This kind of production does not meet the demand of sweet potato in the region's markets. Therefore, sweet potato has to be supplied from other producing regions of the country.

1.2 Problem statement

Sweet potato storage roots are in high demand in most of the major markets of coastal Kenya. The bulk of sweet potato storage roots sold in the region are derived mainly from Nyanza and Western regions of Kenya. This could be partly attributed to the fact that the crop has not been fully exploited in the region. The few farmers growing the crop plant it on small acreages in the high rainfall areas, with limited production of the crop in the low rainfall areas. Moreover, the crop faces competition for space in the high rainfall areas with other food crops. Expansion of production to the low rainfall areas is hindered by unavailability of drought tolerant varieties.

Reports from other parts of the country show that soil ridging has the potential of increasing storage root yields of sweet potato and other root crops (Ahmed *et al.*, 2012). In coastal Kenya, majority of the sweet potato farmers plant the crop on flat ground and thus, there is need to test whether soil ridging could lead to higher storage root yields.

On average, farmers in sweet potato growing regions in coastal Kenya plant 0.2 hectares of sweet potato per household (Makini *et al.,* 2018). Increasing the area under sweet potato is limited by the amount of planting material available at the start of the planting season. Considering that sweet potato is a supplementary staple for the cereals and a household food security crop, there may be food insecurity if the current production in the region is not increased through addressing the constraints limiting the production of the crop.

In coastal Kenya there is a lot of soil erosion especially due to wind during the long dry spells between the rainy seasons. Most of the ornamental plants used for landscaping in the region die due to the long dry spells experienced. Ornamental sweet potato varieties may be used as ground cover landscape plants for beautification in landscapes or for protecting the soil from erosion. Research has shown beneficial effects of groundcover plants in reducing runoff and soil loss compared with bare soil (Zhang *et al.*, 2020). However, ornamental sweet potato varieties that are adaptable to coastal Kenya have not been identified.

1.3 Objectives

1.3.1 Broad Objective

To evaluate the yield and ground coverage of drought tolerant sweet potato clones and ornamental varieties under appropriate agronomic practices for increased production of the crop under the unreliable rainfall conditions of coastal Kenya

1.3.2 Specific Objectives

(i) To determine the storage root yield of selected sweet potato clones on-station under different watering regimes

(ii) To evaluate the yield performance of selected sweet potato clones on-station under different planting beds

(iii) To assess the ground coverage of selected ornamental sweet potato varieties on-station under different planting beds

(iv) To determine the quantities of planting material of selected sweet potato clones on-station under different methods of multiplication

(v) To assess the yield performance of selected drought tolerant sweet potato clones under different ecological locations

1.4 Hypotheses

(i) The storage root yields of selected sweet potato clones do not differ under different watering regimes

(ii) Different sweet potato clones produce similar storage root yields under different planting beds

(iii) The ground coverage of selected ornamental sweet potato varieties does not vary under different planting beds

(iv) Different sweet potato clones produce similar quantities of planting material under different methods of multiplying planting material

(v) Selected drought tolerant sweet potato clones give similar storage root yields under different ecological locations

1.5 Justification

Scarcity of food due to unreliable and insufficient rainfall has been a major problem affecting many households in coastal Kenya. Sweet potato, which is regarded as a famine-relief food or disaster-related food or food security crop, can help mitigate this problem since it often survives where staple crops fail (Andrade *et al*., 2009; Mukhopadhyay *et al.*, 2011). However, exploitation of the potential of the crop is hindered by scarcity of drought tolerant varieties. Currently, sweet potato is grown on a small scale in the high rainfall areas of coastal Kenya where the crop competes for arable land with the region's staples. To expand the area under sweet potato production, there is need to identify high yielding varieties that can tolerate drought as experienced in some parts of the region. Prior to this study, it was observed that most farmers in coastal Kenya plant sweet potato on flat ground. This study therefore also assessed the performance of the drought tolerant sweet potato clones on different planting beds to provide information on the best planting bed for high root yield. Apart from being a good source of human food, animal feed and industrial raw material, sweet potato may also be used for its aesthetic value. The leaves of sweet potato are mostly green, but may contain purple pigmentation (Truong *et al.*, 2018). Such varieties with brightly colored leaves can be used for ornamental purposes such as landscaping, floral arrangements and as ground cover (Sousa *et al.*, 2018). Currently, there are no ornamental sweet potato varieties that have been identified and recommended for use in coastal Kenya. This study therefore sought to identify the best ornamental sweet potato variety that is suited to the region and the type of planting bed to achieve the highest percent soil cover. Shortage of planting material at the onset of the cropping season is the other obstacle to the attainment of full potential of sweet potato in coastal Kenya. The scarcity of planting material is caused by the dry spell that precedes the planting season. Drought has been reported to cause up to 50% non-establishment of vine cuttings in Dokolo and Abalang areas in Uganda (Ebregt *et al.*, 2005). To address the shortage of planting material at the onset of the cropping season, farmers in coastal Kenya conserve sweet potato vines outside their bathrooms (Appendix IIIa) and in swamps (Appendix IIIb) during the dry season. The swampy areas have continued to dry up due to reduced rainfall as a result of climate change. This study therefore sought to identify sweet potato multiplication methods that are adaptable to changes in climatic conditions.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Sweet potato is a perennial crop that is usually cultivated as an annual for vines and storage roots. The crop is believed to have originated from Latin America where it was first domesticated about 5000 years ago (Austin, 1988). It is from here that the crop spread Westward across the Pacific and Eastward across the Atlantic to Europe, Africa and Asia. The Spanish are credited with the spread of the crop across Europe while the Portuguese traders introduced the crop to Africa, India and China (Katayama *et al.*, 2017). The crop reached the East African coast in the late 16th century and was introduced inland by the British (Stathers *et al.*, 2018).

Varieties of sweet potato may be differentiated on the basis of the morphological traits of both leaves and storage roots such as size, color and shape (Yada *et al.*, 2010; Ravi and Saravanan, 2012). Sweet potato leaves have round, reniform, cordate or triangular shape, and moderately or deeply lobed (Ravi and Saravanan, 2012). The leaves are mostly green in color but may contain purple pigmentation (Truong *et al.*, 2018).

After cooking, the storage roots may be differentiated further by color, flavor, mouth feel, sweetness, texture and fiber content. The flesh color may be beige, white, yellow, red, pink, violet, purple and orange (Mohanraj and Sivasankar, 2014). Sweet potato vines have stoloniferous growth habit where the vines can grow up to 3 m long. The vines have nodes that are spaced at intervals, from which roots develop and grow into storage organs. Propagation of sweet potato is usually done asexually, by use of vine cuttings or storage roots. In a few weeks after planting (WAP) the fibrous roots develop into storage roots that store large amounts of nutrients.

By 2018, Sweet potato was grown in over 100 countries, with China being the biggest producer in the world (FAOSTAT, 2018). The crop was ranked as the second most important root and tuber crop after potato in the world (FAOSTAT, 2018). Sweet potato has been used as staple food in many parts of the world (Neela and Fanta, 2019). The crop is among the storage root crops of the tropics that are widely grown and consumed as subsistence staples in Africa, Latin America, the Pacific Islands and Asia (Abewoy, 2021). Despite the immense importance, sweet potato is still produced on a small scale as a secondary activity using inadequate production technology, leading to low quality and productivity (Antonio *et al.*, 2011).

In Sub-Saharan African (SSA) countries sweet potato has been an important food security crop and also a commercial crop (Kivuva *et al.*, 2014a). In the region sweet potato is grown and nutritionally perceived in different ways, including as a staple food crop, as a food security crop, as a secondary or co-staple, as a famine food or disaster-related food, as a vegetable, as a substitute to bread or snack food, as a woman's crop and as a health food (Andrade *et al.*, 2009). In Kenya, sweet potato is an important staple crop (Hagenimana *et al.*, 2001). The main sweet potato growing areas in Kenya are Western, Nyanza, Rift Valley, Central and Coast regions with Nyanza and Western regions being the leading producers. Under the current population pressure on land experienced in the world (Stathers *et al.*, 2018), and unreliable rainfall in the coastal region of Kenya, sweet potato makes a better option than cassava because of its much shorter maturity period.

2.2 Importance of sweet potato

Sweet potato is a multipurpose crop that is grown for its vines and storage roots. The crop can be used as human food, animal feed, source of industrial raw materials, and as an ornamental plant that can be used in landscaping and beautification of gardens. All parts of the plant (roots, leaves and shoots) are edible. The leaves may be used as fresh vegetables or dried and preserved for future use. Farmers in developing countries grow the crop mainly for subsistence, animal feed and for sale at the local markets (Grüneberg *et al*., 2015).

As human food, the crop is an important basic food and nutrition security crop, as well as a cash crop therefore, serving as a source of income to the farming families (Kivuva *et al.*, 2014a). Sweet potato is regarded as a lifesaving or food security crop as it often survives where staple crops fail (Mukhopadhyay *et al.*, 2011). In Pakistan, sweet potato is perceived to be an important vegetable that is high yielding, giving high profits to farmers as it requires less inputs and is successfully grown with less fertilizer and water needs (Saqib *et al.*, 2017). In Nigeria, sweet potato forms part of the diet due to its perceived nutritive values (Esan *et al.*, 2018). The crop storage roots are widely consumed as supplementary staple food or secondary food in Ivory Coast (Koua *et al.*, 2018). The crop is considered important in Kenya, because it is both a food and cash crop, has low input demand and ready local market (Mudege *et al.*, 2020).

In coastal Kenya, sweet potato storage roots are the main economic product from the crop. The storage roots are used as food, either after boiling, roasting or deep frying and taken either alone or with other foods such as milk, porridge, soup or mashed with beans and consumed as a complete meal. They can also be made into chips, crisps or dried and ground into flour. The flour may be composited with wheat flour to make bread, cakes, biscuits, *mandazi*, doughnut and *chapati* or maize, sorghum or millet flour to prepare porridge or *ugali*.

Sweet potato as a food crop is gaining prominence among farmers and consumers because of its nutritive value. Due to the awareness of the high nutritional value of sweet potato there is an increasing consumer demand for the crop among health-conscious consumers in the USA and Europe (USDA, 2015). The crop is currently recognized as a functional food due to several of its nutraceutical components that can be explored for its nutritional and medicinal value, where cultivation of its genotypes with superior health-promoting and medicinal properties can decrease the need for transgenic modifications (Ayeleso *et al.*, 2016). As human food, the storage roots and leaves are a good source of essential nutrients such as carbohydrates, protein, vitamins, calcium and fiber (Mohanraj and Sivasankar, 2014). The storage roots have 25 to 30% carbohydrate content of which 98% is easily digested (Antonio *et al.*, 2011).

The crop is rich in dietary fiber, minerals, vitamins such as vitamin C, β-carotene, carotenoid and bioactive compounds such as phenolic acids and anthocyanin, which also contribute to the color of the flesh (Chandrasekara and Kumar, 2016; Faber *et al.*, 2013). The beta-carotene in sweet potato may help reduce the risk of cancer, including prostate and lung cancer in human beings (Ware, 2019). Sweet potato contains enough beta-carotene, vitamins A, C, E and B6, that makes it good dietary complement to maize (CIP, 2018). It has the ability to produce plenty of calories per hectare relatively quickly, making it ideal for combating hunger and under nutrition (CIP, 2018). The crop is a valuable medicinal plant with anticancer, anti-diabetic, and anti-inflammatory properties (Kwak, 2019). It also has a lower glycemic index which opens perspectives to treat diabetes and obesity and is also richer in nutritional compounds, minerals and vitamins than Irish potatoes (Ellong *et al.*, 2014).

Sweet potato vines can be used as animal feed especially by farmers who grow crops and keep animals. Some varieties have vigorous growth and due to their ability to withstand drought they can be good sources of animal feed. Kebede *et al.* (2011) concluded that substituting concentrate with 50% sweet potato vines is capable for growing Arsi-Bale male goats with acceptable weight gain, feed intake, body measurements and economic returns. It is a healthy, cheap animal feed where livestock fed on sweet potato vines produce less methane, meaning its use could potentially mitigate global warming (CIP, 2018).

Field production of sweet potato provides resources for the processing and pharmaceutical industries (Tobiasz-Salach *et al.*, 2018). During the time of Speke-Grant expedition in the 1860s sweet potato was already widely grown from Zanzibar to Egypt and used as food and for making beer (Stathers *et al.*, 2018). The crop may also be fermented into soy sauce, vinegar, juices, pickles, and sochu (an alcoholic drink produced in Japan) (Chandrasekara and Kumar, 2016). In Ethiopia sweet potato storage roots are processed into many products such as bread, enjera, flour, cookies, stew, local beer and juice (Gurmu *et al.*, 2015). In China sweet potato is used in starch noodle production while in East Asia the crop is mostly used for production of distilled spirits (Grüneberg *et al*., 2015). Some sweet potato cultivars with high biological activities can be used to develop high nutraceutical value products or provide the platform for the identification and isolation of certain bioactive constituents which may serve as a starting or model molecule for the production of semi or novel synthetic drugs (Ayeleso *et al.*, 2016). In the US, scientists have developed genetically modified sweet potato plants containing novel edible vaccines against hepatitis B and the Norwalk virus that may in future provide cheap forms of health protection (Stathers *et al.*, 2018).

In the results of Akinpelu and Adenegan (2011) the cost-benefit ratio showed that sweet potato marketing is a profitable enterprise. In the coastal region of Kenya, sweet potato is commonly and largely grown in the South coast in Kwale County, particularly Mivumoni, Kikoneni and Kanana areas, and some parts of Kilifi County such as Rabai. The crop is rarely cultivated for commercial purposes. However, the subsistence farmers who grow the crop in the region are now becoming aware of the commercial potential and demand of the crop in the towns and major market centers in the region.

Sweet potato has also been shown to improve soil fertility through addition of humus (Makini *et al.*, 2018). The good canopy cover formed by sweet potato leaves smothers weeds, making it easy for farmers to prepare land for a subsequent crop. Ornamental sweet potato varieties have the potential for aesthetic purposes and also for environmental protection. These varieties can help in beautification of the landscapes especially in the tourist hotels at the Coast. They can also help in preventing both water and wind erosion of the soil through provision of soil cover. It is worth noting that to date there is no research that has been done to identify ornamental sweet potato varieties for coastal Kenya. Sweet potato can be used for landscaping and landscaping has been reported to economically increase property and resale values, lower energy costs, improve business and sales, and create positive perceptions for areas in Washington state in the United States of America (Perry, 2021).

2.3 Ecological requirements and cultural practices

2.3.1 Ecological requirements

Sweet potato does best on well-drained, sandy or silt loam soils, which permit expansion of storage roots (Verma, 2014). It is often grown on land with low soil fertility but, under those conditions, yields are significantly lower than their actual potential (Andrade *et al.*, 2009). The crop is intolerant to water logging conditions, (Makini *et al.*, 2018) and performs better in loamy soils than sandy soils (Braun *et al.*, 2003). Sweet potato grows well on a soil pH ranging from 4.5 to 7 (Makini *et al.*, 2018) but highly tolerant to low soil pH (Ila'ava *et al.*, 2000). Good soil aeration encourages storage root formation in sweet potato (Agbede and Adekiya, 2009).

Sweet potato performs better in areas with temperatures ranging from 24 to 28°C. These temperatures are suitable for early shoot and root growth in sweet potato (Belehu and Hammes, 2004). Makini *et al.* (2018) showed that average temperatures of 24^{o}C, adequate sunshine, warm nights and annual rainfall of between 750 to 1,000 mm are optimal for the crop. Gajanayake *et al.* (2015) observed that root fresh and dry biomass started to decline at comparatively low temperatures of 24.0 and 25.6°C, respectively, and suggested that temperatures higher than 24°C have detrimental effects on the mid and late-season growth of sweet potato and development of storage roots. High temperatures at low altitudes reduce the crop storage root production (Belehu, 2003).

Sweet potato requires an annual rainfall of 750-1000 mm (Makini *et al.* (2018). With this kind of rainfall a farmer can realize yield above 20 tons per hectare (Tewe *et al.*, 2003). The crop requires an average of 2 mm of water per day in the early growth stages which increases gradually to 5-6 mm per day in the later growing stages before harvesting (Nedunchezhiyan *et al.*, 2012). In coastal Kenya, sweet potato is grown mainly by small holder farmers who cannot afford irrigation. The reviewed literature shows that no work has been done to identify high yielding varieties of the crop that can tolerate harsh climatic conditions such as drought experienced in some parts of the region.

2.3.2 Cultural practices

Cultural practices such as land preparation, weed control, crop rotation and fertilizer application are among the ways of improving sweet potato yield (Grüneberg *et al.*, 2015). Land preparation for sweet potato growing involves ploughing, harrowing and ridging, activities that are aimed at improving soil structure and removing weeds. Tillage influences soil quality through its effects on soil physical, chemical, and biological properties, which in turn affect crop productivity (Anikwe and Ubochi, 2007). A survey conducted by Echodu *et al.* (2019) in Kenya, Tanzania, Uganda and Rwanda showed that, 43.3% of the farms visited had sweet potato planted on mounds, 35% on ridges, 13.5% on flatland, and 3.5% on mixed mounds and flatland.

Ridges or mounds are also recommended where mechanized harvesting is practiced. These two methods of seedbed preparation also help in conserving soil moisture, reducing soil erosion, and making intercropping with other crops possible. Planting sweet potato vines on ridges has been shown to significantly increase the weight of total fresh storage roots, marketable fresh storage roots, and dry matter of storage roots, while planting on flat or sunken beds caused significant decrease in the three observed parameters (Ahmed *et al.*, 2012). However, the three seedbed types were observed to have similar effect on numbers of both total and marketable storage roots. Ahmed *et al.* (2012) attributed the decrease in marketable storage root yield in response to planting on flat or sunken beds to the relatively compact soil which may limit and depress the expansion of storage roots. Ridges result in significant increase in the number of plants with roots at harvest, number and weight of marketable and non-marketable roots, total root yield and harvest index (Brobbey, 2015).

In order to obtain higher storage root yield and a more pleasant storage root shape, all sweet potato varieties should be planted on ridges rather than on flat land (Braun *et al.*, 2003). In a study by Dumbuya *et al.* (2016), seedbed types were found to have no significant effect on both marketable root weight per plant and total number of marketable roots per plant, but ridges produced significantly higher root weight per hectare and higher net return than mounds. Ridges and mounds provided sufficiently favorable conditions for sweet potato growth and both loosen the soil, optimize infiltration and facilitate root expansion (Dumbuya *et al.*, 2016). Akinboye *et al.* (2015) recommended a combination of ploughing, harrowing and ridging for sweet potato that is to be produced for planting material or for forage. Despite all these recommendations, no study has been conducted to determine the best planting beds for high storage root yield of sweet potato in coastal Kenya.

Propagation of sweet potato is by use of vine cuttings or storage roots. Clean planting material that is free from insects, soil and any symptoms of diseases should be selected. Sweet potato is usually established using vine cuttings from mature crops (Valverde *et al.*, 2007) and storage root yield has been shown to increase with increased number of nodes and length of cutting (Njoku *et al.*, 2009). Storage roots may be used where there are insufficient vine cuttings, or when the level of pest and disease infestation is high such that few healthy vines are left. In drier regions with only one main rainy season, some storage roots are left in the soil over the dry season to be used as planting material for the next rainy season. In coastal Kenya the storage roots method is not viable owing to the long dry spells experienced between the rainy seasons, which may lead to death of all roots.

A delay between vine cutting and planting may affect yield depending on the storage conditions of the cuttings. Storing cuttings for one to two days in humid conditions may be beneficial, as it promotes rooting at the nodes (Makini *et al.*, 2018). Longer storage may adversely affect establishment because of the exhaustion of the energy reserves of the cuttings. To minimize moisture losses, it is advisable that leaves are stripped from the lower portion of each cutting; bundles of cuttings wrapped in a wet cloth or sack and kept in a cool place away from wind. Care should be taken during planting to minimize damage of roots which developed during storage. If planting material is to be maintained in a multiplication plot before planting of the next crop, the cuttings should be planted at a close spacing of approximately 15 x 20 cm and new growth may be ready for making cuttings after two to three months (Makini *et al.*, 2018).

2.4 Sweet potato varieties

Plant varieties can be classified on the basis of their use including human consumption, animal feed and non-food industries and adaptation to agro climatic zones (Grüneberg *et al.*, 2015). These groups are often made more specific on the basis of color, cooking quality, processing characteristics and adaptation to cropping systems and time of maturity (Grüneberg *et al*., 2015). Sweet potato varieties are specific in adaption to agro-climatic conditions such as drought, heat, cold (in tropical highlands), mineral-stress (including acid soils) or extreme salinity and have large differences in taste, protein, starch, sugar, vitamin and mineral content

(Andrade *et al.*, 2009). The genotypes also have distinct differences in their suitability for different finished processed products such as bread, chips among other products.

The flesh color of some sweet potato varieties may range from cream, white, pale yellow, dark yellow, pale orange, intermediate orange, dark cream, dark orange, to those that are strongly pigmented with anthocyanin (Yada *et al.*, 2010). Stable and high yields coupled with good quality attributes are some of the factors determining varieties acceptability. A study by Habibur *et al.* (2015) revealed significant differences among sweet potato varieties in respect to morphological and yield contributing characters after assessing all the characteristics of yield and yield contributing characteristics such as number, length, diameter and total dry matter content of storage roots of sweet potato. Sweet potato quality attributes vary widely where cultivars with very high dry matter and starch content are usually low in sugars, with no or very low beta-carotene content while some varieties with very high beta-carotene content are usually high in individual sugar content and low in dry matter and starch content (Grüneberg *et al*., 2015). Sweet potato varieties also differ in the extent of infection by diseases with some varieties being more susceptible than others (Anginyah *et al.*, 2001). In their study the sweet potato genotypes from Eastern Africa were tolerant to *Alternaria solani* and attributed this to broad genetic base of these local varieties.

Farmers prefer sweet potato varieties with traits such as sweet taste, medium size storage roots, few secondary stems and size and shape of leaves, which are mostly not considered in sweet potato breeding programmes (Abidin, 2004). These traits should be given attention if the breeding programmes aim at cultivars for low-input agriculture as the combined farmers and breeders' efforts may lead to cultivars that would ultimately benefit farmers. According to Kesiime (2014) many of the potato varieties in Uganda were released because of their high yields or resistance to diseases but emphasized the need to develop genotypes that are able to withstand drought as the other strengths are rendered void if a crop receives less than average soil moisture during its growing period. Ali *et al.* (2015b) showed presence of variations among accessions, and the possibility of selecting accessions for further testing for different breeding objectives since some sweet potato accessions recorded higher values for reducing sugar, total sugar, total starch content, pH, dry matter content, total soluble solid, specific gravity and peel content.

In a study by Van Vugt and Franke (2018) there were some differences in fresh root yield due to variety with some achieving much smaller root yield than other varieties. Some of the desired traits that will lead to a variety to be adopted by farmers and consumers include high beta-carotene, good yield, good storage quality, high dry matter content, sweet taste, tolerance to drought, and pests and disease resistance. In Western Kenya, taste, yield, maturity period and availability of vines are key factors that farmers consider when selecting a sweet potato variety for planting (Were *et al.*, 2013). Some sweet potato varieties especially the orange fleshed, contain high quantities of β-carotene or pro-vitamin A but have high moisture content while most of the cream or white fleshed varieties, have a sweet taste and high dry matter content, giving a dry texture.

Genotypes with cream to yellow fleshed storage roots have high dry matter content greater than 30%, contrary to the deep orange-fleshed that are generally of low dry matter content of below 25% (Makanginya, 2012). The orange fleshed varieties currently in use have a low level of consumer acceptance and preference because they have low storage root dry matter content (Gurmu *et al.*, 2015). Processing sweet potato quality traits include dry matter, starch yield, flour yield and peel loss. The findings of Kathabwalika *et al.* (2013) showed significant variations in sweet potato storage root yield and stability among genotypes with some genotypes identified for vine production and others identified for storage root production.

2.4.1 Ornamental sweet potato varieties

Sweet potato is a multipurpose plant due to its potential to many different uses of its roots, leaves, and vines (Sousa *et al.*, 2018). Ornamental sweet potato vines are grown for decorative purposes. They are heat-loving annual vines that can be used in covering beds, hanging over walls or trailing down containers forming large strips of brightly colored foliage in the landscape together with brightly colored flowering plants (Carey *et al.*, 2007).

Ornamental sweet potato are primarily foliage plants with leaves varying in shape depending on cultivar being either heart-shaped, lobed like sycamore or maple leaves, and may occasionally bloom with pale lavender morning glory like flowers (Carey *et al.*, 2007). Ornamental sweet potato vines with purple, green, or variegated leaves which were introduced to the nursery trade have been available in markets (Adam, 2005). In a study by Sousa *et al.* (2018) all accessions evaluated presented considerable noticeable high ornamental potential including leaf shape, leaf lobe type, immature and mature leaf color, leaf lobe number, branch color, branch yield, shape of central leaf lobe, petiole pigmentation, mature leaf size and root yield, and therefore recommended them to be used in floral arrangements, cultivated as potted plants or in garden beds.

Although ornamental sweet potato varieties are grown for their aesthetic value, they also produce storage roots. However, some of the released cultivars like the 'Sweet Caroline' series produce smaller storage roots that are generally not edible. Some of the ornamental sweet potato varieties that have been released have solid purple leaves and stems, and others with light green foliage and many of these also have compact, well-branched, and upright plant architectures (Truong *et al.*, 2018). Depending on the cultivar, ornamental sweet potato vines come in various colors and color combinations which include: white, pink, red, magenta, maroon, purple, and different shades of green. The aggressive growth of ornamental sweet potato vines makes them ideal for use in containers, hanging baskets and outdoor ground covers in flower beds (Mierzejewski, 2016). Most sweet potato plants rapidly cover the ground, but lack canopy depth due to horizontal development of the canopy and poor leaf orientation (Grüneberg *et al*., 2015).

Use of ornamental sweet potato plants in landscaping has gained popularity in the last decade. This has triggered a lot of interest among researchers to develop new cultivars that can be used to decorate different areas. The attractive flowers produced by some varieties of sweet potato have made it to be accepted as an ornamental plant. No research has been carried out in coastal Kenya to identify ornamental varieties as groundcover landscape plants to be used in beautification of landscapes and for protection of soil against wind and water erosion. A study on ornamental sweet potato aims at identifying ornamental varieties with best ground coverage under different planting beds in coastal Kenya.

2.5 Sweet potato production constraints

Sweet potato production is constrained by many biotic, abiotic and socio-economic factors which hinder its production potential. Worldwide, the greatest biotic constraint to sweet potato production is sweet potato viral diseases which often cause serious yield losses, especially in high virus-pressure zones of SSA, followed by sweet potato weevils, nematodes, and fungal diseases, while abiotic stresses affecting the crop include drought, heat, cold and salinity (Grüneberg *et al.*, 2015). In most cases the low yield of sweet potato can be linked to lack of improved varieties, pest and disease incidences, and poor cultural practices (Moyo *et al.*, 2004). The main constraints to sweet potato productivity in Africa as summarized by Andrade *et al.* (2009) include inappropriate agronomic practices such as planting techniques and spacing, site selection, soil fertility management, lack of virus-clean planting material, limited yield potential of local land races and sweet potato weevil.

In Eastern Africa, sweet potato production has many constraints including pests and diseases, insufficient rainfall in drought prone areas, lack of arable land, declining soil fertility, labor shortage due to diversion to non-farm activities, shortage of planting material and dwindling water resources (Gichuki and Hijmans, 2005). In a study carried out in Uganda, Rwanda, Kenya and Tanzania, about 32.6% of farmers ranked pests as their number-one problem, followed by drought (21.6%), diseases (11.9%) and lack of disease-free planting materials (6.8%) (Echodu *et al.*, 2019).

Another challenge facing sweet potato farmers is the acreage under sweet potato production. The results of a base line survey by Were *et al.* (2013) in Western Kenya showed the average land area under sweet potato in acres per farmer was 0.28, 0.33, 0.4 and 0.27 for Busia, Kakamega, Bungoma and Butere-Mumias districts respectively. This is clear evidence that sweet potato is competing with other staples such as maize for arable land. Other challenges in smallholder-based sweet potato production and marketing systems according to Low *et al.* (2020) include seasonality (in terms of availability of the product in the market), lack of access to adequate and quality planting material at the beginning of the growing season, post-harvest losses associated with the bulky nature and improper handling of storage roots, low farm gate price during the peak harvest seasons, poorly developed marketing systems and the image of the crop as a poor person's crop.

2.5.1 Effect of drought on crop production

Inadequate rainfall is one of the major constraints to agricultural productivity and food security and is expected to worsen in future due to climate change (Balestrini *et al.*, 2018). Between 70 and 97% of smallholder farmers are affected adversely by climate change because of small farm sizes and limited access to alternative livelihood activities other than farming (Bagamba *et al.*, 2012). According to Bagamba *et al.* (2012) simulation results showed no economic gains from swamp cultivation, and concluded that in order to improve productivity farmers should plant drought tolerant crops such as sweet potato as one of the options to adapt to climate change.

Worldwide, climate change in the form of extreme heat and drought puts a major challenge to sustainable crop production by negatively affecting crop yield, which is likely to be aggravated in future due to continued greenhouse gas emissions that would lead to further rise in temperature (Dahal *et al.*, 2019). Globally, drought is a major problem reducing crop production (Ahmadizadeh *et al.*, 2012). In Kenya, scarcity of water resources and severe forest degradation could be further worsened by increasing temperatures, evaporation rates and rainfall variability (USAID, 2018). According to USAID (2018) increase in severity of dry spells is among the climate projection which may have an impact on agriculture leading to reduced grain yield and quality, heat stress in livestock and damage to crops and land.

Drought is the main abiotic stress that can strongly interfere with plant performance and crop productivity mostly through inhibition of photosynthesis (Dahal *et al.*, 2019). Drought tolerance in plants is an extremely complex trait where different plants adapt to drought stress through diverse and integrated mechanisms and strategies including morphological, physiological, cellular and molecular changes to survive under drought stress conditions (Fang and Xiong, 2015). Most crops are more sensitive to drought during their reproductive phase (storage root initiation) than during their vegetative phase (Daryanto *et al.*, 2016b). In sweet potato production, water shortage is an environmental stress that affects the growth, quantity and quality of the crop (Rahmawati *et al.*, 2020).

Sub-Saharan agriculture has been identified as vulnerable to ongoing climate change and therefore adaptation of agriculture has been suggested as a way to maintain productivity and better knowledge of intra-specific diversity of varieties is prerequisites for the successful management of such adaptation (Glato *et al.*, 2017). Compared to other storage root crops, sweet potato has a high yield potential and it is adapted even to drought prone areas (Wang *et al.*, 2011). However, as for many crops yield of sweet potato which is an important subsistence crop in SSA, can also be severely impacted by drought stress (Lau *et al.*, 2018). This is because sweet potato root storage and productivity is very sensitive to water deficit stress (Yooyongwech *et al.*, 2014).

The results of Daryanto *et al.* (2016a) showed that the amount of water reduction in sweet potato was positively related with yield reduction, but the extent of the impact depended on the phenological phase during which drought occurred. Gouveia *et al.* (2019) observed sweet potato biomass reduction due to water stress. Yooyongwech *et al.* (2014) observed a decrease in the osmotic potential of sweet potato leaf tissue due to reduced soil water content. Ghanbari *et al.* (2013) observed a 19-28% reduction in bean leaf nitrogen and 39.8% reduction in grain yield due to water stress. Although it is considered a drought tolerant crop, late planting does result in sweet potato yield losses, due to water stress during the root initiation and main bulking time (Low *et al.*, 2020).

New heat and drought-tolerant sweet potato varieties were shown to help farmers adapt to the effects of climate change (CIP, 2018). In a study conducted in Ghana, Dukuh *et al.* (2016) observed no significant influence of irrigation on soil bulk density, pore volume and particle density. Susceptibility to drought is known to be one of the major problems in sweet potato production, hence screening and selection of varieties for drought tolerance may have a positive impact on the livelihood and health of vitamin A deficient people in SSA (Agili *et al.*, 2012). According to Low *et al.* (2020), drought tolerance indices based on measuring root yield under normal and water deficit conditions are often used for selecting among sweet potato breeding clones in stress-prone areas of SSA.

In a study conducted in Mozambique, Andrade *et al.* (2016) observed negative effect of drought and genotype by year interaction on storage root yield. Lau *et al.* (2018)

observed that a subset of genes was differentially regulated between two varieties used in their study, thus representing genotype-specific responses to drought stress. Since climate change is expected to have a negative effect on the quantity and quality of animal feed available (Hidosa and Guyo, 2017), drought tolerant sweet potato cultivars might become even more significant as animal feed compared to less resilient grasses and cereal crops (Low *et al.*, 2020). The effect of drought on sweet potato results in yield loss which, in turn, leads to reduced income for producers, and can be avoided by developing and adopting drought tolerant varieties (Esan *et al.*, 2018).

The maximum production potential of sweet potato is being constrained by severe drought which affects most parts of Africa (Omotobora *et al.*, 2014). In this research Omotobora *et al.* (2014) observed drought tolerance in 12 out of 50 accessions that were pre-screened for drought. In a study by Gouveia *et al.* (2019) some sweet potato accessions showed high water use efficiency and good response to physiological drought stress and were therefore considered the most drought tolerant. Drought stress has been shown to cause up to 37% reduction in fresh root yield of cassava (Turyagyenda *et al*., 2013). The effect of drought on sweet potato may also be countered by irrigation but the extent of improvement in crop growth and development will depend on the depth of irrigation (Delazari *et al.*, 2018).

Increased drought stress significantly reduced the number and starch content of storage roots, with severe drought conditions causing up to 76% reduction in the number of storage roots compared to the optimum conditions (Rahmawati *et al.*, 2020). Insufficient water supply and very high temperatures cause physical damage, physiological disruptions and biochemical changes in a crop, which lead to reduced crop growth and yield (Fahad *et al*., 2017). Although sweet potato can survive severe moisture stress conditions, marketable yield is adversely affected (Laurie *et al.*, 2009). It has been affirmed that weather conditions do influence sweet potato storage root yield, with rainfall having the greatest impact on the crop growth and storage root yield (Richardson, 2019). The introduction of drought-tolerant sweet potato in historical China, mitigated the negative impact of droughts on food supply (Jia, 2013). Drought causes retarded growth in sweet potato genotypes leading to yield reduction (Laurie *et al.*, 2015).

In a study by Esan *et al.* (2018) different varieties performed differently under different stress levels and concluded that the varieties had different levels of tolerance to drought. Some of the genotypes screened were noted to be very susceptible to moisture stress and registered very low root yield while some performed well and were noted to withstand severe moisture stress (Makanginya, 2012). The greatest effect of drought on sweet potato yield occurs during the storage root-bulking phase (Bourke, 1989). However, the extent to which drought affects sweet potato yield is not known. Yield, yield components, and quality traits of sweet potato genotypes vary due to differences in genetic constitution, the environment and genotype-by-environment interactions (Rukundo *et al.*, 2017).

Sweet potato has a large network of genes which are involved in drought stress tolerance mechanisms, and therefore contributing in determining the level of tolerance of each cultivar (Arisha *et al.*, 2020). Kulembeka *et al.* (2004) obtained higher sweet potato storage root yield in sites with high rainfall at planting as compared with sites in which planting was followed by dry spells. According to Laurie *et al.* (2015) drought had a severe effect on the yield of all the genotypes, especially at severe stress but some genotypes produced the highest yield at the mild stress. However, appropriate sweet potato genotypes tolerant to drought conditions must be identified because of the large differences observed among genotypes (Laurie *et al.*, 2015). In their study Lewthwaite and Triggs (2012) observed a reduction in canopy cover and storage root yield in clones that were subjected to water deficit. Moisture stress has been shown to severely affect the agronomic performance of sweet potato genotypes, with those genotypes observed to have the highest stress tolerance index considered tolerant (Makanginya, 2012). Kesiime (2014) characterized potato clones as drought tolerant, moderately tolerant and susceptible based on drought effect on yield and physiological and growth parameters.

Sweet potato is relatively drought tolerant and has higher yield per unit of land than rice and wheat (Jia, 2013). The development of drought tolerant sweet potato varieties is highly desirable for maintaining crop productivity (Zhai *et al.*, 2016). Breeders have put a lot of effort in improving sweet potato tolerance to abiotic stresses (Kang *et al.*, 2018). However, no study has been done to identify drought tolerant sweet potato varieties specifically for coastal Kenya.

2.5.2 Shortage of planting material

Sweet potato vine conservation and multiplication practices are largely influenced by rainfall patterns (Low *et al.*, 2020). According to Adeola *et al.* (2019), availability of vines as planting material is an important factor that needs to be addressed, and extension programme should ensure that farmers have adequate access to vines through the establishment of a sustainable network of multipliers. Maximization of sweet potato production potential may not be realized in SSA, especially in areas that experience dry spells after the growing season, due to lack of planting materials at the beginning of the rainy season (Andrade *et al.*, 2017). Gurmu *et al.* (2019) observed that, although farmers in Ethiopia maintain planting material in their home gardens until the onset of the rainy season, they lose most of it due to recurrent drought.

In a study conducted in the Lake Zone of Tanzania, McEwan *et al.* (2017) showed that farmers with access to lake sides or swampy areas had a system of using these lands for conserving planting material during the dry season, followed by shifting of the vines to upland fields for rain-fed production. In Southern Africa, where the rainfall is unimodal, farmers traditionally leave roots in the ground during the dry season to sprout when the rains start, and then multiply the sprouts to get enough material to plant a new sweet potato crop (Low and Thiele, 2020). However, prolonged dry spells in the region have limited the use of this method of conservation, leading to inadequate planting material at the onset of rains, and, in the long run, loss of some sweet potato germplasm by smallholder farmers (Makunde *et al.*, 2018). In Kenya, 75% of farmers sourced their planting material from their own farms, 46% from other farmers, and 2% from commercial suppliers (Echodu *et al.*, 2019). Farmers have found sweet potato vine conservation during the dry season to be quite challenging, leading to the possibility of shifting to other crops (Mudege *et al.*, 2019).

The results of a study by Adeola *et al.* (2019) showed a direct relationship between vines availability and the intensity of adoption of improved varieties of sweet potato, and therefore recommended the need for inclusion of preservation techniques of vines in any intervention programme. According to Andrade *et al.* (2017) cultivars with short and thick stems had a better survival rate during extended dry spells. Effective seed systems are required in order to provide farmers with sufficient quantities of planting material of required varieties at affordable price and in time for planting season (Bukania, 2016). Unreliable rainfall and extended dry spell of more than 4 months are associated with shortage of sweet potato planting material at the beginning of the cropping season in the drought prone regions of Southern and Eastern Africa, especially for households with no access to land in valley bottoms (Andrade *et al.*, 2009).

Seed provision systems for vegetatively propagated crops in SSA remains a challenging and controversial subject since the conservation of planting material at farm level during the dry season and the availability of sufficient planting material at planting time are two major constraints to sweet potato production, especially in drought prone and low potential areas (Andrade *et al.*, 2009). According to Low *et al.* (2020) recent efforts by CIP in collaboration with African NARIs have focused on developing innovative sweet potato seed systems, including irrigated vine multiplication linked to established decentralized vine multipliers. Presently, no research has been conducted in coastal Kenya to determine the effect of vine multiplication methods both with and without irrigation on the amount of planting material produced. The study being reported here aimed at evaluating the effectiveness of vine multiplication methods both with and without irrigation. The results of this study will likely provide information on viable method(s) which may be adopted by sweet potato farmers in coastal Kenya.

CHAPTER THREE

METHODOLOGY

3.1 Research sites description

On-station studies were conducted at Pwani University farm in Kilifi County, in coastal Kenya between December 2016 and January 2019. Each of the study was conducted for two seasons. The study site is located within the Coastal Lowland Agro-ecological Zone IV (CL4), at an altitude of 15 M.a.s.l. It lies between -3. 615330 and 39.842910. Rainfall received at the site ranges from 1,000 to 1,100 mm annually and is bimodal in nature, coming as long rains (LR) and short rains (SR) seasons. The LR season starts from April and ends in July/August while the SR season starts from October and ends in December (Figure 3.1). Two thirds of the annual rainfall is usually received during the LR season (Saha, 2015). A long dry season is experienced in the region from January to March. The SR season is quite unreliable and may fail altogether, extending the length of the dry period. The temperature range is from 22°C to 30°C and the mean relative humidity is about 80% (Jaetzold *et al.*, 2012). Soils at Pwani University farm are mostly Ferralsols, with low organic matter (5-16 g kg^{-1}), low nitrogen content (0.7 g N kg^{-1}) and a pH between five and seven (Abdallah *et al*., 2021). Phosphorus was therefore applied at planting as Di-ammonium phosphate (DAP) fertilizer, at the rate of 50 kg P_2O_5 ha^{-1}.

The on-farm trials were conducted for three seasons between April 2018 and January 2019 in Mavueni, Kaliang'ombe and Jimba in Kilifi County, and Mrima and Kenya-Loma in Kwale County (Appendices 5.1 - 5.4).

3.2 Experiments

The following experiments were carried out in the study:

3.2.1 Watering regime experiment

Treatments consisted of factorial combinations of the following factors:

Factor A: nine sweet potato clones (6.1A (C1), 4.10 (C2), 7.8 (C3), 15.10 (C4), 7.6AO (C5), 10.10B (C6), 4.2B (C7), 7.6B (C8) and 4.2A (C9)) that had been reported to be drought tolerant (Appendices 4.1 - 4.9) were obtained from KALRO-Muguga for use in this study. A farmer-preferred variety from Kilifi namely, "Rabai" (VR) was included as a local check (Appendix IVj).

Factor B: four different watering regimes

(i) Watering for the first two months after planting and stressing the plants for the next three months - (W2)

(ii) Watering for the first three months after planting and stressing the plants for the next two months - (W3)

(iii) Watering for the first four months after planting and stressing the plants for the next one month - (W4)

(iv) Watering throughout the growing period and not stressing the plants at all - (W0)

A Randomized Complete Block Design (RCBD) was used, with factorial arrangement of treatments. The treatments were replicated three times. Therefore, there were 40 experimental plots in each block, and a total of 120 experimental units.

Watering regime experiment was conducted for two seasons.

3.2.2 Planting bed experiment for sweet potato storage root yield

Treatments consisted of factorial combinations of the following factors:

Factor A: three drought tolerant clones (C7, C8 and C9)

Factor B: three planting beds (flat (P1), raised (P2) and ridge (P3))

RCBD was used, with factorial arrangement of treatments. The treatments were replicated three times. Therefore there were nine experimental plots in each block, and a total of 27 experimental units.

Planting bed experiment for storage roots was conducted for two seasons.

3.2.3 Planting bed experiment for ground coverage of ornamental sweet potato varieties

Treatments consisted of factorial combinations of the following factors:

Factor A: three ornamental sweet potato varieties (Purple heart (V1), Green fingers (V2) and Margarita (V3))

Factor B: three planting beds (flat, raised and ridge)

RCBD was used, with factorial arrangement of treatments. The treatments were replicated three times. Therefore, there were nine experimental plots in each block, and a total of 27 experimental units.

Planting bed experiment for ground coverage was conducted for two seasons.

3.2.4 Multiplication of planting material experiment

Treatments consisted of factorial combinations of the following factors:

Factor A: three drought tolerant clones (C7, C8 and C9)

Factor B: five methods of planting sweet potato vines (planting in pits without lining (PWL), planting in pits with lining (PL), planting on flat grounds (OG), planting in sacks without lining (SWL) and planting in sacks with lining (SL)).

RCBD was used, with factorial arrangement of treatments. The treatments were replicated three times. Therefore, there were 15 experimental plots in each block, and a total of 45 experimental units.

Sweet potato planting material multiplication experiment was conducted during the long rains season and off season under irrigation.

3.2.5 Assessment of drought tolerant sweet potato clones in different locations

Three sweet potato clones selected for drought tolerance (C7, C8 and C9) and one farmer-preferred sweet potato variety (Carrot) were evaluated under different farms for both sweet potato storage root yield and storage root numbers. The five on-farm study sites were selected to represent the sweet potato producing areas in coastal Kenya. The criteria that was used for selecting the on-farm locations was based on both climatic and soil factors. Soil samples were taken from all the on-farm sites for analysis.

RCBD was used, with each of the five on-farm sites forming a replicate. Therefore, there were four experimental plots in each block, and a total of 20 experimental units. The planting of the on-farm trials was done at the start of the long rains season, after the peak of the long rains season and at the start of the short rains season.

3.3 Crop establishment

In the watering regime experiment sweet potato vines were planted in plots measuring 3.75 x 0.9 m (3.375 m^2) in a structure designed to ensure that the treatments were not interfered with by rainfall, and also to mimic the dry spells experienced in some parts of the region (Plate 3.1). The field was tilled to a medium tilth and plots demarcated followed by ridging. Each plot consisted of three ridges, each 0.9 m long and 45 cm high. The ridges were spaced 1.25 m apart. Each ridge was planted with 3 vine cuttings (each 30 cm long), spaced 30 cm apart.

For the planting beds experiments, sweet potato clones and sweet potato ornamental varieties were planted in plots measuring 3.75 x 0.9 m (3.375 m^2). Each plot consisted of three rows 0.9 m long and spaced 1.25 m apart. Each row was planted with 3 vine cuttings, (each 30 cm long), spaced 30 cm apart.

Plots measuring 0.3 x 0.6 m (0.18 m^2) were established for the multiplication of sweet potato planting material. Each plot consisted of two rows, each 0.6 m long and spaced 0.2 m apart. Each row was planted with 6 vine cuttings, spaced 10 cm apart.

In the on-farm trial the plot size was 3.75 x 1.8 m (6.75 m^2). Each plot consisted of three ridges 1.8 m long and spaced 1.25 m apart. Each ridge was planted with 6 vine cuttings, (each 30 cm long), spaced 30 cm apart.

Cuttings of three nodes were planted, with two nodes buried in soil in all the experiments.

DAP fertilizer was applied to all plants at planting at the rate of 50 kg P_2O_5 ha^{-1} except for the plants in the on-farm trial.

Plate 3.1: Structures used to keep rainwater off the experimental plots

3.4 Crop management practices

Plants were hand weeded in the early growth stages of the crop. An insecticide, Dynamec 1.8 EC (Abamectin 1.8g/l), was applied at the rate of 250 ml/ha as recommended to control insect pests (leaf defoliators and mites). Vines were trained to minimize their spread into adjacent plots, as well as preventing them from forming adventitious roots along the stems. Soil was carefully hoed back onto the ridges to fill cracks on the ground, which had formed as a result of storage roots expansion. This was carried out to avoid exposure of the storage roots to weevils in all the experiments except the planting beds for ornamental varieties and multiplication of planting material experiments. Irrigation water was applied when necessary to ensure the plots had optimal soil moisture throughout the growing period except for the on-farm trials. For the watering regime experiment the moisture control was managed by stopping the irrigation in the treatments where their watering regime had ended.

3.5 Data collected

The following data were collected from the experimental plots of the watering regime experiment:

Storage root yield

The crop was harvested five months after planting and storage root yield from each plot was determined. All the three ridges of sweet potato in each plot were harvested for the determination of sweet potato storage root yield. At harvest, plot wet weight was measured after detaching the storage roots from the plant. This was done by measuring all the storage roots harvested from a plot using a weighing scale. Samples, each consisting of two storage roots were taken at random from each plot, labelled and their fresh weight determined. The samples were then oven dried at

105°C for 48 hours at Pwani University chemistry laboratory for DM determination. The following formula was used to calculate DM:

$$DM\ (kg\ ha^{-1}) = \frac{S_{oven}\ (g)}{S_{fresh}\ (g)} * \frac{PW\ (kg)}{A\ (m^2)} * 1{,}000\ m^2 ha^{-1}$$

Where S_{oven} = sample oven weight; S_{fresh} = sample fresh weight; PW = plot weight;

A = net-plot area.

Sweet potato yield was then derived using the following formula:

$$Y = \frac{SW(kg)}{A(m^2\ )} * \frac{10{,}000\ m^2 ha^{-1}}{1{,}000\ kg\ t^{-1}}$$

Where Y = sweet potato yield (t ha^{-1}); SW = field wet weight; A = net-plot area.

Storage root dry weight (DW) was then derived using the following formula:

$$DW\ = WW_{storage\ root}\ (kg) * DM * \frac{1{,}000}{100}$$

Where DW = storage root dry weight (t ha^{-1}); $WW_{storage\ root}$ = wet weight of storage roots; DM% = percent dry matter of storage roots.

Storage root characteristics

The number, length and circumference of marketable storage roots per plant were recorded after harvesting. The storage root circumference was determined using a tape measure around the thickest part of the storage root (Plate 3.2). The length of storage root was measured as the length of the edible portion of the storage root (Plate 3.2). The number of marketable storage roots was taken by counting the individual storage roots per plant.

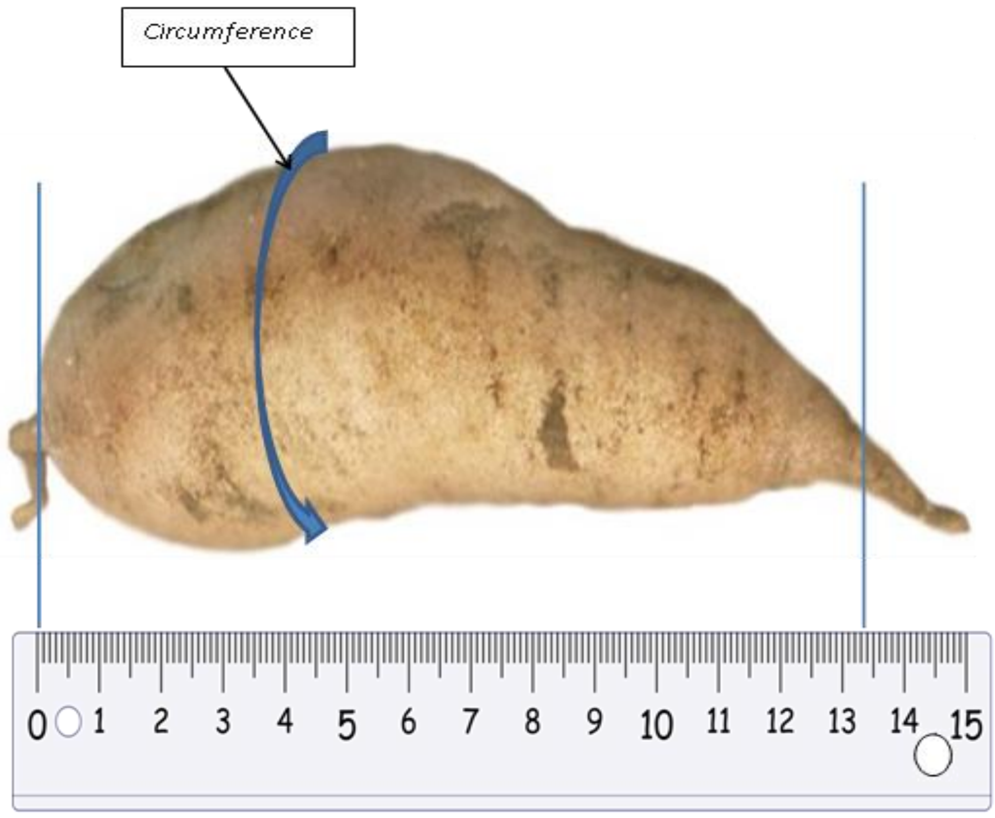


Plate 3.2: Measurement of circumference and length of sweet potato storage root

Storage root nutritional contents

Ten samples, each consisting of two storage roots were taken at random per clone and the farmer-preferred variety and nutritional contents were determined. The samples were taken from the plots which were watered throughout the growing period of the sweet potato plants to get the genetic potential of the clones. Nutritional analysis including protein, starch, vitamin A and total sugar contents of sweet potato storage roots were performed in the department of food science nutrition and technology laboratory of the University of Nairobi.

Protein content

Protein (N × 6.25) was determined according to Association of Official Analytical Chemistry (Association of Official Analytical Chemists, 1980), method. The sweet potato storage roots were cleaned and washed then made into slices and spread in hot air oven trays and allowed to dry at 65 ºC. Drying was continued until the sweet potato became crisp, later made into powder and packed in an aluminum foil bag. The protein content of the dried samples was estimated as per cent total nitrogen by the Kjeldahl procedure. Protein per cent was then calculated by multiplying the per

Total sugar content

The total sugar content of sweet potato storage roots was determined according to the spectrophotometric Anthrone method modified by Tokusoglu *et al.* (2003; 2005) using saccharose as standard anhydroglycose for sweet potato. Standard buffer stock solutions containing anthrone reagent and samples were measured for 620 nm at spectrophotometer.

Total starch content

The total starch content of sweet potato storage roots was determined by using the method of International Starch Institute-Denmark described by Woolfe (1992).

Vitamin A content

2 g sweet potato storage roots sample was extracted with diisopropyl ether according to the method. Then re-saponifed with 5% KOH and washed with 10% sodium chloride. Vitamin A (retinol) stock and standard solutions and sample solutions were measured for 325 nm at spectrophotometer (Speek *et al.*, 1986).

The following data were collected from the experimental plots of the planting beds experiment for storage root yield:

Storage root yield

The crop was harvested five months after planting and storage root yield from each plot was determined. All the three ridges of sweet potato in each plot were harvested for the determination of sweet potato storage root yield. At harvest, plot wet weight was measured after detaching the storage roots from the plant.

Storage root number

The number, of marketable storage roots per plant were recorded after harvesting. The number of marketable storage roots was taken by counting the individual storage roots per plant.

The following data were collected from the experimental plots of the planting beds experiment for ground cover:

Foliage cover (Percent ground cover)-Ornamental quality

Data on percent ground cover (foliage cover) was collected from the experimental plots for ornamental sweet potato varieties. Measurements of ground cover were carried out two months after planting the ornamental sweet potato varieties. Percent ground cover was estimated using the beaded string method (Sarrantonio, 1991). Marks were made on a cotton string at 15 cm intervals. The string was stretched along one diagonal in each plot and all marks falling directly above foliage were counted and recorded. This procedure was repeated for the second diagonal. The total number of possible marks for the two diagonals was recorded.

The following formula by Sarrantonio (1991) was used to determine percent ground cover:

$$G_c = \frac{Total\ marks\ directly\ above\ foliage\ (F'_d + S'_d)}{Total\ possible\ marks\ in\ the\ plot\ (F_d + S_d)}\ x\ 100$$

Where G_c is percent ground cover, F'_d is count in the first diagonal, S'_d is count in the second diagonal, F_d is total marks in the first diagonal, and S_d is total marks in the second diagonal.

The following data were collected from the experimental plots of the planting material multiplication experiment:

Vine yield

Vine yield from each plot was determined by measuring the vine length using a tape measure at eight WAP. The two rows of sweet potato in each plot were harvested for the determination of total vine length per plot. The total vine length per plot was then converted to total vine length per square meter (i.e. vine yield or vine production potential) by using the following formula:

$$Y_v = \frac{L_P}{A_p}$$

Where Y_v = vine yield (m m^{-2}), L_p = total vine length (m) per plot, and A_p = plot area in m^2.

The vine yield (vine production potential) was then used to calculate the land size that would be required to multiply enough sweet potato planting material for one hectare, using the following formula:

$$A_a = \frac{C \; x \; L_c}{Y_v}$$

Where A_a = land size (m^2) required to multiply enough sweet potato planting material for one hectare, C = number of cuttings required to plant one hectare, L_c = length (m) of a cutting, and Y_v = vine yield (m m^{-2}).

The following data were collected from the experimental plots of the on-farm experiment:

Storage root yield

The crop was harvested five months after planting and storage root yield from each plot was determined. All the three ridges of sweet potato in each plot were harvested for the determination of sweet potato storage root yield. At harvest, plot wet weight was measured after detaching the storage roots from the plant.

Storage root number

The number, of marketable storage roots per plant were recorded after harvesting. The number of marketable storage roots was taken by counting the individual storage roots per plant.

3.6 Data analysis

The sweet potato storage root yield and yield characteristics, vine yield and percent ground cover data were all subjected to the analysis of variance (ANOVA) using the General Linear Model (GLM) procedure of the Statistical Analysis System (SAS) Version 9.1 (SAS Institute, 2002). Because of the high variability observed in the data, square root transformation of the original data (n) was performed before analysis to improve the normality of the data. Where the F values were significant, treatment means were separated using the Least Significant Difference (LSD) at the 5% level of significance.

CHAPTER FOUR

YIELD PERFORMANCE OF SELECTED SWEET POTATO CLONES UNDER DIFFERENT WATERING REGIMES

Abstract

The production of sweet potato in coastal Kenya is diminishing due to unreliable rainfall. Farmers are currently using unimproved sweet potato varieties that are not drought tolerant due to unavailability of improved varieties. A study was therefore conducted at Pwani University from 2016 to 2017, to identify sweet potato clones that would give high yield with minimal watering. Nine drought tolerant clones (6.1A, 4.10, 7.8, 15.10, 7.6AO, 10.10B, 4.2B, 7.6B and 4.2A) and a farmer-preferred variety "Rabai" were evaluated under four watering regimes: (i) Watering for the first two months after planting and stressing the plants for the next three months, (ii) Watering for the first three months after planting and stressing the plants for the next two months, (iii) Watering for the first four months after planting and stressing the plants for the next one month, and (iv) Watering throughout the growing period and not stressing the plants at all. The different watering regimes were meant to mimic the occurrence of rains for a given period within the season, followed by their disappearance in the remaining part of the season, as experienced in coastal Kenya. A Randomized Complete Block Design was used, with factorial arrangement of treatments. Treatments were replicated three times. The data collected included storage root yield, storage root characteristics (number, length and circumference) and storage root nutritional contents (protein, starch, vitamin A and total sugars). Sweet potato yield was determined using a weighing scale. The number, length and circumference of storage roots were recorded after harvesting. All the yield and yield characteristics data were subjected to analysis of variance using the general linear model. Storage root circumference was reduced by limited water irrespective of the time it started after planting. Water application that was stopped early in the season

reduced the storage root yield by up to 70%. Sweet potato clones 4.10 and 7.6B had high yield performance across seasons, irrespective of the watering regime. However, clone 4.10 had the lowest content of total sugars (192 mg/100g) and this was considered a bottleneck to the potential adoption by farmers and acceptance by the market. Clones 4.2B, 7.6B and 4.2A had the highest contents of total sugars (1142-1433 mg/100g) and were therefore likely to be adopted by farmers and accepted by the market. Farmers are likely to realize improved storage root yield by planting sweet potato early in the rainfall season to ensure adequate utilization of the rains during the first four months of crop growth. It is therefore recommended that clones 4.2B, 7.6B and 4.2A be multiplied for use by farmers in the drought prone areas of coastal Kenya. In order to realize enhanced storage root yield, it is recommended that farmers plant the crop early enough in the planting season to ensure adequate utilization of the rains.

4.1 Introduction

Sweet potato is among the most important food crops in the world (Gichuki and Hijmans, 2005). Globally, sweet potato yield of 11.4 t ha^{-1} was realized in 2018 (FAOSTAT, 2018). The crop is regarded as both food security and cash crop in Sub-Saharan Africa countries (Kivuva *et al.*, 2014a) and can contribute to sustainable agricultural development, boost economic growth and reduce poverty and, hence, reduce malnutrition and hunger in the region. The crop does well in areas that receive an annual rainfall of between 750 to 1000 mm (Makini *et al.*, 2018).

In coastal Kenya maize is the staple food and it is mainly cultivated by smallholder farmers under rain fed conditions but due to increasing climatic uncertainty and declining soil fertility, crop failures often result in shortages affecting many people every year, therefore crop diversification is very important in addressing this food challenge. Sweet potato is a supplementary staple food in the region, especially when the cereals are not ready. The crop also has potential as a commercial crop in coastal

Kenya. Sweet potato having the advantage of being drought tolerant after establishment has higher yield potential, compared to the staples including maize, and its nutritional benefits is important to farmers in drought prone areas (Motsa *et al.*, 2015).

Drought, resulting from both erratic and low rainfall amounts, poses a major threat to sweet potato production (Mir *et al.*, 2012). Total potato tuber yield was affected by drought leading to 19-23 t ha^{-1}, 11.4-13.7 t ha^{-1} and 8.1-11.3 t ha^{-1} at field capacity, 50% and 25% moisture, respectively (Kesiime *et al.*, 2016). Some sweet potato varieties may exhibit drought tolerance (Aldow, 2017). Under water stress conditions, as vegetative growth decreased storage root yield of sweet potato also reduced (Saqib *et al.*, 2017). The sweet potato clones used in this study were selected for drought tolerance in the Kenyan highlands. This therefore emphasized the need for yield evaluation of sweet potato clones that were bred for drought tolerance, in coastal Kenya under different watering regimes.

Sweet potato varieties that are adaptable to the drier zones of coastal Kenya, agro-ecological zones CL4 and CL5, which receive an average annual rainfall of 600 to 900 mm are yet to be identified. Identification of such varieties will help in the expansion of sweet potato production into the low rainfall areas in the region. Considering the fact that sweet potato is a supplementary staple to cereals and a food security crop, there is need to increase its production by addressing the above constraint. This study was therefore conducted to identify sweet potato clones that can perform well under limited water. Limited water was achieved by withdrawing the watering after a certain time of watering from planting. This was done to ensure the treatments under limited water did not have adequate moisture during the growing period.

4.2 Materials and Methods

4.2.1 Site description

The study was conducted for two seasons (December 2016 to April 2017 and July 2017 to November 2017), at the Pwani University farm in Kilifi County. The site characteristics are as described in Chapter 3, Section 3.1.

4.2.2 Treatments

The following treatments were evaluated:

Factor A: Nine sweet potato clones (6.1A (C1), 4.10 (C2), 7.8 (C3), 15.10 (C4), 7.6AO (C5), 10.10B (C6), 4.2B (C7), 7.6B (C8) and 4.2A (C9)) that had been reported to be drought tolerant (Appendices 4.1 - 4.9) were obtained from KALRO-Muguga for use in this study. A farmer-preferred variety from Kilifi namely, "Rabai" (VR) was included as a local check (Appendix IVj)

Factor B: Watering regimes

(i) Watering for the first two months after planting and stressing the plants for the next three months - (W2)

(ii) Watering for the first three months after planting and stressing the plants for the next two months - (W3)

(iii) Watering for the first four months after planting and stressing the plants for the next one month - W4)

(iv) Watering throughout the growing period and not stressing the plants at all - (W0)

Therefore, there were 40 treatment combinations, replicated three times (making a total of 120 experimental units).

A Randomized Complete Block Design (RCBD) was used. The treatments were arranged in a factorial manner and replicated three times (Table 4.1).

Table 4.1: Experimental field layout

BLOCK 1

PLOT	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
TRT	C7 W4	C2 W3	C4 W4	C6 W2	C3 W0	C7 W2	C5 W4	VR W0	C2 W2	VR W4	C9 W4	C3 W3	C1 W3	C4 W2	C4 W0	VR W2	C9 W2	C3 W4	C1 W4	C6 W4
PLOT	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24	23	22	21
TRT	C6 W0	C6 W3	C1 W0	C8 W2	C2 W0	C9 W0	C8 W4	C1 W2	C7 W0	C2 W4	C5 W2	C7 W3	C3 W2	C8 W0	C4 W3	C9 W3	C5 W0	VR W3	C8 W3	C5 W3

BLOCK 2

PLOT	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
TRT	C4 W0	VR W2	C6 W0	C2 W4	C7 W3	C6 W4	C2 W2	C7 W4	C3 W3	C4 W3	C5 W0	C9 W4	C1 W2	C7 W0	C9 W2	C9 W3	C8 W2	C4 W2	C3 W4	C8 W0
PLOT	80	79	78	77	76	75	74	73	72	71	70	69	68	67	66	65	64	63	62	61
TRT	C5 W3	C3 W2	C4 W4	VR W0	C5 W2	C3 W0	VR W4	C8 W3	C5 W4	C9 W0	C2 W0	C6 W3	C1 W3	C1 W0	C1 W4	VR W3	C7 W2	C6 W2	C8 W4	C2 W3

BLOCK 3

PLOT	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
TRT	C7 W0	C7 W3	C1 W2	C9 W4	C6 W2	VR W2	C4 W4	C2 W4	C5 W3	C4 W2	C5 W0	C3 W3	C8 W0	C4 W0	C2 W2	C3 W0	C2 W0	C6 W3	C1 W0	C8 W2
PLOT	120	119	118	117	116	115	114	113	112	111	110	109	108	107	106	105	104	103	102	101
TRT	C8 W3	C1 W3	C4 W3	C8 W4	VR W0	VR W3	VR W4	C3 W4	C1 W4	C6 W0	C7 W4	C9 W3	C9 W0	C7 W2	C5 W4	C3 W2	C9 W2	C6 W4	C2 W3	C5 W2

4.2.3 Crop establishment and management

The sweet potato vines were planted as described in Chapter 3, Section 3.5. The crop was managed as described in Chapter 3, Section 3.6. Water application in the appropriate plots was done at the rate of 750 ml per plant per day, as per the recommendation by Nedunchezhiyan *et al*. (2012).

4.2.4 Data collection and analysis

The following data were collected:

(i) Storage root yield

(ii) Storage root characteristics (number, length and circumference)

(iii) Storage root nutritional contents (Protein, starch, vitamin A and sugar contents)

The collected data were analyzed as described in Chapter 3, Section 3.8.

4.3 Results and Discussion

Effect of watering regime on yield and yield characteristics of sweet potato storage roots

The number and circumference of marketable sweet potato storage roots were significantly ($F = 30.38$; $P<0.05$), ($F = 50.37$; $P<0.05$) affected by watering regimes (Table 4.2). Marketable storage roots consist of the fraction of total storage roots that meets the size, shape, weight and quality requirements of the intended market (Love and Thompson-Johns, 1999). Plants that were subjected to watering regimes W0 and W4 did not differ in their number of marketable storage root but had significantly higher number of marketable storage roots than those subjected to watering regimes W3 and W2. Sweet potato plants that were subjected to watering regime W2 had the smallest number of marketable storage roots per plant. Plants that were watered throughout the growing season (W0) had significantly thick storage roots, followed by those that were stressed for one month (W4), two months (W3) and lastly for three months (W2). Reducing sizes of storage roots is among the drought tolerance mechanisms used by sweet potato when it is subjected to moisture stress conditions (Kivuva, 2013). This probably explains the observed decrease in the circumference of storage roots where watering was stopped during growth. It is expected that when a plant is subjected to water stress, the rate of photosynthesis will be reduced, leading to a reduction in the amount of photosynthates translocated to the storage organs of the plant. The results of this study are in agreement with those by Kivuva (2013) who reported decreased number of sweet potato storage roots under water stress condition.

Table 4.2: Effect of watering regime on the number and circumference of marketable storage roots per plant

Watering regimes	Number of marketable storage roots per plant	Storage root circumference (cm)
W0	2.42^{a}	12.19^{a}
W4	2.37^{a}	11.01^{b}
W3	1.86^{b}	8.98^{c}
W2	1.43^{c}	6.34^{d}
LSD	0.2845	0.9993
Pr>F	<.0001	<.0001

Watering regimes: W2 = watering for the first two months after planting and stressing the plants for the next three months, W3 = watering for the first three months after planting and stressing the plants for the next two months, W4 = watering for the first four months after planting and stressing the plants for the next one month, W0 = watering throughout the growing period and not stressing the plants at all (i.e. watered up to the time of harvesting)

Means within a column followed by same superscript are not significantly different at $P<0.05$.

Plants that were watered throughout (W0) and those that were subjected to limited water for one month (W4), following continuous watering for four months, did not differ in their number of marketable storage roots. This is attributed to the sufficient soil moisture during the root initiation period, which is within the first few weeks after they are planted, and by the time stress commenced in the W4 treatment, the storage roots were already fully formed. Probably this could have been the reason as to why there was no difference in storage root numbers in W0 and W4 in this study. Water provided late in the growing period is known to encourage vegetative growth but not the development of new storage roots (Ekanayake *et al*, 1990). Stressing sweet potato plants for two months or for three months caused a reduction of the circumference of storage roots by 26 and 48%, respectively. Similarly, two months stress and three months stress reduced the number of marketable storage roots by 23 and 41%, respectively. These results are in agreement with the findings by Ekanayake *et al.* (1990) who observed fewer marketable storage roots in sweet potato plants that had been subjected to water stress than in those plants that were watered throughout the growing season. The results of this study are also in conformity with those of Rahmawati *et al.* (2020) which showed that water stress significantly decreased the number of storage roots by 76.03%.

Makanginya (2012) results showed that water stress reduced the number of storage roots per plant. According to Bok *et al.* (2004) cultivars with larger storage roots produced fewer numbers of storage roots and vice versa. However, this was not the case in this study as the overall best clone C2 had the best storage roots in all the parameters tested including circumference, length and weight.

Watering regime had significant ($F = 68.62$; $P<0.05$), ($F = 63.87$; $P<0.05$) effect on storage root yield per hectare (Table 4.3). Plants that had not been subjected to limited water during the growing season (watering regime W0) had significantly higher fresh storage root yield than those subjected to limited water for one month, following continuous watering for four months after planting (watering regime W4). Prolonged watering, beyond four months after planting, probably led to increased water content in the storage roots and hence increased wet weight. However, the two watering regimes (W0 and W4) had similar effect on dry storage root yield. This is probably an indication that the water applied four months after planting was only effective in increasing the moisture content of sweet potato storage roots. Therefore, farmers growing sweet potato for processing do not have to water the plants four months after planting. Watering that was stopped early in the season, at three (W3) or two (W2) months after planting, led to a 52-70% reduction in the storage root yield. In their study Laurie *et al.* (2015) concluded that drought had a detrimental effect on the growth of sweet potato plants to such an extent that no significant differences could be observed under severe drought conditions between the genotypes, and the yield observed was also largely affected by retarded growth as a result of the drought conditions. These results are in agreement with the findings by Ekanayake and Wanda (2004) and Laurie *et al*. (2009) who observed that irrigation treatments had significant effect on marketable storage root yield. Results observed under this study are consistent with the results of Lewthwaite and Triggs (2012) who observed significant differences in most of the genotypes evaluated with the more irrigated ones producing a higher yield, although some genotypes did not show any difference in yield at different irrigation levels applied. The observed significant reduction in yield of sweet potato that had been subjected to limited water condition in this study could be the result of closure of stomata, with the resultant decline in photosynthetic and transpiration rates, as suggested by Laurie *et al*. (2009). The results of this study are in line with Wamala and Akanda (2013) results which showed that different genotypes had different storage root yield at different watering regimes and some genotypes had stabilized storage root yield even when the water stress was prolonged.

Table 4.3: Effect of watering regime on sweet potato storage root yield (wet-weight and dry-weight basis)

Watering regimes	Storage root yield (wet-weight basis)	Storage root yield (dry-weight basis)
	------------------------- (t $^{ha-1}$)	------------------------
W0	6.40 ^{a}	1.57 ^{a}
W4	5.31 ^{b}	1.43 ^{a}
W3	3.15 ^{c}	0.75 ^{b}
W2	1.99 ^{d}	0.46 ^{c}
LSD	0.6714	0.206
Pr>F	<.0001	<.0001

Watering regimes: W2 = watering for the first two months after planting and stressing the plants for the next three months, W3 = watering for the first three months after planting and stressing the plants for the next two months, W4 = watering for the first four months after planting and stressing the plants for the next one month, W0 = watering throughout the growing period and not stressing the plants at all (i.e. watered up to the time of harvesting)

Means within a column followed by same superscript are not significantly different at $p<0.05$.

Water stress decreased plant growth by affecting the uptake of nitrogen and magnesium that are required for cell growth and chlorophyll synthesis (Rodriguez-Delfin *et al.*, 2012). The high storage root yield observed in sweet potato that had been watered throughout the growing season was probably due to improved cell growth and chlorophyll synthesis, leading to increased photosynthesis. Inadequate rainfall amount has been reported to reduce the rate of photosynthesis and the partitioning of assimilates, leading to low yield (Roitsch *et al.*, 2003). The observed yield reduction in sweet potato subjected to limited water in this study was probably the result of reduced rates of photosynthesis and inefficient partitioning of assimilates. Saqib *et al.* (2017) showed that sweet potato yield parameters (storage root length, storage root diameter, number and fresh weight of marketable storage roots per plant) were directly linked with vegetative growth. Consequently, when moisture stress caused a reduction in vegetative growth, the storage root yield also declined (Saqib *et al*., 2017).

In a study by Makanginya (2012) severe drought reduced both fresh and dry storage root weight of sweet potato genotypes as it is the case with this study. From the results of their experiment Kirnak *et al.* (2001) concluded that water stress significantly decreased leaf chlorophyll concentrations, plant growth and fruit yield in eggplant as severe water stress treatment reduced the fruit yield by 66% compared to control treatment, and high water stress lowered nutrient levels. According to Motsa *et al.* (2015) limiting the biomass due to limiting the canopy which is the only source of biomass for subsequent partitioning to the storage roots in sweet potato would consequently lead to a source limitation of assimilates to storage roots, therefore lowering the yield. Proline was found to be involved in tolerance mechanism and was the main strategy by which plants avoided detrimental effects of water stress. The observed significant effect of watering regime on storage root fresh weight and dry weight, circumference and number per plant is in conformity with the results of Ekanayake and Wanda (2004) that showed significant effect of total irrigation on all measured traits of sweet potato. These findings correlate with those of a research on cassava by Turyagyenda *et al.* (2013) where water stress resulted in mean decline of 37.04% in mean yield and 19.43% in number of roots. The significant effect of watering regime on sweet potato storage root yield and root characteristics could be as a result of a large set of parallel changes in the morphological, physiological and biochemical processes when the clones and the farmer preferred variety were exposed to limited water which may affect growth, as demonstrated by the results of Laurie *et al.* (2009). According to Delazari *et al.* (2018) the reduction in the growth of plants under water stress is due to water stress limiting stomatal conductance, transpiration, leaf growth (LAI) and chlorophyll concentration, proportional to soil moisture conditions.

Effect of watering regimes and clones on yield and yield characteristics of sweet potato storage root

Results of this study showed significant ($F = 1.58$; $P<0.05$) interaction effect of watering regime and sweet potato clone on storage root length (Figure 4.1). Clone C2 produced long storage roots irrespective of the watering regime. The length of storage roots in C9 was reduced by more than 35% when watering was stopped 2, 3 and 4 months after planting. While the farmer-preferred variety produced shorter storage roots than clones C3, C4, and C7 when watering was stopped at four months after planting, it did not differ with the three clones when watered throughout the growing season. This is an indication that the farmer-preferred variety of sweet potato has the same potential as that of clones C3, C4, and C7 when subjected to optimum watering.

When water application was stopped at two months after planting, clone C2 produced longer storage roots than the rest of the clones and the farmer-preferred variety (VR). Sweet potato clones C2, C5 and C8 produced roots of similar length when the plants were subjected to limited water for two months, following continuous watering for three months after planting. These observations show that the response of sweet potato length to watering regime is dependent on both the duration of water application and the variety. These results are not in agreement with those by Ekanayake *et al*. (1990) who observed that the interaction of sweet potato clone and water stress level had no significant effect on sweet potato yield indices.

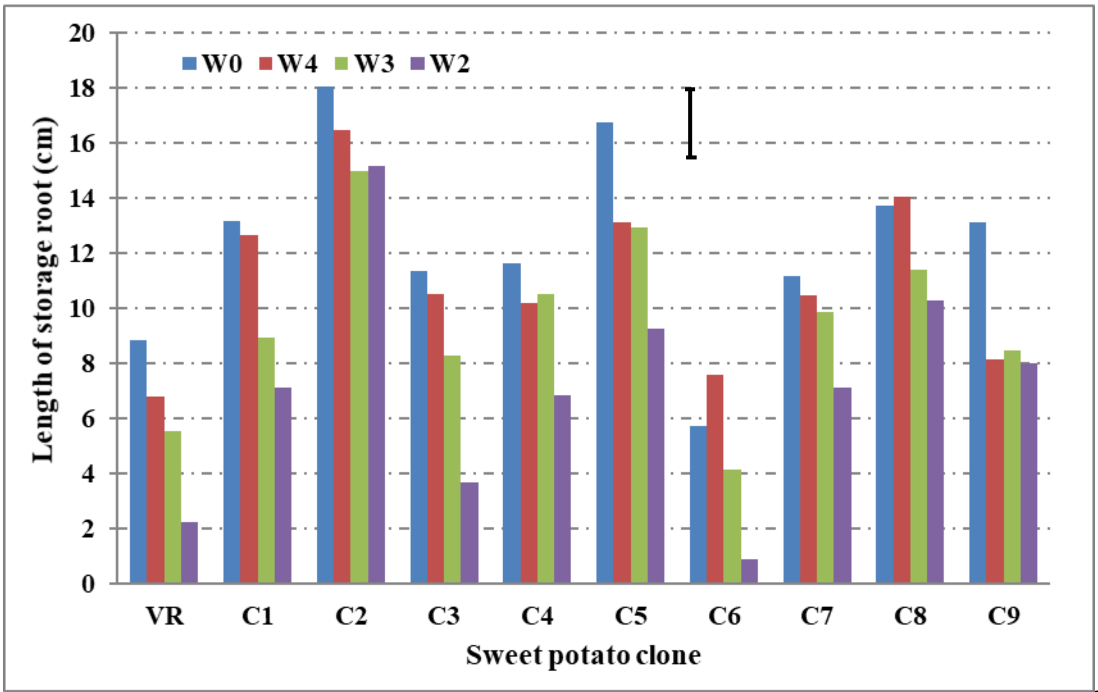


Figure 4.1: Effect of watering regime and sweet potato clone on the length of sweet potato storage root (cm)

The results showed significant (F = 2.03; P<0.05) interaction effect of watering regime and sweet potato clone on percent dry matter of storage root (Figure 4.2). Sweet potato clones C1, C2, C4, C8 and C9 were not affected by stress levels in terms of storage root percent dry matter. Even with severe stress they still had adequate amount of dry matter. This may be attributed to the genetic makeup of these clones. Clone C5 was the most affected by severe stress. The two factors i.e. watering regime and sweet potato clone independently had no significant effect on percent dry matter of storage roots. However, their interaction significantly affected the storage root percent dry matter. This therefore shows that watering regime had influence on the clones, on their performance in terms of percent dry matter or the performance of the clones on percent dry matter depended on the period of water application. The fact that watering regimes independently had no significant effect on percent dry matter of storage roots is contrary to the results of Ekanayake and

Wanda (2004) which showed that root dry matter increased as water stress increased and was the most sensitive root quality trait. These study results of watering regime where there are some significant interactions effect between clones and environment are disagreeing with the results of Ekanayake *et al.* (1990) in which all the sweet potato yield indices had non-significant effect of interactions between clones and environment.

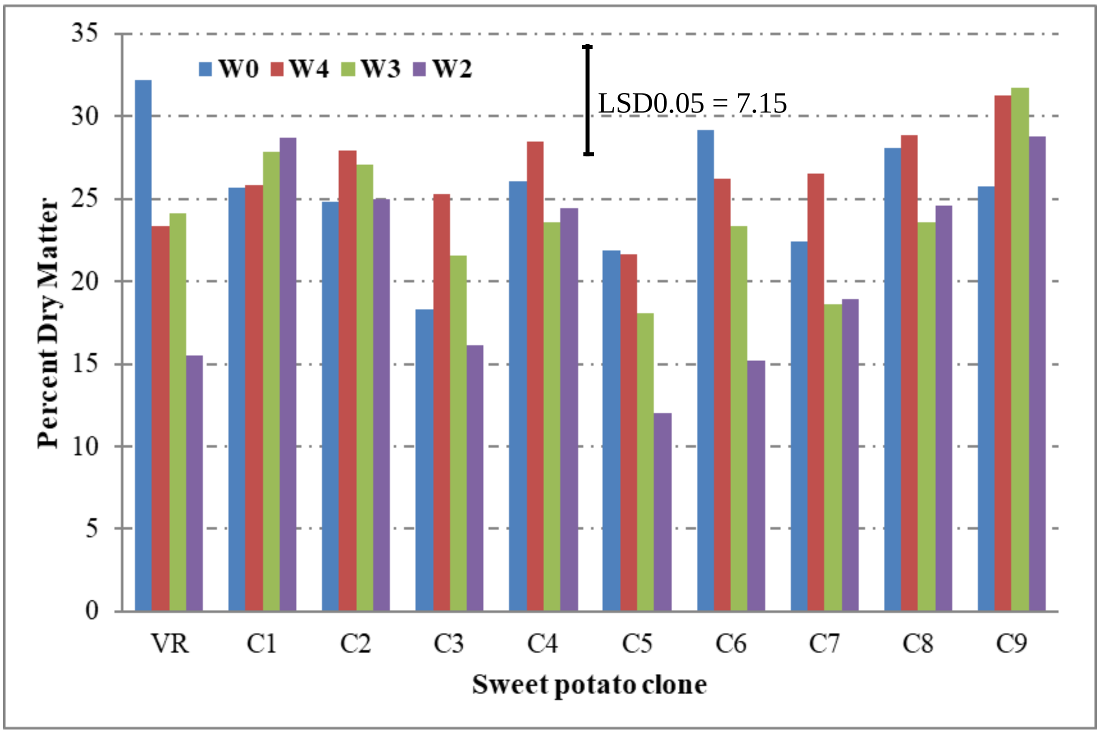


Figure 4.2: Effect of watering regime and sweet potato clone on dry matter (%) of storage root

Effect of clones and seasons on yield and yield characteristics of sweet potato storage root

The results of this study showed that interaction of season and sweet potato clone had significant ($F = 10.67$; $P<0.05$), ($F = 7.23$; $P<0.05$) effect on both fresh and dry storage root yield of sweet potato (Figures 4.3 and 4.4). Sweet potato clone C2 had significantly higher fresh or dry storage root yield than the rest of the drought tolerant clones and the farmer-preferred variety across seasons. While clones C1 and C9 gave higher fresh storage root yield in season 1 than in the second season, clone C8 gave yields that were similar in the two seasons (Figure 4.3). The fresh storage root yields of clones C3 and C7 were higher in the second season than those realized in season 1. While clones C3, C7 and C8 gave lower dry storage root yields in the first season than those realized in the second season (Figure 4.4), clone C2 had significantly higher dry storage root yield in season 1 than in season 2. Osiru *et al.* (2009), observed variable yield response of sweet potato genotypes across seasons. This probably explains the variable yield responses of the drought tolerant clones and farmer-preferred variety evaluated in this study, across seasons.

Clone C2 was superior in its performance probably because it was more tolerant to limited water than the rest of the drought tolerant sweet potato clones and the farmer-preferred variety. This mostly is due to the innate genetic attribute of this clone in response to limited water supply. Mbinda *et al*. (2018) reported that sweet potato plants with high capacity for water retention are most likely to survive low water stress for longer periods than those with low capacity. This probably explains the best performance of sweet potato clone C2 compared with the other clones and the farmer-preferred variety. According to Rykaczewska (2015) plants exposed to high temperatures in dry conditions had lower photosynthetic activity, leading to reduced accumulation of photosynthates in their storage organs. This probably explains the observed low storage root yield from sweet potato subjected to limited water in this study, conducted at a site whose temperatures were high during the study period.

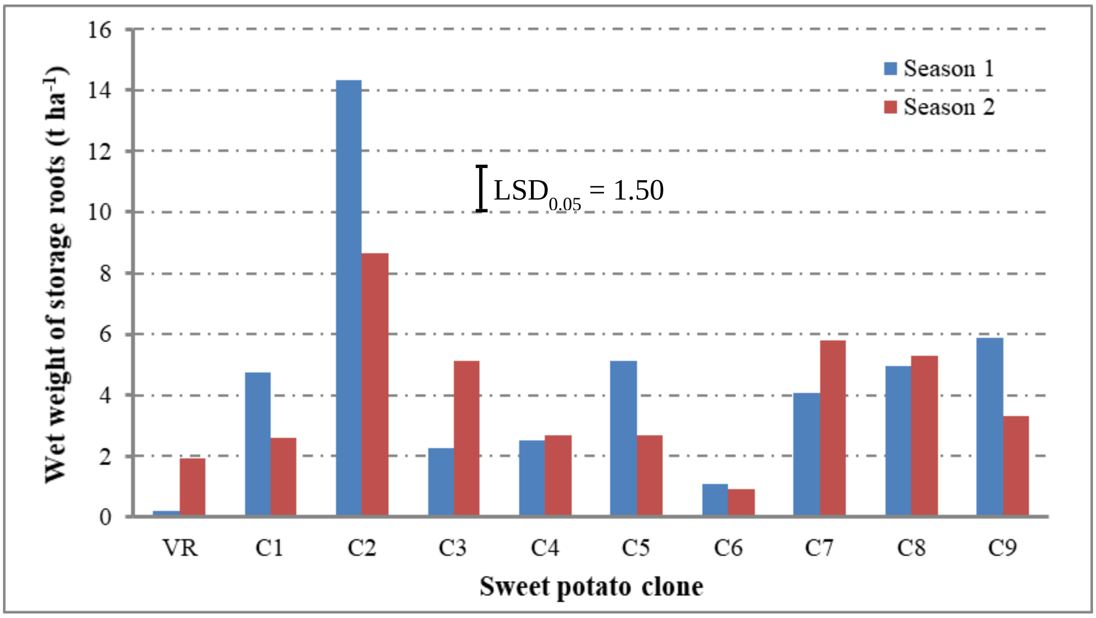


Figure 4.3: Effect of season and sweet potato clone on sweet potato fresh storage root yield (wet-weight basis)

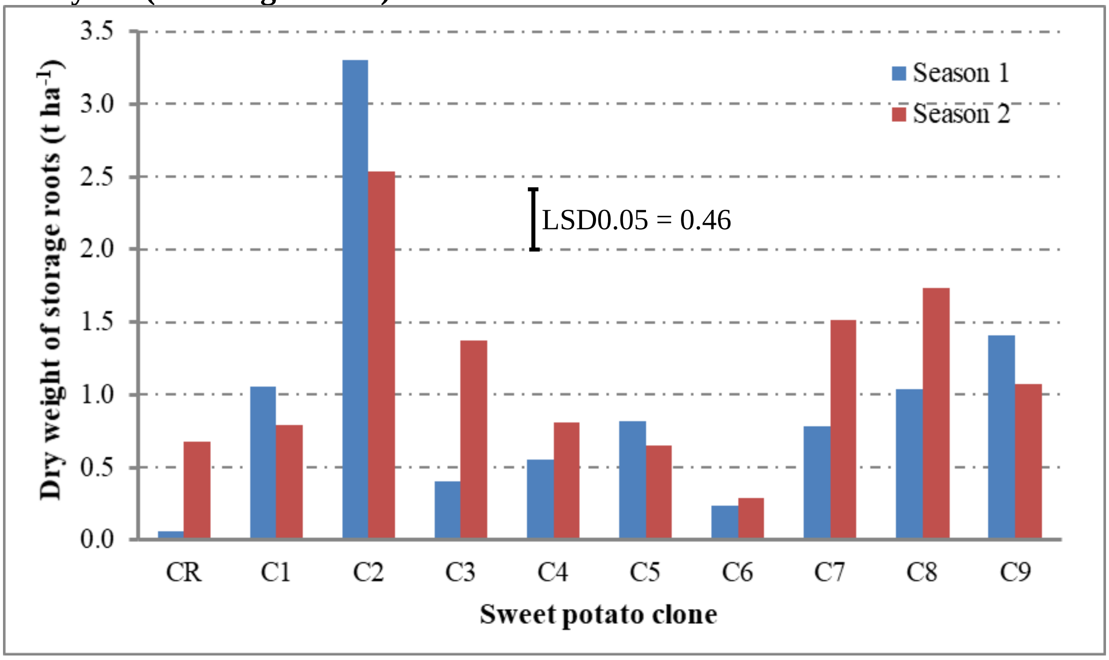


Figure 4.4: Effect of season and sweet potato clone on dry storage root yield of sweet potato (dry-weight basis)

The interaction effect of season and clone on the circumference and length of sweet potato storage roots was significant (F = 11.32; P<0.05), (F = 13.80; P<0.05) (Figures 4.5 and 4.6). While marketable storage roots of clones C3 and C7 and farmer-preferred variety (VR) had significantly smaller circumference in season 1 than in season 2, the reverse was true for clone C9 (Figure 4.5). Sweet potato clones C1, C2, C4, C5, C6 and C8 had similar circumferences of storage roots in both seasons. While the storage roots for clones C1, C4, C5 and C9 were significantly longer in season 1 than in season 2, the reverse was true for the farmer-preferred variety (VR) (Figure 4.6). Clones C2, C3, C6, C7 and C8 produced storage roots that had similar lengths in both seasons. The observed seasonal variability in the size of storage roots of the drought tolerant clones and farmer-preferred variety is in agreement with the observations by sweet potato farmers that the performance of some of the varieties grown in coastal Kenya is season specific. In this case a superior sweet potato variety for the region would be one that maintains high yield level across seasons.

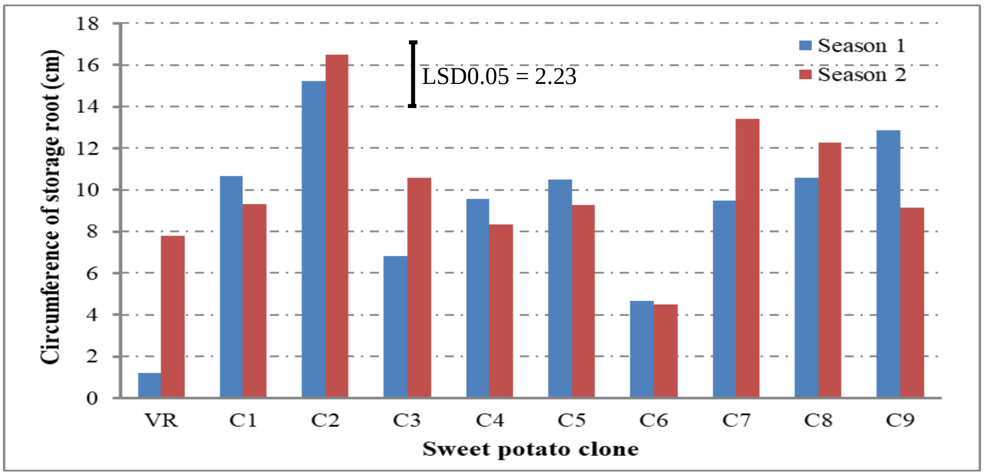


Figure 4.5: Effect of season and sweet potato clone on circumference of sweet potato storage root (cm)

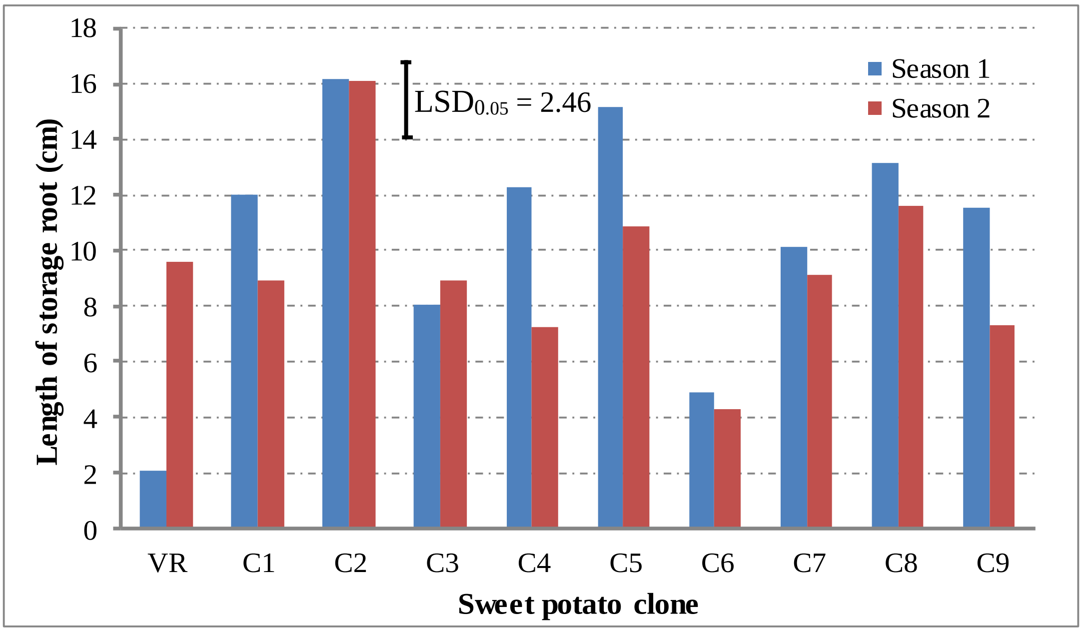


Figure 4.6: Effect of season and sweet potato clone on length of sweet potato storage root (cm)

The results showed significant (F = 12.93; P<0.05) interaction effect of season and clone on number of marketable storage roots per plant (Figure 4.7). Clone C2 maintained the same number of marketable storage roots across seasons. This is an indication that the production of marketable storage roots in clone C2 was not influenced by season. While the number of marketable storage roots was significantly higher for clone C2 than for the other eight clones and the farmer-preferred variety in season 1, it did not differ with clones C3, C7 and C8 in season 2.

Variability among clones for number of marketable storage roots, might be due to both genetic and environmental factors. The ambient temperatures in season 1 were higher than those in season 2 (Appendix Ib). High temperatures are known to have negative effect on dry matter accumulation in sweet potato (Gajanayake *et al.*, 2015).

In potato, elevated temperature significantly lowered the rate of dry matter partitioning to tubers and their growth (Van Dam *et al.*, 1996). Dry matter accumulation will have direct impact on the number of marketable roots, through its influence on the size and shape of sweet potato storage roots. The results of this study therefore show that clone C2 was probably less sensitive to high temperatures than were the other eight clones and the farmer-preferred variety. The observed similarity in the number of marketable storage roots in clones C2, C3, C7 and C8 in season 2 probably shows that these clones had the same potential when subjected to favorable temperatures. Variability for most of the yield components in sweet potato is attributable to genetic factors and also environmental factors (Yadeta *et al.*, 2011). Temperature is among factors affecting sweet potato growth and productivity (Mandal, 2006). During the time these trials were conducted, temperatures were favorable during season 2 which was not the case for season 1. Season 2 was from July to November while season 1 was from December to April, a time when there are high temperatures in coastal Kenya. Lower number of marketable sweet potato storage roots in season 1 compared to season 2 may be explained by the temperature factor. Meteorological data for the two seasons during the experiment showed that season 2 was characterized by favorable temperatures whereas season 1 had higher temperatures.

Sweet potato clones C3 and C6 were not affected by season in terms of their number of marketable storage roots in both seasons. This probably shows that these clones performance in terms of number of marketable storage roots is not influenced by season. Therefore they are able to give the same results irrespective of different conditions. While the farmer-preferred variety had significantly lower number of marketable storage roots in season 1 than in the second season, the reverse was true for clones C1, C2, C4, C5, C7, C8 and C9. This probably shows that these clones performance in terms of number of marketable storage roots is influenced by season. Therefore they perform differently in reference to the conditions they are exposed.

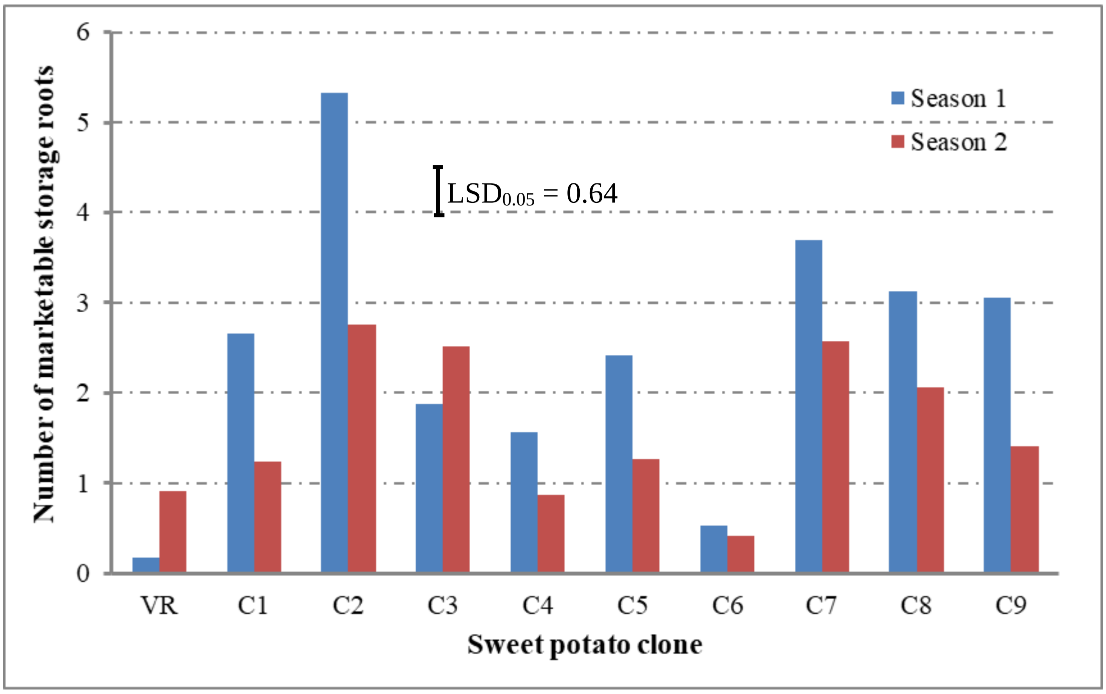


Figure 4.7: Effect of season and sweet potato clone on the number of marketable sweet potato storage roots per plant

It was observed in this study that there was significant (F = 5.17; P<0.05) interaction effect of season and sweet potato clone on percent DM of storage root (Figure 4.8). Sweet potato clones had different dry matter content in different seasons. All the sweet potato clones evaluated in this study had lower % dry matter in season 1 than in season two. Accumulation of dry matter in the evaluated sweet potato clones was influenced by season. Plants exposed to high temperatures in dry conditions had lower photosynthetic activity, leading to reduced accumulation of photosynthates in their storage organs (Rykaczewska, 2015).

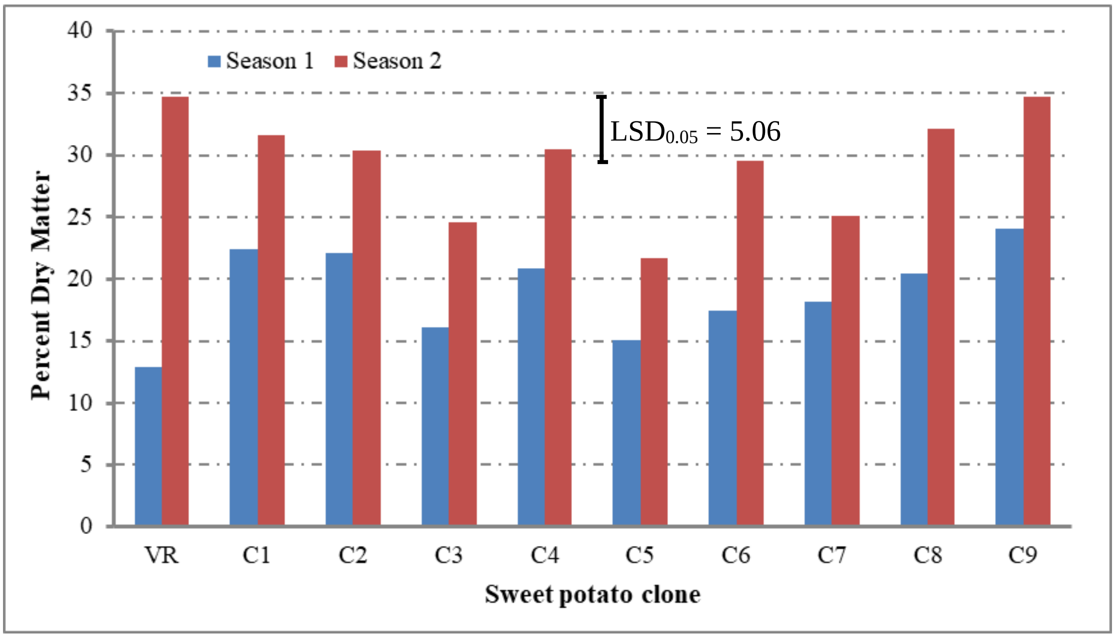


Figure 4.8: Effect of season and sweet potato clone on dry matter (%) of storage root

Sweet potato clone C7 had the highest amount of total sugars and starch, while C5 had the highest amount of vitamin A, and C3 had the highest amount of protein (Table 4.4). Sweet potato has been shown to have an enormous amount of genetic variation for nutritional quality attributes (Andrade *et al.*, 2009). The genotype by environment interaction has been observed to be low for all sweet potato quality traits, except protein, iron and zinc (Andrade *et al.*, 2009). In this study, clone C2 had the least total sugars but was shown to be superior in terms of yield and all the yield parameters. This clone (C2) may however be useful when processed into flour for making food products and animal feeds as well as in the production of starch. Andrade *et al.* (2009) observed that there was low consumption of sweet potato in some West African countries because the roots were too sweet and had low DM compared to cassava.

Table 4.4: Nutritional analysis of sweet potato clones and a farmer preferred variety

Clone	Vitamin A (µg/100g)	Total sugars (mg/100g)	Protein (%)	Starch (%)
VR	25	992.5	7.53	68.54
C1	305.4	477	10.59	59.99
C2	795.9	192	8.46	52.01
C3	69.5	849.5	10.88	47.96
C4	188.5	431.5	8.87	38.46
C5	2570.9	953.5	6.74	56.01
C6	106.2	767.3	10.28	50.87
C7	1712.4	1433.5	7.26	68.92
C8	30.7	1142.4	7.50	61.86
C9	50	1172	9.69	57.40

4.4 Conclusion and Recommendations

Sweet potato clones C2 and C8 maintained the same yield level across seasons, irrespective of the watering regime. However, clone C2 had the least amount of total sugars (192 mg/100g) and this may limit its adoption by farmers and acceptance by the market. Clones C7, C8 and C9 had the highest amounts of total sugars (1142-1433 mg/100g), a characteristic that is likely to boost their adoption by farmers and acceptance by the market. Water application that was stopped early in the season, at two or three months after planting, caused significant reduction of sweet potato storage root yield. Selection of varieties to be tested on-farm was based on their performance in terms of yield and sugar content of storage roots.

Clones C7, C8 and C9 are therefore recommended for multi-locational evaluation in coastal Kenya to ascertain their superiority to the farmer-preferred varieties. The best candidate(s) from the evaluation may then be multiplied for use by farmers in the drought prone areas of coastal Kenya. For improved sweet potato storage root yield, it is recommended that farmers plant the crop relatively early in the rainfall season so that it is not exposed to limited water within the first four months of growth.

CHAPTER FIVE

YIELD PERFORMANCE OF SELECTED SWEET POTATO CLONES UNDER DIFFERENT PLANTING BEDS

Abstract

Sweet potato is grown in several parts of the coastal region of Kenya on a small scale, where on average individual farmers allocate less than 0.2 hectares of land to the crop. One of the major factors limiting the acreage under sweet potato in the region is the slow labour-intensive preparation of planting beds for the crop. Farmers rely on family labor which is usually limited because grown up children go to school and are available to help in farming activities only during weekends. This has led to most farmers planting their sweet potato on flat ground. The study deals with drought tolerant clones bred somewhere else therefore trying to adapt them to coastal conditions. Studies from other parts of the world have shown that unlike other crops, sweet potato gives best performance when grown on ridges or raised beds. The effectiveness of planting sweet potato on special beds (ridges, or raised beds) instead of planting on flat ground has not been assessed in coastal Kenya. A study was therefore conducted to assess the yield of selected drought tolerant sweet potato clones (4.2B, 7.6B and 4.2A) planted on different planting beds (Flat bed, Raised bed and Ridge). The experiment was carried out, using the Randomized Complete Block Design, with the treatments arranged in a factorial manner and replicated three times. Use of raised beds or ridges increased the storage root yield by up to 104% and number of roots per plant by up to 41%, as compared with planting on flat beds. Sweet potato clones 4.2B and 7.6B had similar number of marketable storage roots per plant but both produced higher number of roots than clone 4.2A. It is therefore recommended that farmers plant clones 4.2B and 7.6B on raised beds or ridges for increased number and yield of sweet potato storage roots.

5.1 Introduction

Ridging and construction of raised beds are known to reduce soil bulk density and loosen compacted soils (Agbede and Adekiya, 2009; Akinboye *et al.*, 2015). These methods of preparing planting beds, therefore, enhance soil aeration and the expansion of sweet potato storage roots. Tillage has been shown to influence soil temperature, with conventionally tilled plots having significantly higher soil temperature than no till plots at the early stages of sweet potato growth (Anikwe and Ubochi, 2007). In Ghana tillage method had significant effect on sweet potato yield, where ridging led to higher net benefit than the mound method (Dumbuya *et al.*, 2016). Land preparation by ploughing, harrowing and ridging gave fine soil tilth for easy root growth and development (Akinboye *et al.*, 2015). Convectional tillage increased sweet potato storage root yield by 30% (Agbede, 2010) while planting sweet potato on flat or sunken beds led to 11% reduction in total fresh storage root yield (Ahmed *et al.*, 2012).

Braun *et al.* (2003) in Namibia recommended the planting of sweet potato on ridges rather than on flat beds in loamy sand to obtain high storage root yield. Higher sweet potato storage root yield and number of marketable roots was observed from ridges than from mounds (Brobbey, 2015). Responses to planting beds have also been reported for other root crops. Cassava that was planted on ridges had higher root yield than that planted on flat ground and this was attributed to the increased number of roots per plant under ridge-planting (Ennin *et al.*, 2009).

For farmers planting sweet potato on sloppy land, ridging along the contour will in addition help in erosion control (Akinboye *et al.*, 2015). The effectiveness of planting sweet potato on special planting beds (ridges and raised beds) as compared with planting on flat beds has not been assessed in coastal Kenya. This necessitated the need for a study to establish whether planting beds have any effect on the yield of sweet potato.

5.2 Materials and Methods

5.2.1 Site description

The study was conducted for two seasons (April to August 2018 and July to November 2018) at the Pwani University farm in Kilifi County. The site characteristics are as described in Chapter 3, Section 3.1.

5.2.2 Treatments

The following treatments were evaluated:

Factor A: Three drought tolerant sweet potato clones selected from the watering regime experiment reported in Chapter 4 of this thesis. The three selected clones were the best in terms of yield and sugar content among nine drought tolerant sweet potato clones and a farmer preferred variety. The drought tolerant clones had been obtained earlier from the Kenya Agricultural and Livestock Research Organization (KALRO) Centre at Muguga. The treatments were coded as follows:

(i) 4.2B - (C7)

(ii) 7.6B - (C8)

(iii)4.2A - (C9)

Factor B: Planting beds

(i) Flat bed - (P1)

(ii) Raised bed - (P2)

(iii)Ridge - (P3)

Therefore, there were nine treatment combinations, replicated three times making a total of 27 experimental units.

A Randomized Complete Block Design (RCBD) was used, with the treatments arranged in a factorial manner and replicated three times (Table 5.1).

Table 5.1: Experimental field layout

Block 1		**Block 2**		**Block 3**	
Plot	**Treatment**	**Plot**	**Treatment**	**Plot**	**Treatment**
1	Flat C8	10	Raised C9	19	Ridge C7
2	Flat C9	11	Raised C7	20	Ridge C8
3	Flat C7	12	Raised C8	21	Ridge C9
4	Raised C8	13	Ridge C8	22	Flat C8
5	Raised C7	14	Ridge C7	23	Flat C9
6	Raised C9	15	Ridge C9	24	Flat C7
7	Ridge C7	16	Flat C7	25	Raised C9
8	Ridge C9	17	Flat C8	26	Raised C7
9	Ridge C8	18	Flat C9	27	Raised C8

5.2.3 Crop establishment and management

The first trial (S1) was conducted between April and August 2018, while the second trial (S2) was conducted between July and November 2018. The sweet potato vines were planted as described in Chapter 3, Section 3.5.

The crop was managed as described in Chapter 3, Section 3.6.

5.2.4 Data collection and analysis

The following data were collected:

(i) Storage root yield

(ii) Number of marketable storage roots

Data were analyzed as described in Chapter 3, Section 3.8.

5.3 Results and Discussion

There was no significant interaction effect of season and sweet potato clone on the number of marketable storage roots per plant. Similarly, there was no significant interaction effect of season and planting bed on the number of marketable storage roots per plant. This is an indication that season did not influence the response of sweet potato to the other factors.

The results of this study showed significant ($F = 5.09$; $P<0.05$) effect of season on the number of marketable sweet potato storage roots per plant (Table 5.2). Season 1 had significantly higher number of marketable storage roots per plant than Season 2. The observed higher number of marketable storage roots in season 1 may be attributed to the low temperatures experienced in season 1 compared to those in season 2. High temperatures have negative effect on dry matter accumulation of sweet potato storage roots (Gajanayake *et al.*, 2015). Temperatures higher than 24°C have been reported to have detrimental effects on the growth of sweet potato and development of storage roots (Gajanayake *et al.*, 2015). High temperatures at low altitude reduce sweet potato storage root production (Belehu, 2003).

Table 5.2: Effect of season on the number of marketable sweet potato storage roots per plant

Season	Number of marketable storage roots
S1	2.49 ^{a}
S2	2.02 ^{b}
LSD	0.4272
Pr > F	0.0307
CV	16.85

Seasons: S1 = Season 1, S2 = Season 2

Means within a column followed by same superscript are not significantly different at $P<0.05$

Planting beds had significant (F = 4.95; P<0.05) effect on the number of marketable sweet potato storage roots per plant (Table 5.3). Planting sweet potato on raised beds (P2) or ridges (P3) increased the number of marketable storage roots by 37-41%, as compared with planting on flat beds. This may be attributed to the improved soil conditions on raised beds and ridges. It may be due to increased water infiltration, soil texture and aeration improvement, and reduced bulk density. Raised beds and ridges had similar number of marketable storage roots. The results of this study are contrary to those by Saqib *et al.* (2017) who observed higher number of storage roots on plants grown on ridges than those grown on raised beds.

Planting sweet potato vines on ridges has been shown to significantly increase the weight of total fresh storage roots, marketable fresh storage roots, and dry matter of storage roots, while planting on flat or sunken beds caused significant decrease in the three observed parameters (Ahmed *et al.*, 2012). However, the three seedbed types were observed to have similar effect on numbers of marketable storage roots. Ridges caused significant increase in the number of marketable storage roots (Brobbey, 2015).

Table 5.3: Effect of planting beds on the number of marketable sweet potato storage roots per plant

Planting beds	Number of marketable storage roots
P1	1.79^{b}
P2	2.52^{a}
P3	2.46^{a}
LSD	0.5232
Pr > F	0.0130
CV	16.85

Planting beds: P1 = Flat bed, P2 = Raised bed, P3 = Ridge

Means within a column followed by same superscript are not significantly different at P<0.05

The results of this study also showed significant (F = 14.06; P<0.05) effect of sweet potato clone on the number of marketable storage roots per plant (Table 5.4). Sweet potato clones C7 and C8 had similar number of marketable storage roots per plant but both produced higher number of roots than clone C9. This is probably due to genetic makeup of the clones. These results are in agreement with those by Mwololo *et al.* (2012a) and Mahmud *et al.* (2021) who observed higher number of storage roots per plant in some varieties than in others. Mahmud *et al.* (2021) associated these differences to genotypic differences among the sweet potato varieties. The results are also in conformity with those by Gasura *et al.* (2021) who reported significant differences in the number of storage roots among sweet potato genotypes.

In a study by Van Vugt and Franke (2018) there were some differences in fresh root yield due to variety with some achieving much smaller root yield than other varieties. The findings of Kathabwalika *et al.* (2013) showed significant variations in sweet potato storage root yield and stability among genotypes.

The main effects; season, planting bed and sweet potato clone on the number of marketable storage roots per plant were significant but their interaction effects were not. This therefore shows that the response of sweet potato to one of the three factors is not influenced by the presence of the other(s), with respect to number of marketable storage roots. These results are contrary to those by Ahmed *et al.* (2012) who found no significant effect of seedbed type on number of both total and marketable storage roots. Akinboye *et al.* (2015) reported the highest number of sweet potato storage roots from a treatment combining ploughing, harrowing and ridging.

Table 5.4: Effect of sweet potato clone on the number of marketable sweet potato storage roots per plant

Sweet potato clone	Number of marketable storage root
C7	2.76 a
C8	2.53 a
C9	1.48 b
LSD	0.5232

Pr > F	<.0001
CV	16.85

Drought tolerant sweet potato clones: C7, C8, and C9

Means within a column followed by same superscript are not significantly different at P<0.05

The results of this study showed significant (F = 5.14; P<0.05) interaction effect of season and planting bed on sweet potato storage root yield (Figure 5.1). While planting bed had significant effect on storage root yield in Season 2, it had no effect in Season 1. In Season 2, raised beds gave significantly higher storage root yield than ridges. Sweet potato planted on raised beds produced significantly higher storage root yield in season 2 than it did in season 1.

Planting sweet potato on raised beds or ridges increased the storage root yield by 104% and 53%, respectively, in Season 2 as compared with planting on flat bed. These results are in agreement with those by Ahmed *et al.* (2012) which showed that sweet potato grown on ridges produced significantly higher storage root yield than those grown on flat beds. Ahmed *et al.* (2012) attributed their findings to improved soil physical properties, drainage and aeration, that enabled adequate storage roots growth and expansion. However, the results of this study are disagreeing with the findings by Pepo (2018) which showed that sweet potato planted on flat beds gave higher yield than that planted on ridges. The results also disapprove those reported by Akinboye *et al.* (2015) who observed highest fresh yield of sweet potato under slash and burn system of land preparation compared to ploughing, harrowing and

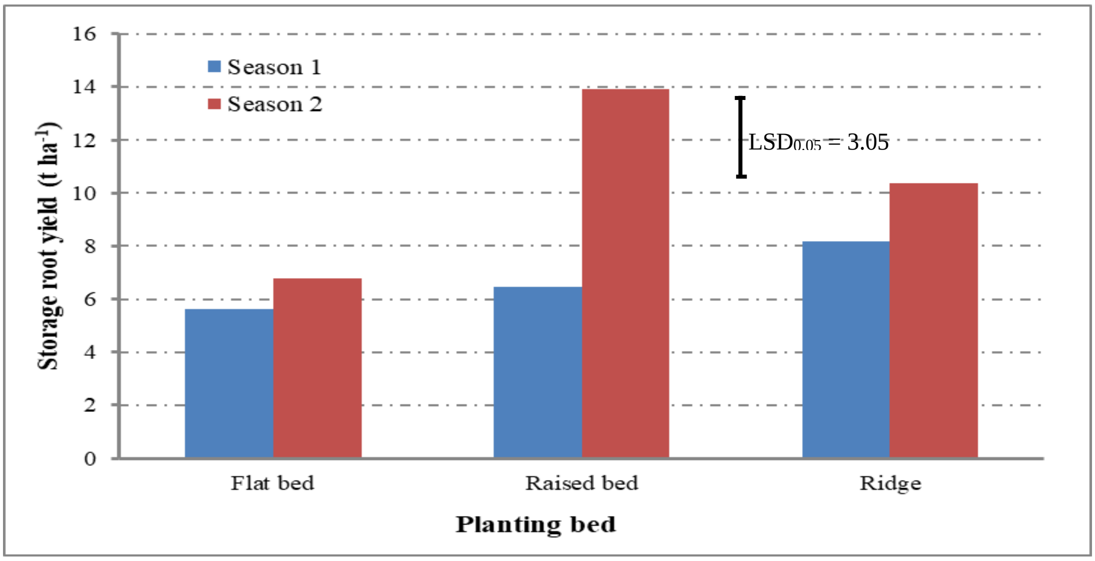


Figure 5.1: Effect of season and planting bed on sweet potato storage root yield

The results of this study showed significant (F = 5.21; P<0.05) interaction effect of season and sweet potato clone on storage root yield (Figure 5.2). These results are in conformity with those by Mcharo *et al.* (2001), Mwololo *et al.* (2012a) and Mahmud *et al.* (2021), who observed significant interaction effect of sweet potato variety and season on root yield. In the current study, while sweet potato clone had significant effect on storage root yield in Season 2, it had no effect in Season 1. Season had significant effect on the performance of clone C7, but had no effect on clones C8 and C9. Season 1 had relatively lower temperatures than season 2. The results of this study therefore show that clone C8 and C9 were probably more sensitive to high temperatures than was clone C7. The observed similarity in the storage root yield in clones C7, C8 and C9 in season 1 probably shows that these clones had the same potential when subjected to favorable temperatures. These results are in agreement with those from a study conducted by Duque (2020) in Pennsylvania, which showed that seven out of ten sweet potato varieties produced consistent yield across years. In Season 2, clone C7 gave the highest storage root yield as compared with clones C8 and C9.

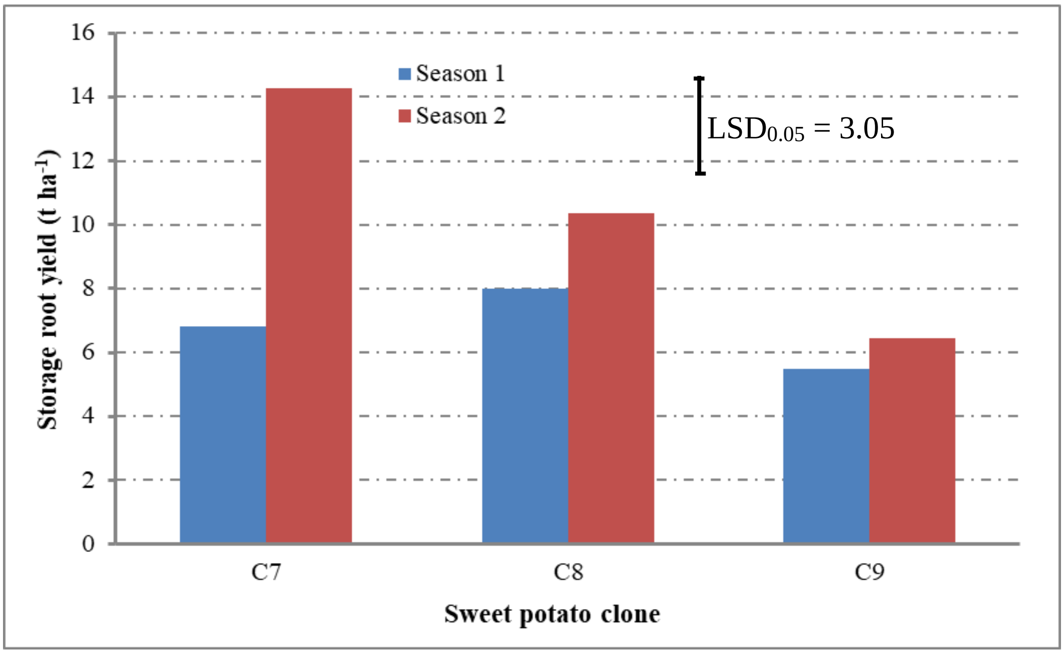


Figure 5.2: Effect of season and sweet potato clone on sweet potato storage root yield (t ha^{-1})

5.4 Conclusion and Recommendations

Sweet potato planted on raised beds or ridges had higher storage root yield and number of marketable storage roots per plant than that planted on flat beds. Clones C7 and C8 were both superior to clone C9 in terms of the number of marketable storage roots per plant. Even though there was seasonal effect on the storage root yield of clone C7, the mean yield of clones C7 and C8 were higher than that of clone C9. From these results, it is recommended that farmers plant clones C7 or C8 on raised beds or ridges for increased yield and number of marketable sweet potato storage roots.

CHAPTER SIX

SOIL COVERING ABILITY OF SELECTED ORNAMENTAL SWEET POTATO VARIETIES UNDER DIFFERENT PLANTING BEDS

Abstract

Ornamental plants are plants that are grown for decorative purposes in gardens and landscape design projects. Some sweet potato varieties are known to have ornamental value and are used for landscaping purposes. Ornamental sweet potato varieties are cultivars of the same species as edible sweet potatoes and are classic plants perfect for landscaping. Their use could be expanded especially in the tourism industry which is a major contributor to the Kenyan economy. However, the full potential of sweet potato as an ornamental is yet to be exploited in coastal Kenya. The effectiveness of ornamental plants in landscaping depends on the extent to which they cover the ground. A study was therefore conducted to evaluate the performance of selected ornamental sweet potato varieties under different planting beds. The aim of this study was to assess the ground covering ability of selected ornamental sweet potato varieties (Purple heart, Green fingers and Margarita) planted on different planting beds (Flat bed, Raised bed and Ridge). The experiment was carried out, using the Randomized Complete Block Design, with the treatments arranged in a factorial manner and replicated three times. Planting beds did not affect the ground covering abilities of the selected ornamental sweet potato varieties. Ornamental sweet potato varieties Purple heart and Green fingers had significantly higher percent ground coverage (68-72%), than variety Margarita (38%) across seasons. These varieties (Purple heart and Green fingers) are therefore recommended for multi-locational evaluation across ecological zones in coastal Kenya to ascertain their ground covering ability.

6.1 Introduction

Sweet potato is considered a multipurpose plant due to the different uses of its roots, leaves, and vines (Sousa *et al.*, 2018). The genus *Ipomoea* is of great importance as an ornamental (Sousa *et al.*, 2018). Sweet potato may also be used to provide ground cover for erosion control during the rainy season (Kwak, 2019). The sweet potato plant is a creeping vine with lobed, heart shaped leaves that are spirally arranged. It produces white or lavender flowers. Varieties of sweet potato differ in terms of size, color and shape of their leaves (Yada *et al.*, 2010; Hue *et al.*, 2012; Ravi and Saravanan, 2012; Ellong *et al.*, 2014; Glato *et al.*, 2017; Sousa *et al.*, 2018). The leaves may have round, reniform (kidney-shaped), cordate (heart-shaped), fingerlike or triangular shape, and may be moderately or deeply lobed (Carey *et al*., 2007; Ravi and Saravanan, 2012). The leaves are mostly green in color but may contain purple pigmentation (Truong *et al.*, 2018).

Ornamental sweet potato just like other ornamental plants is grown for decorative purposes due to their colorful foliage of different shapes. The aggressive growth of ornamental sweet potato vines makes them ideal for use in containers and hanging baskets (Mierzejewski, 2016). Ornamental sweet potato may also be grown outdoors as annual ground cover in flower beds (Mierzejewski, 2016).

The value of ornamental plants depends on their attractive appearance which includes leaf color, shape, texture and variegation, and overall plant structure (Chen, 2021). Sousa *et al.* (2018) reported that sweet potato varieties that possess ornamental characteristics may be ideal for potted plants, cut foliage, use as complement to table arrangements or in garden beds. Sweet potato as an ornamental plant can be used indoor as a potted plant to eliminate indoor air pollutants and for freshness (Saini *et al.*, 2020). When planted as garden plants, ornamental sweet potato can help in the beautification of landscapes especially for the tourism industry

(Plate 6.1). Landscaping has been reported to economically increase property and resale values, as well as create positive perceptions among investors (Perry, 2021).

The ornamental horticulture industry is of great importance in the world (Hovhannisyan and Khachatryan, 2017), where ornamental plant products have been sold all over the world, as their market is extremely competitive (Boutigny *et al.*, 2020). Nelson *et al.* (2018) showed that ornamental plant business was profitable with a mean return of USD 369.73 per annum to labor and management. In addition, some ornamental plants may be used as sinks for the abatement of air pollution at highly polluted sites whereas others can be used as bio indicators (Saxena and Ghosh, 2013).

Sweet potato cultivars vary greatly in form and growth habit with many cultivars having developed through systematic breeding while others appear through natural hybridization and mutation (Atu, 2013). Ornamental sweet potato varieties with purple, green or variegated leaves have been reported to be available in garden centers (Adam, 2005). Sweet potato vines grow rapidly covering the ground (Loebenstein and Thottappilly, 2009) but lack canopy depth due to horizontal development of the canopy and poor leaf orientation (Grüneberg *et al*., 2015).

6.2 Materials and Methods

6.2.1 Site description

The study was conducted for two seasons between July and September 2018, and August and October 2018, at the Pwani University farm in Kilifi County. The site characteristics are as described in Chapter 3, Section 3.1.

6.2.2 Treatments

The following treatments were evaluated:

Factor A: Three ornamental sweet potato varieties (Appendix IIb - d)

(i) Purple heart - V1

(ii) Green fingers - V2

(iii)Margarita - V3

Factor B: Planting beds

(i) Flat bed - (P1)

(ii) Raised bed - (P2)

(iii)Ridge - (P3)

Therefore, there were nine treatment combinations, replicated three times making a total of 27 experimental units.

A Randomized Complete Block Design (RCBD) was used, with the treatments arranged in a factorial manner and replicated three times.

Table 6.1: Experimental field layout

Block 1		Block 2		Block 3	
Plot	**Treatment**	**Plot**	**Treatment**	**Plot**	**Treatment**
1	Ridge, V3	10	Flat, V3	19	Raised, V2
2	Ridge, V2	11	Flat, V1	20	Raised, V3
3	Ridge, V1	12	Flat, V2	21	Raised, V1
4	Flat, V3	13	Raised, V2	22	Ridge, V1
5	Flat, V1	14	Raised, V3	23	Ridge, V2
6	Flat, V2	15	Raised, V1	24	Ridge, V3
7	Raised, V2	16	Ridge, V1	25	Flat, V1
8	Raised, V1	17	Ridge, V2	26	Flat, V3
9	Raised, V3	18	Ridge, V3	27	Flat, V2

6.2.3 Crop establishment and management

The study was conducted between July and September 2018, and August and October 2018. The sweet potato vines were planted as described in Chapter 3, Section 3.5.

The crop was managed as described in Chapter 3, Section 3.6.

6.2.4 Data collection and analysis

Percent ground cover (foliage cover) data were collected

Data were analyzed as described in Chapter 3, Section 3.8.

6.3 Results and Discussion

Ornamental sweet potato varieties differed significantly in their ground covering ability ($F = 28.28$; $P<0.05$) (Table 6.2). Varieties Purple heart (V1) and Green fingers (V2) had higher percent ground coverage than variety Margarita (V3). Despite variety Green fingers (V2) having narrow leaves, the ground covering ability was not different to that of variety Purple heart (V1), and was significantly higher than that of variety Margarita (V3) which had broad leaves. This study results contradict the results of Mwololo *et al.* (2012b) which showed that broad leaved varieties had high ground coverage compared to narrow leaved varieties. The difference in the ground covering ability may be due to genetic makeup of the different varieties as suggested by Ali *et al.* (2015a).

Planting bed did not affect the ground covering ability of the ornamental sweet potato varieties. This study results are in conformity with those by Brobbey (2015) that showed there was no significant effect of seedbed type on percentage ground cover.

Table 6.2: Effect of ornamental sweet potato variety on foliage cover (percent ground cover)

Sweet potato variety	Percent ground cover
Purple heart (V1)	68.11 [a]
Green fingers (V2)	72.00 [a]
Margarita (V3)	38.11 [b]
LSD	10.02
Pr > F	<.0001
CV	24.90

Ornamental sweet potato varieties: Purple heart (V1), Green fingers (V2), Margarita (V3)

Means within a column followed by same superscript are not significantly different at $P<0.05$

There is very limited literature for ornamental sweet potato varieties. This is therefore preliminary work as there is very little earlier information on ornamental sweet potato varieties.

6.4 Conclusion and Recommendations

Sweet potato varieties V1 and V2 showed excellent ground covering ability and are therefore recommended for multi-locational trials in coastal Kenya to ascertain their ground covering ability. If proved to perform well, these varieties may then be multiplied for use in the tourism industry and for environmental protection.

CHAPTER SEVEN

EVALUATION OF PRODUCTION OF PLANTING MATERIAL OF SELECTED SWEET POTATO CLONES UNDER DIFFERENT MULTIPLICATION METHODS

Abstract

Sweet potato is a staple food that contributes to food security for communities in Sub-Saharan Africa. The production of sweet potato in coastal Kenya is low and this has been associated with shortage of planting material during the rainy season. A study was therefore conducted at the Pwani University farm to assess different methods for the production of sweet potato planting material. The methods evaluated in this study were: planting in pits without lining, planting in pits with lining, planting on flat grounds, planting in sacks without lining and planting in sacks with lining. A Randomized Complete Block Design was used, with factorial arrangement of treatments. Treatments were replicated three times. Vine yield data was collected from the experimental plots and subjected to analysis of variance using the general linear model. In the long rains season, sweet potato in the treatments without lining produced longer vines than those with lining. Different vine planting methods produced similar vine lengths in the off-season multiplication. The planting methods without lining are recommended for use by farmers during the long rains season multiplication of planting material. It is also recommended that farmers start the multiplication during off-season and continue during the long rains season so as to multiply enough planting material that will allow expansion of the area under sweet potato.

7.1 Introduction

Sweet potato is an important storage root crop grown in over 120 countries in the world, on about 8 million hectares of land, and with a total annual production of about 92M tons with a yield of 11.4 t ha^{-1} (FAOSTAT, 2018). Lack of access to sufficient planting material at the beginning of the rains is one of the value chain challenges in the predominantly smallholder-based sweet potato production systems in Sub-Saharan Africa (SSA) (Low *et al*., 2020). Accessing planting material of adapted cultivars is among the challenges that should be properly tackled for achieving dissemination and wider adoption of improved sweet potato cultivars in SSA (Low *et al*., 2020). The major constraint hindering the attainment of full production potential of sweet potato in Kenya is inadequate planting material at the onset of planting season (Njeru *et al*., 2004; Gichuki and Hijmans, 2005). Vine shortage was reported by Ume *et al*. (2016) as one of the major constraints of sweet potato production in Ebonyi state, Nigeria.

The difficulty in conserving and accessing sweet potato vines during long dry spells was reported as a key sweet potato farming challenge for farmers in Bungoma and Homa Bay counties, Kenya (Mudege *et al*., 2020). Farmers in Eastern Uganda suffer a chronic shortage of planting material at the beginning of the rainy season (Namanda, 2012). In places where planting time is once a year in the main rainy season farmers cannot save sweet potato vines for the next planting season because of the long dry season (Aldow, 2017). However, where farmers plant sweet potato twice a year they are able to save planting material after harvest by planting sweet potato vines near their homes (home garden) during the dry season, to serve as source of planting material for the next planting season (Aldow, 2017; Gurmu *et al*., 2019). In Malawi, farmers experience insufficient planting material at the onset of rains and have to wait for the sprouting of sweet potato in the early weeks of the rainy season, leading to late planting (Van Vugt and Franke, 2018). This is also the case with sweet potato farmers in coastal Kenya.

On average farmers in coastal Kenya plant 0.2 hectares of sweet potato (Makini *et al*., 2018). Even if farmers wanted to expand their area under sweet potato they are limited by the amount of planting material available at the start of the planting season (V. Mzinga, personal communication). In a study conducted in Northeastern Uganda, Abidin (2004) observed that sweet potato is mostly planted late in the planting season due to lack of planting material early in the season. Shortage of planting material was reported by more than 80% of farmers in Ethiopia as one of the major sweet potato production constraints in that country (Gurmu *et al*., 2015).

It has been observed that the dry conditions that are experienced between cropping seasons cause death of sweet potato vines that remain on farms after harvest, thus contributing to their shortage in the succeeding season (Mwololo *et al*., 2012b; B. Abdallah, personal communication). In some study sites in coastal Kenya, including Mwaluvanga and Lukore there was depressed vine yield due to drought (Mwololo *et al*., 2012b). Farmers in the region have the option of multiplying planting material off-season under irrigation or at the onset of rainy season, since they normally plant their crop mid-season after the peak of the rains.

Different methods of multiplication and maintenance of planting material have been recommended by different studies done in other parts of the world. Intensive methods of conserving planting material using domestic wastewater as a partial solution to shortage of planting material were recommended by Gibson *et al*. (2009). Farmers in Soroti District of Uganda have developed mechanisms and strategies to manage vine availability (Isubikalu, 2007). These included plot reservations and use of storage roots, establishment of sweet potato gardens under a large shade tree, and planting sweet potato vines in swamps during the dry season. Farmers in the Lake Zone of Tanzania, who have access to lakesides or swampy areas, were using these lands to conserve planting material during the dry season (McEwan *et al*., 2017). In Southern Tigray, Ethiopia, lack of sweet potato planting material has prevented farmers from planting the crop (Aldow, 2017).

Maintenance of planting material during the prolonged dry season is a challenge, and results in delayed planting to allow for the bulking of sufficient planting material early in the rainy season (Stathers *et al*., 2018). Vine conservation techniques that included small-scale dry season irrigation to help provide significant quantities of planting material at the beginning of the rains were recommended by Stathers *et al*. (2018). Farmers with swamp land in six districts of Uganda were able to benefit from sale of sweet potato vines at the start of the cropping system (Okonya and Kroschel, 2014).

In some parts of coastal Kenya such as Rabai and Kanana, farmers conserve sweet potato vines outside bathrooms (Appendix IIIa) and in swamps (Appendix IIIb) during the dry season in order to have some planting material at the onset of the cropping season. Considering that sweet potato is a supplementary staple to the cereals, as well as a household food security crop (Jia, 2013), there may be food insecurity in the sweet potato growing areas in coastal Kenya if the production is not increased. This calls for efforts to address the constraints limiting the production of the crop, especially inadequacy of planting material during the cropping season. There is also need for sweet potato multiplication technologies that are adaptable to changes in climatic conditions since the swampy areas, where farmers used to multiply planting material, have continued to dry up due to reduced rainfall. A study was therefore conducted to evaluate technologies for production of sweet potato planting material. This study aimed at enhancing sweet potato production in Kwale and Kilifi counties through increased production of planting material and thus increasing its availability to farmers at the onset of the subsequent cropping season. Timely provision of sufficient sweet potato planting material to farmers will help in increasing production and meeting the demand for the crop in the region.

7.2 Materials and Methods

7.2.1 Site description

The study was conducted for two seasons in coastal Kenya in 2018, at the Pwani University Farm in Kilifi County. The site characteristics are as described in Chapter 3, Section 3.1.

7.2.2 Treatments

The following treatments were evaluated in this study:

Factor A: Three sweet potato clones bred for drought tolerance

Three selected drought tolerant sweet potato clones, 4.2B, 7.6B and 4.2A, were evaluated. The three selected clones were the best in terms of yield and sugar content among the nine-drought tolerant sweet potato clones that had been obtained earlier from the Kenya Agricultural and Livestock Research Organization (KALRO) Centre at Muguga, and whose performance is reported in Chapter 4 of this thesis. The treatments were coded as follows:

(i) Drought tolerant sweet potato clone 4.2B - (C7)

(ii) Drought tolerant sweet potato clone 7.6B - (C8)

(iii) Drought tolerant sweet potato clone 4.2A - (C9)

Factor B: Vine method of planting

(i) In pit with lining - (PL): This consisted of a pit measuring 0.3 x 0.6 m (0.18 m^2) with its surface lined with polythene before placing the growing medium (soil-manure mixture)

(ii) In pit without lining - (PWL): This consisted of a pit measuring 0.3 x 0.6 m (0.18 m^2) with the growing medium placed in it without a polythene lining

(iii) In sack with lining - (SL): This consisted of a sack measuring 0.3 x 0.6 m (0.18 m^2) with its surface lined with polythene before placing the growing medium (soil-manure mixture)

(iv) In sack without lining - (SWL): This consisted of a sack measuring 0.3 x 0.6 m (0.18 m^2) with the growing medium placed in it without a polythene lining

(v) On flat ground - (OG): This was a control treatment in which sweet potato vines were planted on flat ground in plots measuring 0.3 x 0.6 m (0.18 m^2)

Therefore, there were fifteen treatment combinations, replicated three times (making a total of 45 experimental units).

Table 7.1: Experimental field layout

Block 1		Block 2		Block 3	
Plot	**Treatment**	**Plot**	**Treatment**	**Plot**	**Treatment**
1	C9SL	16	C8SL	31	C9SL
2	C8PL	17	C9PL	32	C7PL
3	C9SWL	18	C8OG	33	C8SWL
4	C7OG	19	C7PWL	34	C7OG
5	C8PWL	20	C9SL	35	C9PWL
6	C8SL	21	C9PWL	36	C7SL
7	C9PL	22	C7SL	37	C9PL
8	C7PWL	23	C9SWL	38	C8PWL
9	C8SWL	24	C8PWL	39	C9SWL
10	C9PWL	25	C7PL	40	C7PWL
11	C8OG	26	C7OG	41	C8OG
12	C7SWL	27	C8SWL	42	C7SWL
13	C7PL	28	C9OG	43	C8PL
14	C9OG	29	C7SWL	44	C9OG
15	C7SL	30	C8PL	45	C8SL

A Randomized Complete Block Design (RCBD) was used, with a factorial arrangement of treatments. The treatments were replicated three times. Plots for Block 1 were established under a tree, those for Block 2 under shade-net and those for Block 3 in the open field. Light intensity was the blocking factor. Variation within a block were minimized as much as possible.

7.2.3 Crop establishment and management

The first trial coincided with the long rains season (April to July 2018), while the second trial was conducted off-season (August to October 2018), purely under irrigation. The first trial was meant to mimic the current farmers' practice of multiplying sweet potato planting material at the onset of the LR season while targeting to plant the crop in May/June. The sweet potato vines were planted as described in Chapter 3, Section 3.5.

The crop was managed as described in Chapter 3, Section 3.6.

7.2.4 Data collection and analysis

Vine yield from each plot was determined by measuring the length of vine, using a tape measure, at eight WAP. Two rows of sweet potato in each treatment were harvested for the determination of total vine length per plot. The total vine length per plot was then converted to total vine length per square meter (i.e. vine yield or vine production potential) by using the following formula:

$$Y_v = \frac{L_P}{A_p}$$

Where Y_v = vine yield (m m^{-2}), L_p = total length of vine (m) per plot, and A_p = plot area in m^2.

The vine yield (vine production potential) was then used to calculate the land size that would be required to multiply enough sweet potato planting material for one hectare, using the following formula:

$$A_a = \frac{C \ x \ L_c}{Y_v}$$

Where A_a = land size (m^2) required to multiply enough sweet potato planting material for one hectare, C = number of cuttings required to plant one hectare, L_c = length (m) of a cutting, and Y_v = vine yield (m m^{-2}).

Vine yield data were subjected to the analysis of variance (ANOVA) using the general linear model (GLM) procedure of the statistical analysis system (SAS), Version 9.1 (SAS Institute, 2002).

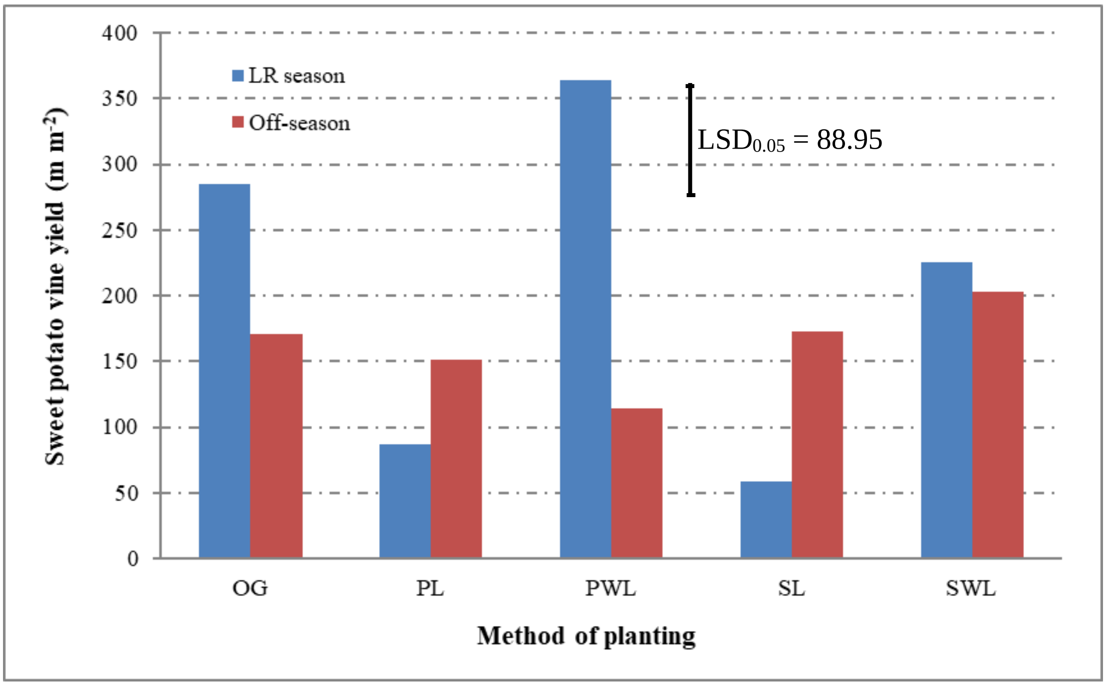
Square root transformation of the original data (n) was performed before analysis to improve the normality of the data. Where the F values were significant, treatment means were separated using the least significant difference (LSD) at the 5% level of significance. The land size required to multiply sweet potato planting material for one hectare was regressed against the vine production potential of sweet potato under different methods of multiplication to estimate the size of nursery bed that farmers will have to set aside for the production of sweet potato planting material, depending on the vine production potential of a given sweet potato variety.

7.3 Results and Discussion

The results of this study showed significant ($F = 10.22$; $P<0.05$) interaction effect of season and method of planting on sweet potato vine length (Figure.7.1). During the LR season, sweet potato planted in pits without lining (PWL), or on flat grounds (OG), or in sack without lining (SWL) had significantly longer vines than that planted in pits with lining (PL) or sack with lining (SL). This observation was not evident during off-season. This is probably an indication that when multiplication of sweet potato planting material is done solely under irrigation (as was done off-season), any of the methods of planting would give the same vine yield.

Rainfall received during the LR season probably led to the accumulation of excessive amounts of water in the soil for treatments with lining, leading to waterlogged conditions. Sweet potato growth is known to be adversely affected by waterlogged conditions (Bourke, 1989). Waterlogging causes damage to plants due to the depletion of oxygen as water replaces air in the soil pore spaces. This leads to denitrification due to the anaerobic conditions created by the shortage of oxygen in the soil, resulting into loss of soil nitrogen which is important for crop growth. Waterlogged crops have slow growth and are unable to achieve canopy closure, critical for crops to achieve high yield (Mitchell, 2008).

Roots translocate low amounts of nutrients to the leaves when sweet potato is subjected to waterlogging (Lin *et al.*, 2006). The lack of significant differences between treatments (planting methods) without lining and those with lining during off-season is probably an indication that the irrigation water did not create waterlogged conditions in the treatments with lining, leading to similar rates of elongation of sweet potato vines with or without lining. Farmers who planted sweet potato twice a year were able to save planting material after harvest by planting sweet potato vines near their homes (home garden) during the dry season and, thus, to keep planting material for the next planting season (Aldow, 2017). Therefore, it would be very appropriate for the farmers to adopt planting in sacks without lining as it would be easier to manage and also possible to put the sacks under shade in case of harsh climatic conditions.

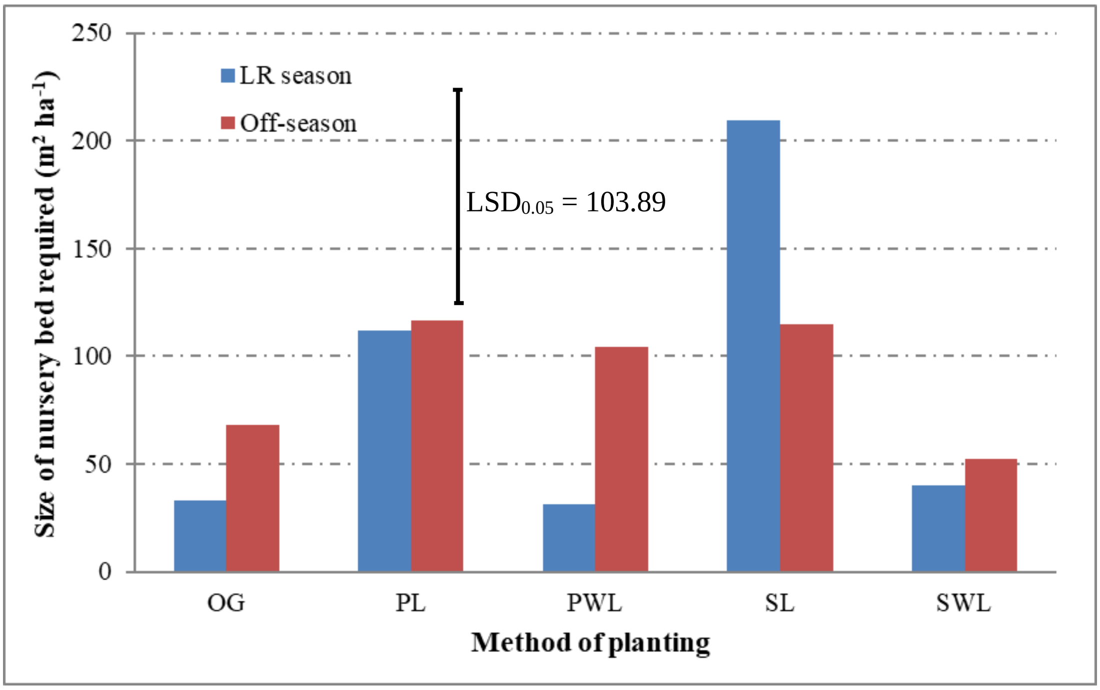


LR = Long rains; On flat ground (OG), Pit without lining (PWL), Pit with lining (PL), Sack without lining (SWL), Sack with lining (SL)

Figure 7.1: Effect of season and method of planting on sweet potato vine length

The results of this study also showed significant ($F = 3.54$; $P<0.05$) interaction effect of season and method of planting on the size of nursery bed required to produce enough sweet potato vines to plant one hectare of land (Figure 7.2). Sweet potato planted in the LR season on flat grounds (OG), or in pits without lining (PWL), or in sack without lining (SWL) required significantly smaller land area than that planted in sacks with lining (SL). Similar results were not evident during off-season. This may have been an indication that when multiplication of sweet potato planting material is done solely under irrigation (as was done off-season), the same size of nursery bed would be required under any of the methods of planting to produce material required for planting one hectare. The lack of significant differences between planting methods without lining and those with lining during off-season may mean that any of the methods of planting would give the same amount of planting material required to plant one hectare of sweet potato.

The amount of sweet potato vines used by farmers for multiplication of planting material under their current practice is normally limited due to the loss of vines experienced during the January-March dry spell that proceeds the LR season. Off-season multiplication of planting material with irrigation would minimize the death of sweet potato vines due to drought, as it is currently experienced by farmers in coastal Kenya. The material obtained from the off-season multiplication would enable farmers start the LR season multiplication with a lot more vines than they would without having done any multiplication during the preceding off-season. If farmers were to adopt off-season followed by LR season multiplication of planting material, they would produce enough material that would enable them expand the area under sweet potato production.



LR = Long rains; On flat ground (OG), pit without lining (PWL), pit with lining (PL), sack without lining (SWL), sack with lining (SL)

Figure 7.2: Effect of season and method of planting on the size of nursery bed required to produce enough sweet potato vines to plant one hectare

The results of this study showed a negative relationship between the vine production potential of sweet potato (vine length per square metre) and the size of nursery bed required to produce enough planting material to plant one hectare (Figure 7.3). The coefficient of determination (R^2 =0.9733) shows that around 97% of the sizes of nursery bed required to produce enough sweet potato vines to plant one hectare could be explained by the increase in the total length of sweet potato vines produced on one square metre of land (vine production potential), and only 3% of the results was due to random variation. Figure 7.3 is therefore a useful tool that may be used by farmers who are planning to produce sweet potato planting material. Using this tool, they would be able to estimate the size of nursery bed they will have to set aside for the production of sweet potato planting material, depending on the vine production potential of a given sweet potato variety. The higher the vine production potential of a given sweet potato variety, the smaller the size of nursery bed needed to multiply enough planting material for one hectare.

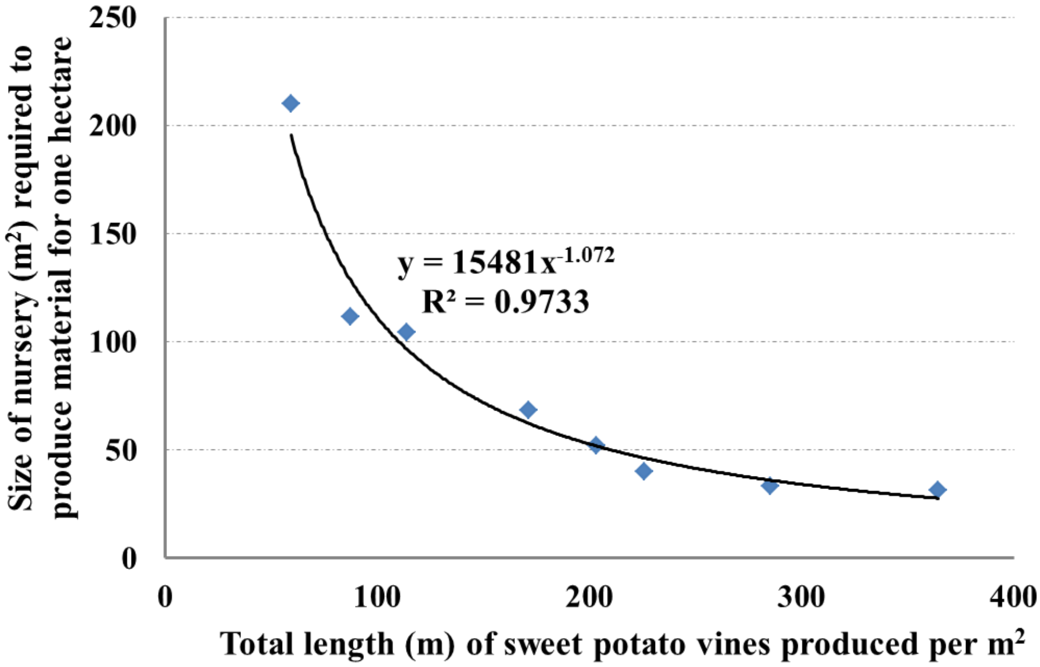


Figure 7.3: Relationship between vine production potential and size of nursery required to produce planting material enough for one hectare

7.4 Conclusion and Recommendations

During the LR season, treatments without lining had longer sweet potato vines and required smaller land area to produce material required to plant one hectare of sweet potato than those with lining. However, in the off-season multiplication of vines with irrigation all the treatments had similar vine length and therefore required the same land area to produce material to plant one hectare.

For the LR season multiplication of sweet potato planting material, it is recommended that farmers plant the vines on flat ground or in pits without lining or in sacks without lining. This would allow free drainage of water and minimize chances of waterlogging. For off-season multiplication under irrigation farmers can use any of the methods of planting. To multiply enough planting material that will enable farmers expand the area under sweet potato, it is recommended that they start the multiplication during off-season and continue during the LR season.

CHAPTER EIGHT

ASSESSMENT OF THE YIELD PERFORMANCE OF SELECTED DROUGHT TOLERANT SWEET POTATO CLONES IN DIFFERENT LOCATIONS

Abstract

Sweet potato in Coastal Kenya is grown on a small scale in agro-ecological zones CL2 and CL3, which receive an annual rainfall of between 1,000-1400 mm. Very minimal sweet potato production is done in the low rainfall areas because of lack of sweet potato varieties that are drought tolerant or adaptable to the different agro-ecological zones with different climatic conditions. Earlier studies have shown variations in storage root yield among sweet potato genotypes and across different agro-ecological zones. Currently, evaluation of drought tolerant sweet potato varieties for their adaptability in different locations has not been done in coastal Kenya. Identification of varieties that are adaptable to different locations in the region is critical for increased production of the crop. A study was therefore conducted at Kaliang'ombe, Jimba and Mavueni locations in Kilifi County, and Mrima and Kenya-Loma locations in Kwale County, through on-farm field evaluation. The aim of this study was to assess the storage root yield of selected drought tolerant sweet potato clones (4.2B, 7.6B and 4.2A) against a farmer preferred variety *Carrot* in the different locations. The study was conducted for three seasons: at the start of the long rains, after the peak of the long rains, and during the short rains. A Randomized Complete Block Design was used, with treatments replicated five times. All the data were subjected to the analysis of variance using the general linear model procedure. Sweet potato clone 4.2B, had significantly higher number of marketable storage roots per plant than the other two clones (7.6B and 4.2A) and the farmer preferred variety *Carro*t. Clone 7.6B did not differ significantly with the farmer preferred variety *Carrot* but the two produced higher number of

marketable storage roots per plant than clone 4.2A. Sweet potato planted at the start of the long rains and after the peak of the long rains produced higher number of marketable storage roots per plant than that planted during the short rains. The crop that was planted after the peak of the long rains had significantly higher storage root yield per plant than that which was planted either at the start of the long rains or during the short rains. From the results of this study, it is recommended that farmers plant sweet potato after the peak of the long rains season for increased yield of storage roots. It is also recommended that farmers plant sweet potato clone 4.2B for increased number of marketable storage roots.

8.1 Introduction

Farmers participation in the on-farm evaluation of new crop varieties enhances the adoption of the best among the varieties (Saleh *et al.*, 2004). Significant differences in sweet potato storage root yield among genotypes and also across different agro-ecological zones were observed by Kathabwalika *et al.* (2013), an indication that different genotypes are likely to perform differently in different locations, probably because of differences in weather conditions. Sweet potato yield differences in two research sites were attributed to differences in soils or weather conditions (Hartemink *et al.*, 2000). Sweet potato is known to be adaptable to many agro-ecological zones and has a growing period of between three to five months, depending on variety and environmental conditions (Afuape *et al.*, 2011). There exists a clear pattern of genotype by environment interactions with respect to sweet potato storage root yield, and breeding for yield performance in low-yielding or marginal environments should be given specific consideration (Grüneberg *et al.*, 2005).

The number and yield of sweet potato storage roots were influenced by agro-ecological zones, with some variations also observed within agro-ecological zones (Tairo *et al.*, 2008). Multi-locational trials were recommended for the selection of high-yielding varieties intended for commercial production to improve farmers’ yield and income across agro-ecological zones in Nigeria (Wariboko and Ogidi, 2013). Genotype by environment interactions with respect to root yield, showing inconsistency in the performance of breeding lines across environments and seasons was seen in a study by Adebola *et al.* (2013).

Farmer participation in variety selection was recommended by Abidin (2004). According to Laurie and Magoro (2008) the use of participatory varietal selection proved to be a useful selection method since it involves farmer in the evaluation process, giving them a feeling of ownership of the outcome. The results of a study conducted in Uganda showed that two of the eleven sweet potato varieties evaluated through farmer-participatory approach were adaptable to various agro-ecological zones of Northern and Southern regions (Abidin, 2004). In a study by Kambale (2017), genotypes, sites and seasons affected sweet potato leading to high variability in fresh root yield.

Some drought tolerant genotypes had high yield in particular environments (specific interaction between genotypes and environments) while others had high yield across environments (stable genotypes), implying that the genotypes varied in their ability to tolerate drought (Kivuva *et al.*, 2014b). These researchers recommended that breeding programmes for drought tolerance should factor in evaluation across environments while selecting drought tolerant clones for wide or narrow environments. High variation in fresh root yield among sweet potato genotypes was observed across sites and in different seasons and this was attributed to both genetic and environmental factors (Kambale, 2017). Factors such as genotype, environment, management and socio-economic interactions are important when choosing a crop variety since they are likely to affect the overall performance of a crop (Tittonell and Giller, 2013).

Currently, drought tolerant varieties that are suitable for the different agro-ecological zones in coastal Kenya have not been identified. A study was therefore conducted to investigate the performance of sweet potato clones bred for drought tolerance to different locations in coastal Kenya. The study objective was to enhance sweet potato production in the region through identification of high yielding clones for coastal Kenya which can maintain same yield across locations, and which meet farmer and consumer preferences. The participatory approach was applied in the evaluation of sweet potato clones against a farmer preferred variety in on-farm trials to identify clones that would perform well across locations in coastal Kenya.

8.2 Materials and Methods

8.2.1 Site description

The study was conducted on-farm in coastal Kenya for three seasons between April 2018 and January 2019. There were five on-farm sites: two in Kwale County and three in Kilifi County. Farms were selected in Mrima and Kenya Loma locations in Kwale County, and Kaliang'ombe, Jimba and Mavueni locations in Kilifi County for the on-farm evaluation of selected sweet potato clones under different locations in coastal Kenya (Table 8.1). The five on-farm study sites were selected to represent the sweet potato producing areas in coastal Kenya. The study sites characteristics are shown in Appendix Ic.

8.2.2 Treatments

<u>Sweet potato clones</u>:

Three selected drought tolerant sweet potato clones, 4.2B, 7.6B and 4.2A, were evaluated on farmers' fields against one farmer-preferred variety known as *Carrot*. The three selected clones were the best in terms of yield and sugar content among the nine-drought tolerant sweet potato clones that had been obtained earlier from KALRO Centre at Muguga, and whose performance is reported in Chapter 4 of this thesis. The treatments were coded as follows:

(i) Farmer preferred variety *Carrot* - (VC)

(ii) 4.2B - (C7)

(iii) 7.6B - (C8)

(iv) 4.2A - (C9)

Therefore, there were four treatments, replicated five times making a total of 20 experimental units (Table 8.1).

A Randomized Complete Block Design (RCBD) was used, with each of the five on-farm sites forming a replicate. The treatments were not replicated in each farm and each farm was only representing one replicate.

Table 8.1: Experimental field layout

Block 1		Block 2		Block 3		Block 4		Block 5	
Plot	Treatment	Plot	Treatment	Plot	Treatment	Plot	Treatment	Plot	Treatment
1	C8	5	C7	9	C8	13	C9	17	VC
2	VC	6	VC	10	C7	14	C7	18	C9
3	C9	7	C8	11	C9	15	VC	19	C7
4	C7	8	C9	12	VC	16	C8	20	C8

8.2.3 Crop establishment and management

The first trial coincided with the start of the long rains (LR) season (S1), the second trial was started after the peak of the LR season (S2), while the third trial coincided with the short rains (SR) season (S3). The on-farm trials were conducted under rain-fed conditions. The second trial was meant to mimic the current farmers' practice of planting sweet potato after the peak of the LR season. The sweet potato vines were planted as described in Chapter 3, Section 3.5.

The crop was managed as described in Chapter 3, Section 3.6. These trials were researcher designed and farmer managed and the farmer was involved in the management of the trials.

8.2.4 Data collection and analysis

The following data were collected:

(i) Storage root yield

(ii) Number of marketable storage roots

Data were analyzed as described in Chapter 3, Section 3.8.

8.3 Results and Discussion

There was no significant interaction effect of season and sweet potato clone on the number of marketable storage roots per plant. The main effects of season and clone are therefore reported.

The results of this study showed significant ($F = 12.08$; $P<0.05$) effect of season on the number of sweet potato storage roots per plant (Table 8.2). Sweet potato planted in seasons S1 and S2 produced higher number of marketable storage roots per plant than that planted in season S3 (coinciding with the SR season). These results are consistent with those reported by Kambale (2017), which showed significant differences among seasons for number of sweet potato storage roots. Farmers in coastal Kenya believe that most of the sweet potato varieties cannot form storage roots during the SR season (V. Mzinga, personal communication). The result of this study therefore confirms why farmers in the region do not plant sweet potato during the SR season. This study dispels the farmers' belief because the sweet potato planted during the SR season formed storage roots, even though in smaller numbers than those realized during the LR season. The numbers of storage roots realized in seasons S1 and S2 were not significantly different probably because by the time the rains stopped during season S2, storage roots had already been formed. According to Ekanayake *et al.* (1990), any moisture provided late in the growing period only led to vegetative growth of sweet potato but not storage root formation, which was probably the case for season S1.

Table 8.2: Effect of season on the number of marketable sweet potato storage roots per plant

Season	Number of marketable storage roots per plant
S1	2.5170 ^{a}
S2	2.9315 ^{a}
S3	1.5835 ^{b}
LSD	0.5074
Pr>F	<.0001

Season: S1 = planted at the start of long rains, S2 = planted after the peak of long rains, S3 = planted during short rains

Means within a column followed by same superscript are not significantly different at P<0.05

The results of this study also showed significant (F = 4.45; P<0.05) effect of sweet potato clone on the number of sweet potato storage roots per plant (Table 8.3). Sweet potato clone C7, had significantly higher number of marketable storage roots per plant than the other two drought tolerant clones (C8 and C9) and the farmer preferred variety (VC). Clone C8 did not differ significantly with the farmer preferred variety

(VC) but the two produced higher number of marketable storage roots per plant than clone C9. The difference in the number of marketable storage roots of different clones may be attributed to the genetic make-up of the clones. This study results are consistent to those reported by Tairo *et al.* (2008), which showed significant variation among sweet potato germplasm with respect to the number of roots per plant. The results of Habibur *et al.* (2015) revealed considerable variations among the genotypes in terms of the number of storage roots.

Table 8.3: Effect of sweet potato clone on the number of marketable sweet potato storage roots per plant

Sweet potato clone	Number of marketable storage roots per plant
C7	3.0100 ^{a}
C8	2.3293 ^{b}
C9	1.6167 ^{c}
VC	2.4200 ^{b}
LSD	0.5859
Pr > F	0.0082

Drought tolerant sweet potato clones: C7, C8, and C9; Farmer preferred sweet potato variety *Carrot*: VC

Means within a column followed by same superscript are not significantly different at P<0.05

In this study, it was observed that season had significant (F = 18.56; P<0.05) effect on sweet potato storage root yield per plant (Table 8.4). Season S2 had significantly higher storage root yield per plant than seasons S1 and S3. Excessive soil-moisture conditions are known to have negative effect on the formation of storage roots, particularly when such conditions occur soon after planting (Wilson, 1982). These results confirm why farmers in coastal Kenya plant sweet potato after the peak of the LR season (S2). The present study results are in line with those reported by Hartemink *et al.* (2000) and Kambale (2017), which showed significant variations in sweet potato storage root yield across seasons.

Table 8.4: Effect of season on sweet potato storage root yield per plant

Season	Storage root yield per plant
S1	0.29050 ^{b}
S2	0.65550 ^{a}
S3	0.20400 ^{b}
LSD	0.1491
Pr>F	<.0001

Season: S1 = planted at the start of long rains, S2 = planted after the peak of long rains, S3 = planted during short rains

Means within a column followed by same superscript are not significantly different at $P<0.05$

8.4 Conclusion and Recommendations

Sweet potato clone C7 had a higher number of marketable storage roots per plant than clones C8 and C9 as well as the farmer preferred variety (VC). Season S2, which starts after the peak of the LR season was superior to season S3 in terms of both the number and yield of storage roots per plant. The former was also superior to season S1 in terms of storage root yield per plant. From these results, it can be recommended that farmers plant sweet potato after the peak of the long rains season for increased yield of storage roots. It is also recommended that farmers plant sweet potato clone C7 for increased number of marketable storage roots.

CHAPTER NINE

GENERAL CONCLUSION AND RECOMMENDATIONS

9.1 Conclusion

9.1.1 Watering regime

Water application that was stopped early in the season, after two or three months of growth, led to a significant decrease in sweet potato storage root yield. Sweet potato clones C2 and C8 produced significantly higher storage root yield than the rest of the clones across seasons, irrespective of the watering regime. However, C2 had the lowest content of total sugars and this is likely to affect its adoption by farmers. Clones C7, C8 and C9 had the highest contents of total sugars and were therefore likely to be adopted by farmers.

9.1.2 Planting beds for storage root production

Sweet potato planted on raised beds or ridges produced higher storage root yield and number of roots per plant than that planted on flat beds. Planting sweet potato clones C7 and C8 on raised beds and ridges led to significantly higher storage root yield than planting the two clones on flat beds. Season of planting sweet potato influenced the effect of both the planting beds and sweet potato clones in terms of storage root yield.

9.1.3 Planting beds for ground coverage

Two of the three ornamental sweet potato varieties that were evaluated in the study (Purple heart and Green fingers) produced about 70% percent ground coverage, as compared with variety Margarita that produced about 40% ground coverage.

9.1.4 Multiplication of planting material

During the LR season, sweet potato planted in pits or sacks without lining and those planted on flat ground had longer vines and required smaller land area to produce material required to plant one hectare of sweet potato than that planted in pits or sacks with lining. However, during the off-season multiplication of vines under irrigation, all the vine planting methods had similar vine length and therefore required the same size of nursery bed to produce material to plant one hectare. This is an indication that the use of lining is only necessary during the off-season multiplication of vines, where moisture retention is crucial.

9.1.5 Assessment of drought tolerant sweet potato clones in different locations

Three drought tolerant sweet potato clone (C7, C8 and C9) and one farmer preferred variety *Carrot* (VC) were evaluated under different farm locations. Clone C7 produced significantly higher number of marketable storage roots per plant than the other two clones and the farmer preferred variety. Planting sweet potato at the start of the long rains season (S1) or after the peak of the long rains season (S2) led to the production of higher number of marketable storage roots per plant than when the crop was planted during the short rains season (S3). Sweet potato planted in season S2 produced significantly higher storage root yield per plant than that planted in seasons S1 and S3.

9.2 Recommendations

9.2.1 Watering regime

The best candidates (C7, C8 and C9) may be multiplied for use by farmers in the drought prone areas of the region. For enhanced sweet potato storage root yield, it is recommended that farmers plant the crop at an appropriate time to ensure that it is not exposed to limited water.

9.2.2 Planting beds for storage root production

It is recommended that farmers plant sweet potato clones C7 and C8 on raised beds or ridges for high storage root yield.

9.2.3 Planting beds for ground coverage

Ornamental sweet potato varieties Purple heart and Green fingers are recommended for evaluation across agro-ecological zones in coastal Kenya to confirm their ground covering ability. Any variety that performs well across locations may then be multiplied for landscaping in the tourism industry and for soil conservation purposes in other areas.

9.2.4 Multiplication of planting material

Sweet potato vine planting methods without lining are recommended for multiplication of planting material in the long rains season. It is also recommended that farmers start the multiplication during off-season and continue during the long rains season so as to multiply enough planting material that will allow expansion of the area for sweet potato production.

9.2.5 Assessment of drought tolerant sweet potato clones in different locations

From the results of the on-farm study, it is recommended that farmers plant sweet potato clone C7 after the peak of the long rains season (S2) for increased number and yield of sweet potato storage roots respectively.

Areas for further research

Evaluation of the vine survival capacity of the best drought tolerant sweet potato clones identified in this study

Evaluation of water use efficiency among selected drought tolerant sweet potato clones

Root quality assessment for the best drought tolerant sweet potato clones identified in this study: sensory evaluation and cooking quality

Determination of the best plant spacing for 100% ground coverage by the best ornamental sweet potato varieties identified in this study

REFERENCES

Abdallah, B., Githiri, S. M., Kariuki, W. and Saha, H. M. 2021. Evaluation of different methods of multiplying sweet potato planting material in coastal lowland Kenya. *African Journal of Agricultural Research*. 17(2): 208-214. DOI: 10.5897/AJAR2020.15164.

Abewoy, D. 2021. Review on postharvest handling practices of root and tuber crops. *International Journal of Plant Breeding and Crop Science*. 8(1): 992-1000. ISSN: 2167-0449.

Abidin, P.E. 2004. Sweet potato breeding for Northeastern Uganda: Farmer varieties, farmer participatory selection and stability of performance. PhD. Thesis, Wageningen University, the Netherlands. 1-155. ISBN: 90-8504-033-7. http://edepot.wur.nl/193585.

Adam, K. L. 2005. Sweet potato: Organic production. ATTRA.1-800-346-9140.

Adebola, P.O., Shegro, A., Laurie, S.M., Zulu, L.N. and Pillay, M. 2013. Genotype x environment interaction and yield stability estimate of some sweet potato [*Ipomoea batatas* (L.) Lam] breeding lines in South Africa. *Journal of Plant Breeding and Crop Science.* 5(9): 182-186. DOI: 10.5897/JPBCS2013.0387.

Adeola, R.G., Ogunleye, K.Y. and Adewole, W.A. 2019. Adoption intensity determinants for improved sweet potato varieties among farmers in Nigeria. *International Journal of Agricultural Management and Development.* 9(3): 203-211. ISSN: 2159-5860.

Afuape, S.O., Okocha, P.I. and Njoku, D. 2011. Multivariate assessment of the agro morphological variability and yield components among sweet potato

(*Ipomoea batatas* (L.) Lam) landraces. *African Journal of Plant Science*. 5(2): 123-132. ISSN 1996-0824.

Agbede, T.M. 2010. Tillage and fertilizer effects on some soil properties, leaf nutrient concentrations, growth and sweet potato yield on an Alfisol in Southwestern Nigeria. *Soil and Tillage Research*. 110: 25-32. DOI: 10.1016/j.still.2010.06.003.

Agbede, T.M. and Adekiya, A.O. 2009. Tillage effects on soil properties and performance of sweet potato on an Alfisol in Southwestern Nigeria, *American-Eurasian Journal of Sustainable Agriculture*. 3(3): 561-568.

Agili, S., Nyende, B., Ngamau, K. and Masinde, P. 2012. Selection, yield evaluation, drought tolerance indices of orange-flesh sweet potato (*Ipomoea batatas* Lam) Hybrid Clone. *Journal of Nutrition and Food Science*. 2(3): 1-8. DOI:10.4172/2155-9600.1000138.

Ahmadizadeh, M., Valizadeh, M., Shahbazi, H. and Nori, A. 2012. Behavior of durum wheat genotypes under normal irrigation and drought stress conditions in the greenhouse. *African Journal of Biotechnology*. 11(8): 1912-1923.

Ahmed, M., Nigussie-Dechassa, R. and Abebie, B. 2012. Effect of planting methods and vine harvesting on shoot and tuberous root yields of sweet potato [*Ipomoea batatas* (L.) Lam.] in the Afar region of Ethiopia. *African Journal of Agricultural Research*. 7(7): 1129-1141. DOI: 10.5897/AJAR11.894 ISSN: 1991-637X.

Akinboye, O.E., Oyekale, K.O. and Aiyelari, E.A. 2015. Effects of land preparation methods on the growth and yield of sweet potato (*Ipomoea Batatas* LAM) *International Journal of Research in Agriculture and Forestry*. 2(1): 33-39. ISSN: 2394-5915.

Akinpelu, A.O. and Adenegan, K.O. 2011. Performance of sweet potato Marketing System in Umuahia Market, Abia State, Nigeria. *Continental Journal of Agricultural Economics.* 5(1): 7-13.

Aldow, A.M. 2017. Factors affecting sweet potato production in crop-livestock farming systems in Ethiopia. Master's Thesis. 60 ECTS. Department of Plant Sciences. Master of Science in Agro ecology.

Ali, S., Mohammed, W. and Shimelis, B. 2015b. Evaluation of sweet potato [*Ipomoea Batatas* (L.) Lam.] accessions for their physicochemical attributes in Ethiopia. *International Journal of Asian Studies*. 15: 49-54. ISSN: 2409-6938.

Ali, S., Mohammed, W. and Shimelis. B. 2015a. Agronomic and physicochemical evaluation of sweet potato [*Ipomoea batatas* (L.) Lam.] collections in Ethiopia. *Advances in Crop Science and Technology.* 3(3): 1-8. 172. DOI:10.4172/2329-8863.1000172. ISSN: 2329-8863.

Andea, G. 2012. Sweet potato production up in Kenya. http://www.kacekenya.co.ke/news.asp?ID=275. (1).

Andrade, M., Barker, I., Cole, D., Dapaah, H., Elliott, H., Fuentes, S., Grüneberg, W., Kapinga, R., Kroschel, J., Labarta, R., Lemaga, B., Loechl, C., Low, J., Lynam, J., Mwanga, R., Ortiz, O., Oswald, A. and Thiele, G. 2009. Unleashing the potential of sweet potato in Sub-Saharan Africa: Current challenges and way forward. International Potato Center (CIP), Lima, Peru. Working Paper 2009-1. 1-208. ISSN 0256-8748.

Andrade, M.I., Makunde, G.S., Ricardo, J., Menomussanga, J., Alvaro, A. and Grüneberg, W.J. 2017. Survival of sweet potato (*Ipomoea batatas* [L] Lam) vines in cultivars subjected to long dry spells after the growing season in Mozambique. *Open Agriculture*. 2: 58-63. DOI: 10.1515/opag-2017-0006.

Andrade, M.I., Naico, A., Ricardo, J., Eyzaguirre, R., Makunde, G.S., Ortiz, R. and Grüneberg, W.J. 2016. Genotype 3 environment interaction and selection for drought adaptation in sweet potato (*Ipomoea batatas* [L.] Lam.) in Mozambique. *Euphytica*. 209: 261-280. DOI: 10.1007/s10681-016-1684-4 A.

Anginyah, T.J., Narla, R.D., Carey, E.E. and Njeru, R. 2001. Etiology, effect of soil ph and sweet potato varietal reaction to alternaria leaf petiole and stem blight in Kenya. *African Crop Science Journal*. 9(1): 287-292. DOI:10.4314/acsj.v9i1.27650.

Anikwe, M.A.N. and Ubochi, J.N. 2007. Short-term changes in soil properties under tillage systems and their effect on sweet potato (*Ipomoea batatas* L.) growth and yield in an Ultisol in South-eastern Nigeria. *Australian Journal of Soil Research*. 45: 351-358. DOI: 10.1071/SR07035 0004-9573/07/050351.

Antonio, G.C., Takeiti, C.Y., de Oliveira, R.A. and Park, K.J. 2011. Sweet potato: Production, morphological and physicochemical characteristics and technological process. *Fruit, vegetable and cereal science and biotechnology*. 5 (2): 1-18.

Association of Official Analytical Chemists, 1990. Official methods of analysis of the Association of Official Analytical Chemists. Method no.92307. AOAC: Washington D.C., USA.

Arisha, M.H., Ahmad, M.Q., Tang, W., Liu, Y., Yan, H., Kou, M., Wang, X., Zhang, Y. and Li, Q. 2020. RNA-sequencing analysis revealed genes associated drought stress responses of different durations in hexaploid sweet potato.

Scientific reports, nature research. 10:12573. DOI: 10.1038/s41598-020-69232-3.

Atu, L.L. 2013. Studies on propagation materials and growing conditions for sweet potato (*Ipomoea batatas* (L.) Lam) production. M.Sc. Thesis. The University of Queensland. Australia.

Austin, D.F. 1988. The taxonomy, evolution and genetic diversity of sweet potatoes and related wild species. In: Exploration, maintenance and utilization of sweet potato genetic resources. Report of the First Sweet potato Planning Conference 1987. International Potato Center, Lima, Peru. 27-59.

Ayeleso, T. B., Ramachela, K. and Mukwevho, E. 2016. A review of therapeutic potentials of sweet potato: Pharmacological activities and influence of the cultivar. *Tropical Journal of Pharmaceutical Research*. 15(12): 2751-2761.

Bagamba, F., Bashaasha, B., Claessens, L. and Antle, J. 2012. Assessing climate change impacts and adaptation strategies for smallholder agricultural systems in Uganda. *African Crop Science Journal*. 20(2): 303-316.

Balestrini, R., Chitarra, W., Antoniou, C., Ruocco, M. and Fotopoulos, V. 2018. Improvement of plant performance under water deficit with the employment of biological and chemical priming agents. *The Journal of Agricultural Science*. 156: 680-688. DOI: 10.1017/s0021859618000126.

Belehu, T. 2003. Agronomical and physiological factors affecting growth, development and yield of sweet potato in Ethiopia. PhD. Thesis, University of Pretoria, Pretoria.

Belehu, T. and Hammes, P.S. 2004. Effect of temperature, soil moisture content and type of cutting on establishment of sweet potato cuttings. *South African Journal of Plant and Soil*. 21(2): 85-89.

Bok, I., Moamogwe, M., Molatlhegi, M., Hunyepa, M. and Ramogotsi, I. 2004. Evaluation of South African bred cultivars of sweet potato under Botswana conditions. *African crop science journal*. 12(3): 201-204.

Bourke, R.M. 1989. Influence of soil moisture extremes on sweet potato yield in the Papua New Guinea Highlands. *Mountain Research and Development*. 9(3): 322-328.

Boutigny, A.L., Dohin, N., Pomin, D. and Rolland, M. 2020. Overview and detectability of the genetic modifications in ornamental plants. *Hortic Res*. **7(**11). DOI: 10.1038/s41438-019-0232-5.

Braun B., Kashile M. and Shishwandu, M. 2003. The influence of ridging on sweet potato production under dry land condition. *Agricola*. 2003: 7-13.

Brobbey, A. 2015. Growth, yield and quality factors of sweet potato (*Ipomoea batatas* (L) Lam) as affected by seedbed type and fertilizer application. M.Sc. Thesis. Kwame Nkrumah University of Science and Technology, Kumasi, Ghana. 1-95.

Bukania, C. 2016. Sweet potato seed systems and crop management community of practice. Fifth consultation-Marketing Strategies for Quality Sweet potato Seed Corridor. 1-64.

Carey, D., Whipker, B. and Wayne Buhler, W. 2007. Producing ornamental sweet potato vine commercially. *Greenhouse Product News.* 17(11): 1-4.

Chandrasekara, A. and Kumar, T.J. 2016. Roots and tuber crops as functional foods: A review on phytochemical constituents and their potential health benefits. *International Journal of Food Science*. 2016: 1-16. Article ID 3631647.

Chen, J. 2021. Ornamental Plant Research Inaugural Editorial. *Ornamental Plant Research*. 1: (1). DOI: 10.48130/OPR-2021-0001.

CIP. 2018. Towards food system transformation. International Potato Center, Annual Report. ISSN 0256-6311 DOI: 10.4160/02566311/2018.

Claessens, L., Stoorvogel, J.J. and Antle, J.M. 2009. Ex ante assessment of dual-purpose sweet potato in the crop-livestock system of Western Kenya: a minimum data approach. *Agricultural Systems.* 99: 13-22. DOI:10.1016/j.agsy.2008.09.002.

Dahal, K., Li, X-Q., Tai, H., Creelman, A. and Bizimungu, B. 2019. Improving potato stress tolerance and tuber yield under a climate change scenario-a current overview. *Front. Plant Sci*. 10(563): 1-16. DOI: 10.3389/fpls.2019.00563.

Daryanto, S., Wang, L. and Jacinthe, P. 2016a. Drought effects on root and tuber production: A meta-analysis. *Agricultural Water Management.* 176: 122-131. http://dx.doi.org/10.1016/j.agwat.2016.05.019 0378-3774.

Daryanto, S., Wang, L. and Jacinthe, P. 2016b. Global synthesis of drought effects on cereal, legume, tuber and root crops production: A review. *Agricultural Water Management*. DOI: 10.1016/j.agwat.2016.04.022.

Delazari, F.T., Assis, I.R., Cabrera, D.F.V., Ferreira, M.G., Dias, L.E., Rueda, A., Zanuncio, J.C. and Silva, D.J.H. 2018. Morpho-physiological characteristics by sweet potato cultivars as function of irrigation depth. *Anais da Academia*

Brasileira de Ciências. 90(4): 3541-3549. DOI.10.1590/0001-3765201820170687.

Dukuh, I. G., Owusu-Sekyere, J., Bart-Plange, A., Okyere, J. and Asagadunga, A.P. 2016. The Effect of deficit irrigation and manure on soil properties, growth and yield of orange fleshed sweet potato [*Ipomoea batatas* Lam]. *Scholars Journal of Agriculture and Veterinary Sciences* 3(7): 463-473.

Dumbuya, G., Sarkodie-Addo, J., Daramy, M.A. and Jalloh, M. 2016. Growth and yield response of sweet potato to different tillage methods and phosphorus fertilizer rates in Ghana. *Journal of Experimental Biology and Agricultural Sciences*. 4(5): 475-483.

Duque, L. O. 2020. Performance of sweet potato varieties grown using black plastic mulch in Pennsylvania. Horticulture Technology. 30(6): 797-802. DOI: DOI: 10.21273/HORTTECH04689-20.

Ebregt, E., Struik, P.C., Abidin P.E. and Odongo, B. 2005. Pest damage in sweet potato, groundnut and maize in North-eastern Uganda with special reference to damage by millipedes (Diplopoda). *Wageningen Journal of Life Sciences*. 53(1): 49-69.

Echodu, R., Edema, H., Wokorach, G., Zawedde, C., Otim, G., Luambano, N., Ateka, E.M. and Asiimwe, T. 2019. Farmers' practices and their knowledge of biotic constraints to sweet potato production in East Africa. *Physiological and Molecular Plant Pathology*. 105: 3-16. DOI: 10.1016/j.pmpp.2018.07.004.

Ekanayake, I.J. and Wanda, C. 2004. Effect of irrigation on sweet potato root carbohydrates and nitrogenous compounds. *Food, Agriculture and Environment*. 2(1): 243-248.

Ekanayake, I.J., Malagamba, P. and Midmore, D.J. 1990. Effect of water stress on yield indices of sweet potatoes. In: Howeler, R. (Ed.). *Proceedings of Eighth Symposium of International Society for Tropical Root Crops*. Bangkok, Thailand: 520-528.

Ellong, E., Billard, C. and Adenet, S. 2014. "Comparison of physicochemical, organoleptic and nutritional abilities of eight sweet potato (*Ipomoea batatas*) Varieties." *Food and Nutrition Sciences*. 5(2): 196-311. DOI: 10.4236/fns.2014.52025.

Ennin, S. A., Otoo, E. and Tetteh, F.M. 2009. Ridging, a mechanized alternative to mounding for yam and cassava production. *West African Journal of Applied Ecology*. 15: 1-8.

Esan, V.I. Omilani, O.O. Adejumo, S.A. Adeyemo, T.O. and Akinbode, O.A. 2018. Screening of sweet potato ((*Ipomoea batatas* [L.] Lam.) cultivars for drought tolerance. *International Journal of Environment, Agriculture and Biotechnology*. 3(3): 732-741.

Faber, M., Laurie, S.M. and van Jaarsveld, P.J. 2013. Total β-carotene content of orange sweet potato cultivated under optimal conditions and at a rural village. *African Journal of Biotechnology*. 12(25): 3947-3951.

Fahad, S., Bajwa, A.A., Nazir, U., Anjum, S.A., Farooq, A., Zohaib, A., Sadia, S., Nasim, W., Adkins, S., Saud, S., Ihsan, M.Z., Alharby, H., Wu, C., Wang, D. and Huang, J. 2017. Crop production under drought and heat stress: Plant responses and management options. *Frontiers in Plant Science*. 8(1147): 1-16. DOI: 10.3389/fpls.2017.01147.

Fang, Y. and Xiong, L. 2015. General mechanisms of drought response and their application in drought resistance improvement in plants. *Cellular and*

Molecular Life Sciences. 72(4): 673-689. DOI: 10.1007/s00018-014-1767-0. ISSN 1420-682x.

FAOSTAT. 2018. FAOSTAT data. Available online: http://faostat.fao.org/

Gajanayake, B., Reddy K.R. and Shankle M.W. 2015. Quantifying growth and developmental responses of sweet potato to mid-and late-season temperature. *Agronomy Journal*. 107(5): 1854-1862.

Gasura, E., Matsaure, F., Setimela, P.S., Rugare, J.T., Nyakurwa, C.S. and Andrade, M. 2021. Performance, variance components, and acceptability of pro-vitamin a-biofortified sweet potato in Southern Africa and implications in future breeding. *Frontiers in Plant Science*. 12:696738. DOI: 10.3389/fpls.2021.696738.

Ghanbari, A.A., Mousavi, S.H. Gorji, A.M. and Rao, I. 2013. Effects of water stress on leaves and seeds of bean *(Phaseolus vulgaris L.)*. *Turkish Journal of Field Crops*. 18(1): 73-77.

Gibson, R.W., Mwanga, R.O.M., Namanda, S., Jeremiah, S.C. and Barker, I. 2009. Review of sweet potato seed systems in East and Southern Africa. International Potato Center (CIP), Lima, Peru. *Integrated Crop Management. Working Paper* 1: 48.

Gichuki, S.T. and Hijmans, R.J. 2005. Mapping sweet potato in Eastern Africa. ICT Update-a current awareness bulletin for ACP Agriculture.

Glato, K., Aidam, A., Kane, N.A., Bassirou, D., Couderc, M. and Zekraoui, L. 2017. Structure of sweet potato (*Ipomoea batatas*) diversity in West Africa covaries with a climatic gradient. *PLOS ONE*. 12(5): 1-17. DOI: 10.1371/journal.pone.0177697.

Gouveia, C.S.S., Ganança, J.F.T., de Nóbrega, H.G.M., de Freitas, J.G.R., Lebot, V. and Pinheiro de Carvalho, M.A.A. 2019. Drought avoidance and phenotypic flexibility of sweet potato (*Ipomoea batatas* (L.) Lam.) under water scarcity conditions. *Not Bot Horti Agrobo*. 47(4): 1-10. DOI: 10.15835/nbha47411633.

Grüneberg, W.J., Ma, D., Mwanga, R.O.M., Carey, E.E., Huamani, K., Diaz, F., Eyzaguirre, R., Guaf, E., Jusuf, M., Karuniawan, A., Tjintokohadi, K., Song, Y.S., Anil, S.R., Hossain, M., Rahaman, E., Attaluri, S.I., Some, K., Afuape, S.O., Adofo, K., Lukonge, E., Karanja, L., Ndirigwe, J., Ssemakula, G., Agili, S., Randrianaivoarinovy, J.M., Chiona, M., Chipungu, F., Laurie, S.M., Ricardo, J., Andrade, M., Rausch Fernandes, F., Mello, A.S., Khan, M.A., Labonte, D.R. and Yencho, G.C. 2015. Advances in sweet potato breeding from 1992 to 2012. In: Low, J., Nyongesa, M., Quinn, S. and Parker, M. (eds). Potato and sweet potato in Africa. Transforming the value chains for food and nutrition security. Oxford shire (UK). CAB International. 3-68. ISBN: 978-1-78064-420-2.

Grüneberg, W.J., Manrique, K., Dapeng, Z. and Hermann, M. 2005. Genotype x environment interactions for a diverse set of sweet potato clones evaluated across varying Eco geographic conditions in Peru. *Crop Science*. 45: 2160-2171. DOI: 10.2135/cropsci2003.0533.

Gurmu, F., Abele, W., Tsegaye, G. and Gezahen, G. 2019. Sweet potato seed business model: The case of the South Agricultural Research Institute. *Ethiopia Journal of Agricultural and Crop Research*. 7(8): 127-136. DOI: 10.33495/jacr_v7i8.19.126 ISSN: 2384-731X.

Gurmu, F., Hussein, S. and Laing, M. 2015. Diagnostic assessment of sweet potato production in Ethiopia: Constraints, post-harvest handling and farmers' preferences. *Research on Crops*. 16(1): 104-115.

Habibur, R., Saiful Islam, A.F.M., Abdul Maleque, M.D. and Rehenuma, T. 2015. Morpho-physiological evaluation of sweet potato (*Ipomoea batatas* L.) genotypes in acidic soil. *Asian Journal of Crop Science.* 7(4): 267-276. DOI: 10.3923/ajcs.2015.267.276URL. ISSN: 1994-7879.

Hagenimana, V., Low, J., Anyango, M., Kurz, K., Gichuki, S.T., Kabira, J., 2001. Enhancing vitamin A intake in young children in Western Kenya: orange fleshed sweet potatoes and women farmers can serve as key entry points. *Food and Nutrition* Bulletin. 22(4): 376-387.

Hartemink, A.E., Poloma, S., Maino, M., Powell, K.S., Egenae, J. and O'Sullivan, J.N. 2000. Yield decline of sweet potato in the humid lowlands of Papua New Guinea. *Agriculture, Ecosystems and Environment*. 79: 259-269.

Hidosa, D. and Guyo, M. 2017. Climate change effects on livestock feed resources: A review. *Journal of Fisheries and Livestock Production*. 5(4): 1-4. doi: 10.4172/2332-2608.1000259. ISSN: 2332-2608.

Hovhannisyan, V. and Khachatryan, H. 2017. Ornamental Plants in the United States: An Econometric Analysis of a Household-Level Demand System. Agribusiness. 33(2): 226-241. DOI: 10.1002/agr.21488.

Hue, S.M., Chandran, S. and Boyce, A.N. 2012. Variation of leaf and storage roots morphology on *Ipomoea batatas* L. (Sweet potato) cultivars. Asia pacific symposium on postharvest research. 943(6): 73-79.

Ila'ava, V.P., Asher, C.J. and Blamey, F.P.C. 2000. Response of sweet potato cultivars to acid soil infertility factors. 1. Effects of solution pH on early growth. *Australian Journal of Agricultural Research*. 51: 23-28.

Isubikalu, P. 2007. Stepping-stones to improve upon functioning of participatory agricultural extension programs: Farmer field schools in Uganda. PhD Thesis. Wageningen University, Netherlands. 1-193.

Jaetzold, R., Schmidt, H., Hornetz, B. and Shisanya, C. 2012. Farm Management handbook of Kenya. Vol. II/ Part C, Sub-Part C2, Coast Province. Ministry of Agriculture, Kenya, in corporation with the German Agency for International Cooperation (GIZ).

Jia, R. 2013. Weather shocks, sweet potatoes and peasant revolts in historical China. *The Economic Journal*. 124(575): 92-118.

Kambale, M.H. 2017. Genetic analysis of sweet potato (*Ipomoea batatas* (L.) Lam.) genotypes for beta-carotene content and root yield in Kenya. MSc Thesis. University of Nairobi. 1-88.

Kang, C., He, S., Zhai, H., Li, R., Zhao, N. and Liu, Q. 2018. A sweet potato auxin response factor gene (IbARF5) is involved in carotenoid biosynthesis and salt and drought tolerance in transgenic Arabidopsis. *Frontiers in Plant Science.* 9(1307): 1-13. DOI: 10.3389/fpls.2018.01307.

Katayama, K., Kobayashi, A., Sakai, T., Kuranouchi, T. and Kai, Y. 2017. Recent progress in sweet potato breeding and cultivars for diverse applications in Japan. *Breeding science*. 67(1): 3-14. DOI:10.1270/jsbbs.16129.

Kathabwalika, D.M., Chilembwe, E.H.C., Mwale V.M., Kambewa, D. and Njoloma, J.P. 2013. Plant growth and yield stability of orange fleshed sweet potato (*Ipomoea batatas*) genotypes in three agro-ecological zones of Malawi.

International Research Journal of Agricultural Science and Soil Science. 3(11): 383-392. ISSN: 2251-0044. DOI: 10.14303/irjas.2013.120.

Kebede, T., Gutu, T. and Tadesse, E. 2011. Performance and economic efficiency of browsing ArsiBale goats supplemented with sweet potato (*Ipomoea batatas* L.) vines as replacement for concentrate. *International Journal of Livestock Production.* 2(7): 92-99.

Kesiime, V.E. 2014. Inheritance of Tolerance to Drought from Selected Potato (*Solanum tuberosum*) Cultivars in Uganda. MSc. Thesis. Makerere University. 1-82.

Kesiime, V.E., Tusiime, G., Kashaija, I.N., Edema, R., Gibson, P., Namugga, P. and Kakuhenzire, R. 2016. Characterization and Evaluation of Potato Genotypes (*Solanum tuberosum L*) for Tolerance to Drought in Uganda. *American Journal of Potato Research*. 93(6): 543-551. DOI: 10.1007/s12230-016-9533-5. ISSN: 1874-9380.

Kirnak, H., Kaya, C., Tas, I. and Higgs, D. 2001. The influence of water deficit on vegetative growth, physiology, fruit yield and quality in eggplants. *Bulgarian Journal of Plant Physiology*. 27: 34-46. Https: //pdfs. Semantic scholar .org/4ece/44d95 0f4a7 4f695 d3ef7 c2d61 0c00a bc1af a.pdf.

Kivuva, B.M. 2013. Breeding sweet potato (*Ipomoea batatas* [L.] Lam.) for drought tolerance in Kenya. PhD Thesis. University of KwaZulu-Natal, Pietermaritzburg. 1-198.

Kivuva, B.M., Githiri, S.M., Yencho, C.G. and Sibiya, J. 2014b. Genotype x Environment Interaction for Storage Root Yield in Sweet potato Under Managed Drought Stress Conditions. *Journal of Agricultural Science*. 6(10): 41-56. ISSN: 1916-9760.

Kivuva, B.M., Musembi, F.J., Githiri S.M., Yencho, C.G. and Sibiya, J. 2014a. Assessment of production constraints and farmers preferences for sweet potato genotypes. *Journal of Plant Breeding and Genetics*. 2(1): 15-29. ISSN: 2305-297X.

Koua, G.A.Y., Zoué, T.L., Mégnanou, R.M. and Niamké, S. L. 2018. Nutritive profile and provitamin A value of sweet potatoes flours (*Ipomoea batatas* Lam) consumed in Côte d'Ivoire. *Journal of Food Research*. 7(5): 36-48.

Kulembeka, H.P., Rugutu, C.K., Kanju, E., Chirimi, B., Rwiza, E. and Amour, R. 2004. The agronomic performance and acceptability of orange fleshed sweet potato varieties in the lake zone of Tanzania. *African crop science journal*. 12(3): 229-240.

Kwak, S. 2019. Biotechnology of the sweet potato: Ensuring global food and nutrition security in the face of climate change. *Plant Cell Reports.* 38: 1361-1363. DOI: 10.1007/s00299-019-02468-0.

Lau, K.H., Del Rosario Herrera, M., Crisovan, E., Wu, S., Fei, Z., Khan, M.A., Buel, C.R. and Gemenet, D.C. 2018. Transcriptomic analysis of sweet potato under dehydration stress identifies candidate genes for drought tolerance. *Plant Direct*. 2: 1-13. DOI: 10.1002/pld3.92.

Laurie, R.N., Duplooy, C.P. and Laurie, S.M. 2009. Effect of moisture stress on growth and performance of orange-fleshed sweet potato varieties. *African Crop Science Conference Proceedings*. 9: 235-239. ISSN: 1023-070X/2009 $ 4.00.

Laurie, R.N., Laurie, S.M., du Plooy, C.P., Finnie, J.F. and van Staden, J. 2015. Yield of drought-stressed sweet potato in relation to canopy cover, stem length and stomatal conductance. *Journal of Agricultural Science*. 7(1): 201-214. ISSN: 1916-9760.

Laurie, S.M. and Magoro, M.D. 2008. Evaluation and release of new sweet potato varieties through farmer participatory selection. *African Journal of Agricultural Research*. 3(10): 672-676. ISSN: 1991- 637X.

Lewthwaite, S. L. and Triggs, C. M. 2012. Sweet potato cultivar response to prolonged drought. *Agronomy New Zealand.* 42: 1-10Lin, K., Chao, P., Yang, C., Cheng, W., Lo, H. and Chang, T. 2006. The effects of flooding and drought stresses on the antioxidant constituents in sweet potato leaves. Botanical Studies. 47: 417-426.

Loebenstein, G. and Thottappilly, G. (Eds). 2009. The Sweet potato, Springer Science+Business Media, p. 522.

Love, S.L. and Thompson-Johns, A. 1999. Seed piece spacing influences yield, tuber size distribution, stem and tuber density, and net returns of three processing potato cultivars. *HortScience*. 34(4):629-633.

Low, J.W. and Thiele G. 2020. Understanding innovation: The development and scaling of orange-fleshed sweet potato in major African food systems. *Agricultural Systems*. 179(102770): 1-15. DOI.org/10.1016/j.agsy.2019.102770.

Low, J.W., Ortiz, R., Van Damme, E., Andrade, M., Biazin, B. and Grüneberg W.J. 2020. Nutrient-dense orange-fleshed sweet potato: advances in drought-tolerance breeding and understanding of management practices for sustainable next-generation cropping systems in Sub-Saharan Africa. *Frontiers in Sustainable Food Systems*. 4(50): 1-22. DOI=10.3389/fsufs.2020.00050 ISSN=2571-581X.

Mahmud, A.A., Alam, M.J., Heck, S., Grüneberg, W.J., Chanda, D., Rahaman, E.H.M.S., Molla, M.S.H., Anwar, M.M., Talukder, M.A.-A.H., Ali, M.A. Amin, M. N., Alhomrani M., Gaber A. and Hossain, A. 2021. Assessing the productivity, quality and profitability of orange fleshed sweet potatoes grown in riverbank of the tista floodplain agro-ecological zone of Bangladesh. *Agronomy*, 11: 1-17. DOI: 10.3390/agronomy11102046.

Makanginya, S.A. 2012. Yield evaluation, selection and drought tolerance indices of orange-fleshed sweet potato (*Ipomoea batatas* Lam) under water stress conditions. PhD. Thesis. Jomo Kenyatta University of Agriculture and Technology. 1-244.

Makini, F.W., Mose, L.O., Kamau, G.K., Salasya, B., Mulinge, W.W., Ongala, J., Makelo, M.N. and Fatunbi, A.O. 2018. Innovation opportunities in sweet potato production in Kenya. Forum for Agricultural Research in Africa (FARA), Accra Ghana. 1-89. ISBN: 978-9988-8776-2-0.

Makunde, G.S., Andrade, M.I., Menomussanga, J. and Grüneberg, W. 2018. Adapting sweet potato production to changing climate in Mozambique. *Open Agriculture*. 3: 122-130. DOI.org/10.1515/opag-2018-0012.

Mandal, R.C. 2006. Tropical root and tuber crops, Agrobios, India. 360 pages.

Mbinda, W., Ombori, O., Dixelius, C. and Oduor, R. 2018. *Xerophyta viscosa Aldose Reductase*, XvAld1, enhances drought tolerance in transgenic sweet potato. *Molecular biotechnology*. 60(3): 203-214. ISSN: 1073-6085. DOI: 10.1007/s12033-018-0063-x.

McEwan, M.A., Lusheshanija, D., Shikuku, K.M. and Sindi, K. 2017. Specialized sweet potato vine multiplication in Lake Zone, Tanzania: What sticks and what changes? *Open Agric*. 2: 64-69. DOI: 10.1515/opag-2017-0007.

Mcharo, M., Carey, E.E. and Gichuki S.T. 2001. Performance of selected sweet potato varieties in Kenya. *African crop science journal*. 9(1): 49-57. ISSN: 1021-9730/2001.

Mierzejewski, K. 2016. Ornamental Sweet Potatoes: How to grow an ornamental sweet potato plant. https://www.gardeningknowhow.com/edible/vegetables/sweet-potato/grow-sweet-potato-plant.htm.

Mir, R.R., Zaman-Allah, M., Sreenivasulu, N., Trethowan, R. and Varshney, R.K. 2012. Integrated genomics, physiology and breeding approaches for improving drought tolerance in crops. *Theoretical and Applied Genetics*. 125(4): 625-645. DOI: 10.1007/s00122-012-1904-9.

Mitchell, P.D. 2008. The effects of floods on agriculture. 608.265.6514.

Mohanraj, R. and Sivasankar, S. 2014. Sweet potato (*Ipomoea batatas* [L.] Lam)-A valuable medicinal food: A Review. *Journal of Medicinal Food*. 17(7): 733-741.

Motsa, N.M., Modi, A.T. and Mabhaudhi, T. 2015. Sweet potato *(Ipomoea batatas* L.) as a drought tolerant and food security crop. *South African Journal of Science*. 111(11/12): 1-8. DOI: 10.17159/sajs.2015/20140252.

Moyo, C.C., Benesi I.R.M., Chipungu, F.P., Mwale, C.H.L., Sandifolo, V.S. and Mahungu, N.M. 2004. Cassava and sweet potato yield assessment in Malawi. *African Crop Science Journal*. 12(3): 295-303.

Mudege, N.N., Kwikiriza, N. and Heck, S. 2020. Gender analysis of sweet potato value chains: The impact of introducing orange-fleshed varieties to industrial buyers in Homa Bay and Bungoma, Kenya. Scaling up Sweet potato through

Agriculture and Nutrition Project (SUSTAIN). Lima (Peru). International Potato Center. 60. ISBN: 9789290605416.

Mudege, N.N., Temesgen, B.B. and Brouwer, A.R. 2019. Gender situational analysis of the sweet potato value chain in selected districts in Sidama and Gedeo Zones, in Southern Ethiopia. Lima: Peru. International Potato Center. 1-111. Social Sciences Working Paper No. 2019-1.

Mukhopadhyay, S.K., Chattopadhyay, A., Chakraborty, I. and Bhattacharya, I. 2011. Crops that feed the world 5: Sweet potato. Sweet potatoes for income and food security. *Food Security*. 3: 283-305. DOI: 10.1007/s12571- 011-0134-3.

Mwololo, J.K., Mburu, M.W.K. and Muturi, P.W. 2012a. Performance of sweet potato varieties across environments in Kenya. *International Journal of Agronomy and Agricultural Research*. 2(10): 1-11.

Mwololo, J.K., Muturi, P.W., Mburu, M.W.K., Njeru, R.W., Kiarie, N., Munyua, J.K., Ateka, E.M., Muinga, R.W., Kapinga, R.E. and Lemaga, B. 2012b. "Integration of farmers in technology developments as a basis for enhancing sweet-potato productivity in Kenya. 1-8.

Namanda, S. 2012. Current and potential systems for maintaining sweet potato planting material in areas with prolonged dry seasons: A biological, social and economic framework. PhD Thesis, University of Greenwich, London. 1-236.

Nedunchezhiyan, M., Byju, G. and Ray, R.C. 2012. Effect of tillage, irrigation and nutrient levels on growth and yield of sweet potato in rice fallow. International Scholarly Research Network. *Sweet potato Agronomy*. 13.

Neela, S. and Fanta, S. W. 2019. Review on nutritional composition of orange-fleshed sweet potato and its role in management of vitamin A deficiency. *Food science and nutrition*. 7(6): 1920-1945. https://doi.org/10.1002/fsn3.1063.

Nelson, I.U., Udo, E.S. and Jacob, D.E. 2018. Profitability of ornamental plant business in Akwa Ibom State, Nigeria. *Eurasian Journal of Forest Science*. 6 (1): 35-43.

Njeru, R.W., Mburu, M.W.K., Cheramagoi, E., Gibson, R.W., Kiburi, Z.M., Obudho, E. and Yobera, D. 2004. 'Studies on the physiological effects of viruses on sweet potato yield in Kenya'. *Annals of Applied Biology*. 145: 71-76.

Njoku, J.C., Muoneke, C.O., Okocha, P.I. and Ekeleme, F. 2009. Effect of propagule size and intra-row spacing on the growth and yield of sweet potato in a humid Agro-ecological Zone. *Niger Agriculture Journal*. 40(1): 115-124.

Okonya, J.S. and Kroschel, J. 2014. Gender differences in access and use of selected productive resources among sweet potato farmers in Uganda. *Agriculture and Food Security*. 3: 1-10.

Omotobora, B.O., Adebola, P.O. Modise, D.M., Laurie S.M. and Gerrano, A.S. 2014. Greenhouse and field evaluation of selected sweet potato (*Ipomoea batatas* (L.) LAM) accessions for drought tolerance in South Africa. *American Journal of Plant Sciences*. 5: 3328-3339. DOI: 10.4236/ajps.2014.521348.

Osiru, M.O., Olanya, O.M., Adipala, E., Kapinga, R. and Lemaga, B. 2009. Yield stability analysis of '*Ipomoea batatas*' L. cultivars in diverse environments. *Australian Journal of Crop Science*. 3(4): 213-220. ISSN: 1835-2693.

Pepo, P. 2018. The effect of different planting methods on the yield and spad readings of sweet potato (*Ipomoea batatas* L.). *Columella-Journal of Agricultural and Environmental Sciences*. 5(1): 7-12.

Perry, L. 2021. The economic value of landscaping. http://www.uvm.edu/pss/ppp/articles/econvalue.html.

Rahmawati, N., Lahay, R.R., Irmansyah, T. and Mawarni, L. 2020. Yield and tuber quality of orange-fleshed sweet potato cultivars under drought stress in greenhouse. *Earth and Environmental Science.* 454(012159): 1-7. DOI: 10.1088/1755-1315/454/1/012159.

Ravi, V. and Saravanan, R. 2012. Crop physiology of sweet potato. *Fruit, vegetable and cereal science and biotechnology*. 6(1): 17-29.

Richardson, K.V.A. 2019. The impact of different weather conditions on ground cover development and tuber yield of sweet potato. *Gladstone Road Agricultural Centre Crops Research Report*. 27: 1-15.

Rodríguez-Delfín, A., Posadas, A., León-Velarde, C., Mares, V. and Quiroz, R. 2012. Effect of salt and water stress on the proline and total chlorophyll content and nutrients uptake on two sweet potato cultivars grown on soilless culture. *Acta Horticulturae*. 947(4): 55-62 DOI: 10.17660/ActaHortic.2012.947.4.

Roitsch, T., Balibrea, M.E., Hofmann, M., Proels, R. and Sinha, A.K. 2003. Extracellular invertase: Key metabolic enzyme and pathogenesis-related protein. *Journal of Experimental Botany*. 54(382): 513-524.

Rukundo, P., Shimelis, H., Laing, M. and Gahakwa, D. 2017. Combining ability, maternal effects, and heritability of drought tolerance, yield and yield components in sweet potato. *Frontiers in Plant Science*. 7(1981): 1-14. DOI: 10.3389/fpls.2016.01981.

Rykaczewska, K. 2015. The effect of high temperature occurring in subsequent stages of plant development on potato yield and tuber physiological defects. *American Journal of Potato Research.* 92: 339-349.Saha, H.M. 2015. Resource use under maize-green manure legume intercropping systems. LAP Lambert Academic Publishing, Germany: Deutschland. pp 230.

Saini, I., Chauhan, J., and Kaushik, P. 2020. Medicinal Value of Domiciliary Ornamental Plants of the Asteraceae Family. *Journal of Young Pharm*. 12: 3-10.

Saleh, H.H., Thabit, Z.O. and Ali, A.H. 2004. On-farm evaluation of sweet potato varieties in Zanzibar. *African crop science journal*. 12(3): 253-258.

Saqib, M., Khalid, M.F., Hussain, S. and Anjum, M.A. 2017. Effect of water stress and planting system on growth, yield and quality of sweet potato. *Acta Scientiarum. Polonorum Hortorum Cultus*. 16(6): 201-210. DOI: 10.24326/asphc.2017.6.18. ISSN 1644-0692.

Sarrantonio, M. 1991. Methodologies for screening soil-improving legumes. Rodale Institute Research Center, Pennsylvania. 1-310.

Speek, A.J., Temaliwa, C.R. and Schrijver, J. 1986. Determination of beta-carotene content and vitamin A activity of vegetables by high performance liquid chromatography and spectrophotometry. *Food Chemistry*. 19: 65-74.

Statistical Analysis Systems Institute (2002). SAS/STAT user’s guide. Version 9.1 SAS Institute Inc. Cary. NC.

Saxena, P. and Ghosh, C. 2013. Ornamental plants as sinks and bio indicators. *Environmental Technology*. 34(23): 3059-3067. DOI: 10.1080/09593330.2013.800590.

Sousa, R.M.D., Peixoto, J.R., Amaro, G.B., Vilela, M.S., Costa, A.P. and Nóbrega, D.S. 2018. Ornamental potential of sweet potato accessions. *Bioscience Journal*. 34(1): 11-16. DOI: 10.14393/BJ-v34n6a2018-39985.

Stathers, T., Low, J., Mwanga, R., Carey, T., McEwan, M., David, S., Gibson, R., Namanda, S., McEwan, M., Malinga, J., Ackatia-Armah, R., Benjamin, M., Katcher, H., Blakenship, J., Andrade, M., Agili, S., Njoku, J., Sindi, K., Mulongo, G., Tumwegamire, S., Njoku, A., Abidin, E., Mbabu, A., Mkumbira, J., Ogero, K., Rajendran, S., Okello, J., Bechoff, A., Ndyetabula, D., Grant, F., Maru, J., Munyua, H. and Mudege, N. 2018. Everything you ever wanted to know about sweet potato: Reaching agents of change ToT manual. International Potato Center, Lima, Peru. https://hdl.handle.net/10568/98334. 12. 1-664.

Tairo, F., Mneney, E. and Kullaya, A. 2008. Morphological and agronomical characterization of Sweet potato [*Ipomoea batatas* (L.) Lam.] germplasm collection from Tanzania. *African Journal of Plant Science*. 2(8): 77-85.

Tewe, O.O., Ojeniyi, F.E. and Abu, O.A. 2003. Sweet potato Production, Utilization and Marketing in Nigeria. Social Sciences Department, International Potato Center (CIP), Lima, Peru.

Tittonell, P. and Giller, K.E. 2013. When yield gaps are poverty traps: the paradigm of ecological intensification in African smallholder agriculture. *Field Crops Research*. 143: 76-90. 0378-4290 DOI: 10.1016/j.fcr.2012.10.007.

Tobiasz-Salach, R., Krochmal-Marczak, B. and Sawicka, B. 2018. Impact of cultivations technology on the yield of sweet potato (*Ipomoea batatas* L) tubers. *Emirates Journal of Food and Agriculture*. 30(11): 978-983. DOI: 10.9755/ejfa.2018.v30.i11.1863.

Tokusoglu O., Kocak, S., Aycan, S. and Yildirim Z. 2003. Comparative study for detection of B-group vitamins and folic acid by gas chromatography-mass spectrometry (GC-MS) and differential pulse polarography (DPP) in sweet potato (*Ipomoea batatas* L.). In 2003 IFT Annual Meeting Book of Abstracts. p. 239. July 12-16 in McCormick Place, South Building, Chicago IL, USA.

Tokusoglu O., Yildirim Z. and Durucasu I. 2005. Nutraceutical phenolics (total polyphenols, chlorogenic [5-O-Caffeoylquinic] acid) in tubers, leaves, stalks and stems of new developed sweet potato (*Ipomoea batatas* L.): Alterations in tubers during short-term storage. *Journal of Food Technol.* 3(3): 444-448.

Truong V. D., Avula, R.Y., Pecota, K.V. and Yencho, G.C. 2018. Sweet potato production, processing and nutritional quality. Handbook of Vegetables and Vegetable Processing. Volume II, Second Edition. *John Wiley and Sons Ltd*. 2(35): 811-838.

Turyagyenda, F.L., Kizito, E.B., Baguma, Y. and Osiru, D. 2013. Evaluation of Ugandan Cassava Germplasm for Drought tolerance. *Intl. J. Agric. And Crop Sci*. 5 (3): 212-226.

Ume, S.I., Onunka, B.N., Nwaneri, T.C. and Okoro, G.O. 2016. Socio-economic determinants of sweet potato production among small holder women farmers in Ezza South local government area of Ebonyi State, Nigeria. *Global Journal of Advanced Research*. 3(9): 872-883. ISSN: 2394-5788.

United States Department of Agriculture (USDA). 2015. Commodity Highlight: Sweet potatoes. Economic Research Service Situation and Outlook Report VGS-355-SA1, Washington DC.

USAID. 2018. Climate Risk Profile Kenya. USAID Fact Sheet, pp. 1-5.

Valverde R.A., Clark C.A., Jari P.T. and Valkonen J.P.T. 2007. Viruses and virus disease complexes of sweet potato. *Plant Viruses.* 1(1): 116-126.

Van Dam, J., Kooman, P.L. and Struik, P.C. 1996. Effects of temperature and photoperiod on early growth and final number of tubers in potato (*Solanum tuberosum* L.). *Potato Res*. 39:51-62. DOI: 10.1007/BF02358206.

Van Vugt, V.D. and Franke, A.C. 2018. Exploring the yield gap of orange-fleshed sweet potato varieties on smallholder farmers' fields in Malawi. *Field Crops Research*. 221: 245-256. ISSN: 0378-4290. DOI: 10.1016/j.fcr.2017.11.028.

Verma V.M. 2014. Sweet potato cultivation guide. Kosrae Agricultural Experiment Station. 1-10.

Wamala, M. and Akanda, S. 2013. Effect of early water stress on the growth and development of ten selected sweet potato genotypes. *Niugini Agrisaiens.* 5: 10-18.

Wang, Z., Li, J., Luo, Z., Huang, L., Chen, X., Fang, B., Li, Y., Chen, J. and Zhang, X. 2011. Characterization and development of EST-derived SSR markers in cultivated sweet potato (*Ipomoea batatas)*. *BMC Plant Biology*. 11(139): 1-9. http://www.biomedcentral.com/1471-2229/11/139.

Ware, M. 2019. What's to know about sweet potatoes? Newsletter.

Wariboko, C. and Ogidi, I.A. 2013. Evaluation of the performance of improved sweet potato (*Ipomoea batatas* L. LAM) varieties in Bayelsa State, Nigeria. *African Journal of Environmental Science and Technology*. 8(1): 48-53. DOI: 10.5897/AJEST2013. 1572 ISSN: 1996-0786.

Were, H.K., Omuterema, S., Ndolo, P., Imbuga, B., Omuse, C.N. and Keya, N.C.O. 2013. Sweet potato production and use in sugarcane growing areas of Western Kenya. *International Journal of Disaster Management and Risk Reduction*. 5(1): 121-133.

Wilson, L.A. 1982. Tuberization in sweet potato (*Ipomoea batatas* (L) Lam). In Villareal, R. L. and Griggs, T. D. (eds.), Sweet Potato. Proceedings of the First International Symposium. Asian Vegetable Research and Development Centre, Tainan, Taiwan. pp. 79-9.

Woolfe, J.A. 1992. Sweet potato: An untapped food resource. Cambridge University Press, UK. 1-363.

Yada, B., Tukamuhabwa, P., Wanjala, B.L., Kim, D.J., Skilton, R.A., Alajo, A. and Mwanga R.O.M. 2010. Characterization of Ugandan sweet potato germplasm using fluorescent labeled simple sequence repeat markers. *Hortscience*. 45: 225-230.

Yadeta, B., Belew, D., Gebreselassie, W. and Marame, F. 2011. Variability, heritability and genetic advance in hot pepper (Capsicum annuum L.) genotypes in West Shoa, Ethiopia. *American-Eurasian Journal of Agriculture and Environmental Science*. 10(4), 587-592.

Yooyongwech, S., Samphumphuang, T., Theerawitaya, C. and Cha-Um, S. 2014. Physio-morphological responses of sweet potato [*Ipomoea batatas* (L.) Lam.] genotypes to water-deficit stress. *POJ*. 7(5): 361-368.

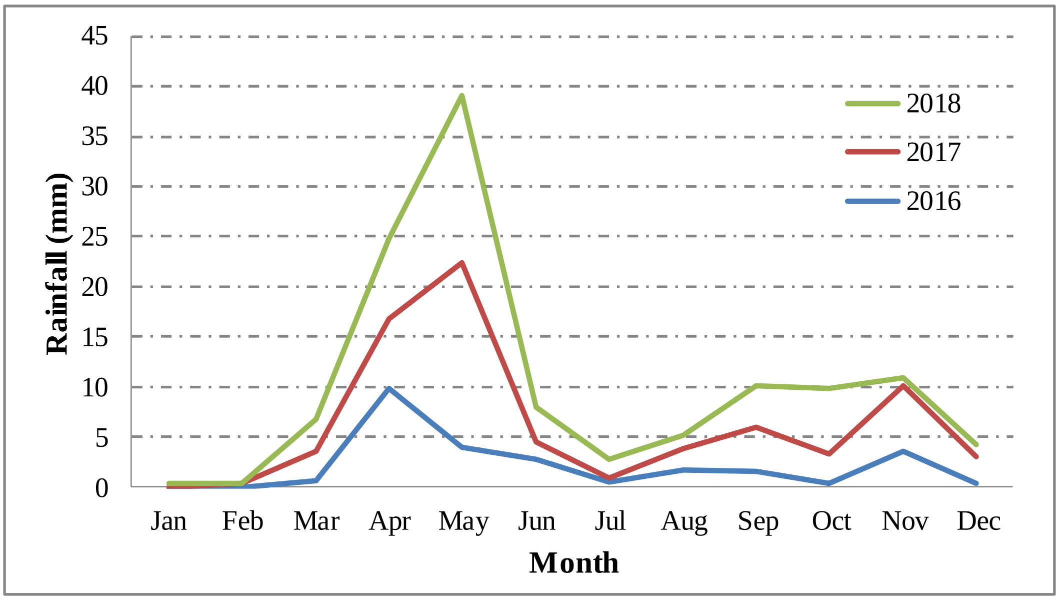
Zhai, H., Wang, F., Si, Z., Huo, J., Xing, L., An, Y., He, S. and Liu, Q. 2016. A myo-inositol-1-phosphate synthase gene, IbMIPS1, enhances salt and drought tolerance and stem nematode resistance in transgenic sweet potato. *Plant Biotechnology Journal.* 14: 592-602. DOI: 10.1111/pbi.12402.

Zhang, N., Zhang, Q., Li, Y., Zeng, M., Li, W., Chang, C., Xu, Y. and Huang, C. 2020. Effect of groundcovers on reducing soil erosion and non-point source pollution in citrus orchards on red soil under frequent heavy rainfall. *Sustainability*. 12: 1-16. DOI: 10.3390/su12031146.

APPENDICES

Appendix I: Characteristics of the study sites

Appendix Ia: Rainfall distribution at the on-station study site (Pwani University) in 2016, 2017 and 2018



Source: KALRO-Mtwapa meteorological station

Appendix Ib: Temperature (°C) during the watering regime experiment

	Minimum temperature	Maximum temperature
December 2016	23.9	31.6
January 2017	26.5	33
February 2017	25.5	33.3
March 2017	27.1	34
April 2017	27	32.5
May 2017	25	31
June 2017	25	30
July 2017	25.5	30.6
August 2017	24.5	30
September 2017	24.5	30
October 2017	25.5	31.5
November 2017	25.5	32

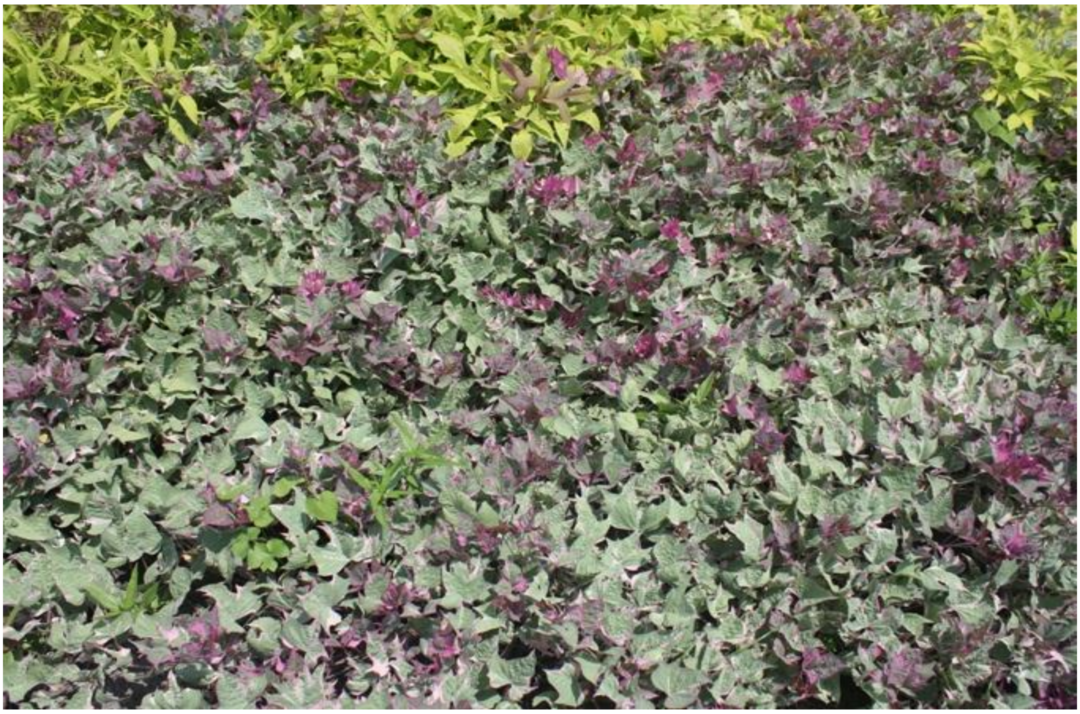
Source: KALRO-Mtwapa meteorological station

Appendix Ic: Characteristics of the sites used for on-farm trials

Site	GPS	County	AEZ	Average (mm)	Soil texture	Soil fertility
Kaliang'ombe	-3. 901419 39.540543	Kilifi	CL3	900	Loamy Sand	Low N, OC, and P, Adequate K
Jimba	-3. 896962 39 541081	Kilifi	CL3	900	Sandy Loam	Low N, OC and K, Adequate P
Mavueni	-3.680750 39.795083	Kilifi	CL3	1000	Loamy Sand	Low N, OC, P and K
Mrima	-4.4966170 39.246517	Kwale	CL2	1300	Loamy Sand	Low N and OC, Adequate P and K
Kenya-Loma	-4.494117 39.213333	Kwale	CL3	1200	Loamy Sand	Low N, OC, and P, Adequate K

Appendix II: Ornamental sweet potato varieties

Appendix IIa: An illustration of ground coverage by ornamental sweet potato



Appendix IIb Ornamental sweet potato variety Purple heart (V1)

Appendix IIc: Ornamental sweet potato variety Green fingers (V2)

Appendix IId: Ornamental sweet potato variety Margarita (V3)

Appendix III: Preservation of sweet potato planting material

Appendix IIIa: Sweet potato variety Rabai planting material being preserved outside a bathroom in Rabai, Kilifi County, Kenya

Appendix IIIb: Planting material being preserved in a swampy area in Kanana, Kwale County, Kenya

Appendix IV: Sweet potato clones and farmer preferred varieties

Appendix IVa: Sweet potato clone 6.1A (C1) foliage and storage roots in the

watering regime experiment

Appendix IVb: Sweet potato clone 4.10 (C2) foliage and storage roots in the watering regime experiment

Appendix IVc: Sweet potato clone 7.8 (C3) foliage and storage roots in the watering regime experiment

Appendix IVd: Sweet potato clone 15.10 (C4) foliage and storage roots in the watering regime experiment

Appendix IVe: Sweet potato clone 7.6AO (C5) foliage and storage roots in the watering regime experiment

Appendix IVf: Sweet potato clone 10.10B (C6) foliage and storage roots in the watering regime experiment

Appendix IVg: Sweet potato clone 4.2B (C7) foliage and storage roots in the watering regime experiment

Appendix IVh: Sweet potato clone 7.6B (C8) foliage and storage roots in the watering regime experiment

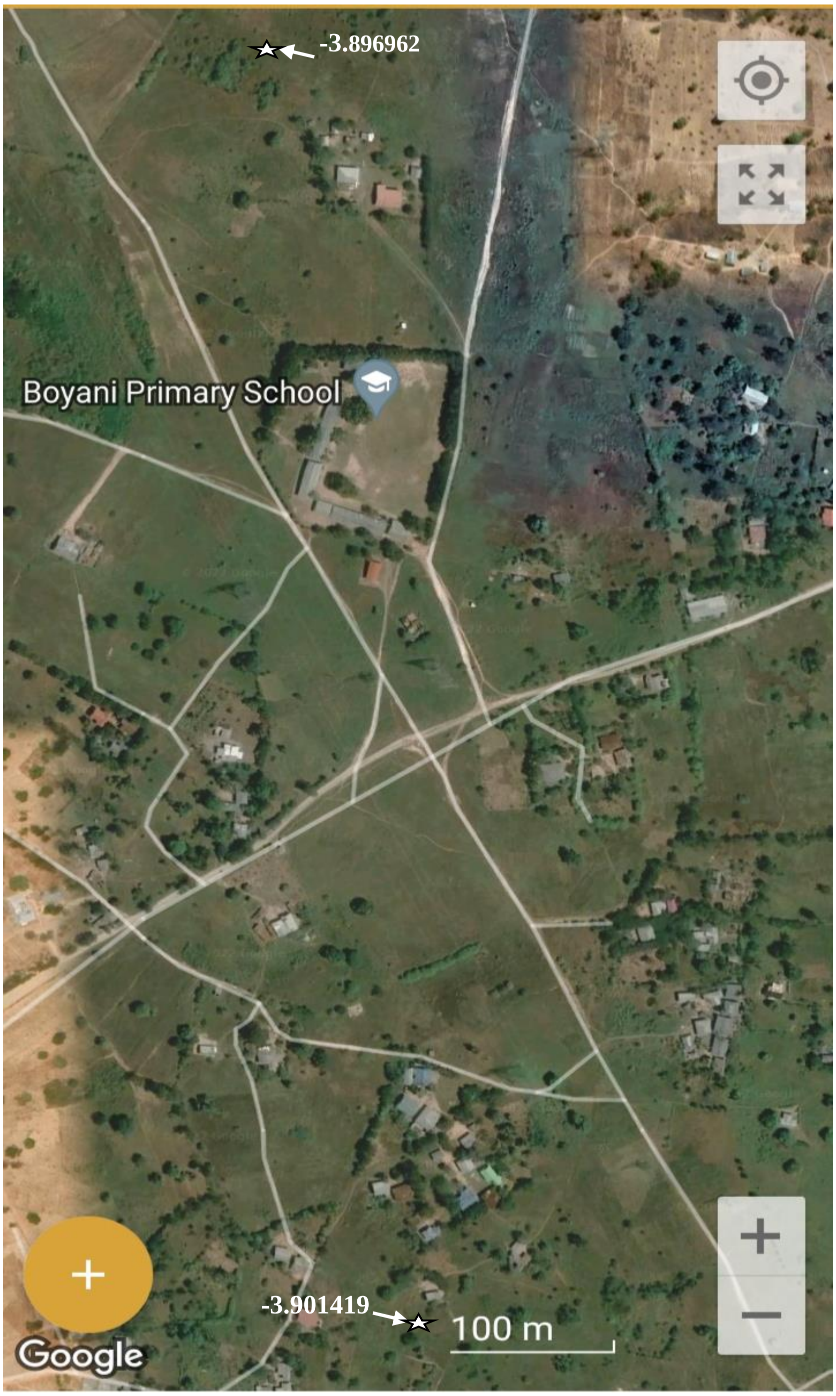
Appendix IVi: Sweet potato clone 4.2A (C9) foliage and storage roots in the watering regime experiment

Appendix IVj: Farmer preferred variety Rabai (VR) foliage and storage roots in the watering regime experiment

Appendix IVk: Farmer preferred variety Carrot (VC) foliage and storage roots in the on-farm experiment

Appendix V: Satellite images showing the location of on-farm study sites

Appendix Va: Jimba and Kaliang'ombe on-farm study sites



Source: Google map (Downloaded on 01-12-2022)

Appendix Vb: Mavueni on-farm study site

Source: Google map (Downloaded on 01-12-2022)

Appendix Vc: Mrima on-farm study site

Source: Google map (Downloaded on 01-12-2022)

Appendix Vd: Kenya-Loma on-farm study site

Source: Google map (Downloaded on 01-12-2022)

Appendix VI: Tables showing output from Analysis of Variance for different parameters using SAS software

Appendix VIa: Effect of watering regime on the number of sweet potato storage roots per plant

Source	DF	Sums of Squares	Mean Square	F Value	Pr > F
BLOCK	2	2.87012333	1.43506167	16.94	<.0001
SEASON	1	3.25501042	3.25501042	38.42	<.0001
CLONE	9	41.90421042	4.65602338	54.95	<.0001
WR	**3**	**7.72272792**	**2.57424264**	**30.38**	**<.0001**
SEASON*CLONE	9	9.86259375	1.09584375	12.93	<.0001
CLONE*WR	27	3.29325125	0.12197227	1.44	0.0876
SEASON*CLONE*WR	30	2.02344583	0.06744819	0.80	0.7648
Error	158	13.38667667	0.08472580		
Corrected Total	239	84.31803958			

WR = Watering regime

Appendix VIb: Effect of watering regime on sweet potato storage root circumference

Source	DF	Sums of Squares	Mean Square	F Value	Pr > F
BLOCK	2	2.57635083	1.28817542	4.13	0.0178
SEASON	1	2.98820167	2.98820167	9.58	0.0023
CLONE	9	98.61999833	10.95777759	35.14	<.0001
WR	**3**	**47.11408167**	**15.70469389**	**50.37**	**<.0001**
SEASON*CLONE	9	31.75936500	3.52881833	11.32	<.0001
CLONE*WR	27	8.56101833	0.31707475	1.02	0.4496
SEASON*CLONE*WR	30	9.14933333	0.30497778	0.98	0.5055

Error	158	49.2630492	0.3117915
Corrected Total	239	250.0313983	

WR = Watering regime

Appendix VIc: Effect of watering regime on sweet potato fresh storage root yield (wet-weight basis)

Source	DF	Sums of Squares	Mean Square	F Value	Pr > F
BLOCK	2	3.9118918	1.9559459	8.34	0.0004
SEASON	1	0.2978626	0.2978626	1.27	0.2616
CLONE	9	108.0536650	12.0059628	51.17	<.0001
WR	**3**	**48.3004756**	**16.1001585**	**68.62**	**<.0001**
SEASON*CLONE	9	22.5402797	2.5044755	10.67	<.0001
CLONE*WR	27	8.6414918	0.3200553	1.36	0.1233
SEASON*CLONE*WR	30	5.3211205	0.1773707	0.76	0.8145
Error	158	37.0726289	0.2346369		
Corrected Total	239	234.1394159			

WR = Watering regime

Appendix VId: Effect of watering regime on sweet potato dry storage root yield (dry-weight basis)

Source	DF	Sums of Squares	Mean Square	F Value	Pr > F
BLOCK	2	1.03352710	0.51676355	7.16	0.0011
SEASON	1	0.90540450	0.90540450	12.55	0.0005
CLONE	9	26.39923962	2.93324885	40.66	<.0001
WR	**3**	**13.82287765**	**4.60762588**	**63.87**	**<.0001**
SEASON*CLONE	9	4.69478029	0.52164225	7.23	<.0001

CLONE*WR	27	1.90265140	0.07046857	0.98	0.5038
SEASON*CLONE*WR	30	1.73373804	0.05779127	0.80	0.7584
Error	158	11.39894357	0.07214521		
Corrected Total	239	61.89116216			

WR = Watering regime

Appendix VIe: Interaction effect of watering regime and sweet potato clone on the length of sweet potato storage root

Source	DF	Sums of Squares	Mean Square	F Value	Pr > F
BLOCK	2	5.10278250	2.55139125	7.73	0.0006
SEASON	1	0.54055042	0.54055042	1.64	0.2026
CLONE	9	92.49696208	10.27744023	31.13	<.0001
WR	3	39.76638458	13.25546153	40.15	<.0001
SEASON*CLONE	9	41.01992875	4.55776986	13.80	<.0001
CLONE*WR	**27**	**14.12463625**	**0.52313468**	**1.58**	**0.0435**
SEASON*CLONE*WR	30	11.05810417	0.36860347	1.12	0.3233
Error	158	52.1666175	0.3301685		
Corrected Total	239	256.2759663			

WR = Watering regime

Appendix VIf: Interaction effect of watering regime and sweet potato clone on storage root % dry matter of sweet potato

Source	DF	Sums of Squares	Mean Square	F Value	Pr > F
BLOCK	2	7.35075250	3.67537625	4.34	0.0146
SEASON	1	89.97626042	89.97626042	106.26	<.0001
CLONE	9	45.26926708	5.02991856	5.94	<.0001
WR	3	26.67567458	8.89189153	10.50	<.0001

SEASON*CLONE	9	39.36822708	4.37424745	5.17	<.0001
CLONE*WR	**27**	**46.50418792**	**1.72237733**	**2.03**	**0.0038**
SEASON*CLONE*WR	30	32.78142917	1.09271431	1.29	0.1605
Error	158	133.7890475	0.8467661		
Corrected Total	239	421.7148462			

WR = Watering regime

Appendix VIg: Interaction effect of season and sweet potato clone on fresh storage root yield (wet-weight basis) of sweet potato

Source	DF	Sums of Squares	Mean Square	F Value	Pr > F
BLOCK	2	3.9118918	1.9559459	8.34	0.0004
SEASON	1	0.2978626	0.2978626	1.27	0.2616
CLONE	9	108.0536650	12.0059628	51.17	<.0001
WR	3	48.3004756	16.1001585	68.62	<.0001
SEASON*CLONE	**9**	**22.5402797**	**2.5044755**	**10.67**	**<.0001**
CLONE*WR	27	8.6414918	0.3200553	1.36	0.1233
SEASON*CLONE*WR	30	5.3211205	0.1773707	0.76	0.8145
Error	158	37.0726289	0.2346369		
Corrected Total	239	234.1394159			

WR = Watering regime

Appendix VIh: Interaction effect of season and sweet potato clone on dry storage root yield (dry-weight basis) of sweet potato

Source	DF	Sums of Squares	Mean Square	F Value	Pr > F
BLOCK	2	1.03352710	0.51676355	7.16	0.0011
SEASON	1	0.90540450	0.90540450	12.55	0.0005
CLONE	9	26.39923962	2.93324885	40.66	<.0001
WR	3	13.82287765	4.60762588	63.87	<.0001

SEASON*CLONE	**9**	**4.69478029**	**0.52164225**	**7.23**	**<.0001**
CLONE*WR	27	1.90265140	0.07046857	0.98	0.5038
SEASON*CLONE*WR	30	1.73373804	0.05779127	0.80	0.7584
Error	158	11.39894357	0.07214521		
Corrected Total	239	61.89116216			

WR = Watering regime

Appendix VIi: Interaction effect of season and sweet potato clone on storage root circumference of sweet potato

Source	DF	Sums of Squares	Mean Square	F Value	Pr > F
BLOCK	2	2.57635083	1.28817542	4.13	0.0178
SEASON	1	2.98820167	2.98820167	9.58	0.0023
CLONE	9	98.61999833	10.95777759	35.14	<.0001
WR	3	47.11408167	15.70469389	50.37	<.0001
SEASON*CLONE	**9**	**31.75936500**	**3.52881833**	**11.32**	**<.0001**
CLONE*WR	27	8.56101833	0.31707475	1.02	0.4496

SEASON*CLONE*WR	30	9.14933333	0.30497778	0.98	0.5055
Error	158	49.2630492	0.3117915		
Corrected Total	239	250.0313983			

WR = Watering regime

Appendix VIj: Interaction effect of season and sweet potato clone on the length of sweet potato storage root

Source	DF	Sums of Squares	Mean Square	F Value	Pr > F
BLOCK	2	5.10278250	2.55139125	7.73	0.0006
SEASON	1	0.54055042	0.54055042	1.64	0.2026
CLONE	9	92.49696208	10.27744023	31.13	<.0001
WR	3	39.76638458	13.25546153	40.15	<.0001
SEASON*CLONE	**9**	**41.01992875**	**4.55776986**	**13.80**	**<.0001**
CLONE*WR	27	14.12463625	0.52313468	1.58	0.0435
SEASON*CLONE*WR	30	11.05810417	0.36860347	1.12	0.3233
Error	158	52.1666175	0.3301685		
Corrected Total	239	256.2759663			

WR = Watering regime

Appendix VIk: Interaction effect of season and sweet potato clone on the number of sweet potato storage roots

Source	DF	Sums of Squares	Mean Square	F Value	Pr > F
BLOCK	2	2.87012333	1.43506167	16.94	<.0001
SEASON	1	3.25501042	3.25501042	38.42	<.0001
CLONE	9	41.90421042	4.65602338	54.95	<.0001
WR	3	7.72272792	2.57424264	30.38	<.0001
SEASON*CLONE	**9**	**9.86259375**	**1.09584375**	**12.93**	**<.0001**
CLONE*WR	27	3.29325125	0.12197227	1.44	0.0876
SEASON*CLONE*WR	30	2.02344583	0.06744819	0.80	0.7648
Error	158	13.38667667	0.08472580		
Corrected Total	239	84.31803958			

WR = Watering regime

Appendix VI l: Interaction effect of season and sweet potato clone on % dry matter of sweet potato storage root

Source	DF	Sums of Squares	Mean Square	F Value	Pr > F
BLOCK	2	7.35075250	3.67537625	4.34	0.0146
SEASON	1	89.97626042	89.97626042	106.26	<.0001
CLONE	9	45.26926708	5.02991856	5.94	<.0001
WR	3	26.67567458	8.89189153	10.50	<.0001
SEASON*CLONE	**9**	**39.36822708**	**4.37424745**	**5.17**	**<.0001**

CLONE*WR	27	46.50418792	1.72237733	2.03	0.0038
SEASON*CLONE*WR	30	32.78142917	1.09271431	1.29	0.1605
Error	158	133.7890475	0.8467661		
Corrected Total	239	421.7148462			

WR = Watering regime

Appendix VIm: Effect of season on the number of marketable sweet potato storage roots per plant

Source	DF	Sums of Squares	Mean Square	F Value	Pr > F
BLOCK	2	0.667778	0.333889	0.56	0.5766
SEASON	**1**	**3.034074**	**3.034074**	**5.09**	**0.0307**
PB	2	5.907778	2.953889	4.95	0.013
CLONE	2	16.77778	8.388889	14.06	<.0001
SEASON*PB	2	2.667037	1.333519	2.24	0.1225
SEASON*CLONE	2	1.179259	0.58963	0.99	0.3827
PB*CLONE	4	3.094444	0.773611	1.3	0.2909
SEASON*PB*CLONE	4	1.95963	0.489907	0.82	0.5208
Error	34	20.28556	0.596634		
Corrected Total	53	55.57333			

PB = Planting bed

Appendix VI n: Effect of planting bed on the number of marketable sweet potato storage roots per plant

Source	DF	Sums of Squares	Mean Square	F Value	Pr > F
BLOCK	2	0.667778	0.333889	0.56	0.5766
SEASON	1	3.034074	3.034074	5.09	0.0307
PB	**2**	**5.907778**	**2.953889**	**4.95**	**0.013**
CLONE	2	16.77778	8.388889	14.06	<.0001

SEASON*PB	2	2.667037	1.333519	2.24	0.1225
SEASON*CLONE	2	1.179259	0.58963	0.99	0.3827
PB*CLONE	4	3.094444	0.773611	1.3	0.2909
SEASON*PB*CLONE	4	1.95963	0.489907	0.82	0.5208
Error	34	20.28556	0.596634		
Corrected Total	53	55.57333			

PB = Planting bed

Appendix VIo: Effect of sweet potato clone on the number of marketable sweet potato storage roots per plant

Source	DF	Sums of Squares	Mean Square	F Value	Pr > F
BLOCK	2	0.667778	0.333889	0.56	0.5766
SEASON	1	3.034074	3.034074	5.09	0.0307
PB	2	5.907778	2.953889	4.95	0.013
CLONE	**2**	**16.77778**	**8.388889**	**14.06**	**<.0001**
SEASON*PB	2	2.667037	1.333519	2.24	0.1225
SEASON*CLONE	2	1.179259	0.58963	0.99	0.3827
PB*CLONE	4	3.094444	0.773611	1.3	0.2909
SEASON*PB*CLONE	4	1.95963	0.489907	0.82	0.5208
Error	34	20.28556	0.596634		
Corrected Total	53	55.57333			

PB = Planting bed

Appendix VIp: Interaction effect of season and planting bed on sweet potato storage root yield

Source	DF	Sums of Squares	Mean Square	F Value	Pr > F
BLOCK	2	200.6248	100.3124	9.89	0.0004
SEASON	1	175.6807	175.6807	17.32	0.0002
PB	2	156.3437	78.17185	7.71	0.0017

CLONE	2	199.4826	99.7413	9.83	0.0004
SEASON*PB	**2**	**104.2548**	**52.12741**	**5.14**	**0.0112**
SEASON*CLONE	2	105.5937	52.79685	5.21	0.0107
PB*CLONE	4	57.68074	14.42019	1.42	0.2478
SEASON*PB*CLONE	4	47.32074	11.83019	1.17	0.3428
Error	34	344.8285	10.14202		
Corrected Total	53	1391.81			

PB = Planting bed

Appendix VIq: Interaction effect of season and sweet potato clone on sweet potato storage root yield

Source	DF	Sums of Squares	Mean Square	F Value	Pr > F
BLOCK	2	200.6248	100.3124	9.89	0.0004
SEASON	1	175.6807	175.6807	17.32	0.0002
PBT	2	156.3437	78.17185	7.71	0.0017
CLONE	2	199.4826	99.7413	9.83	0.0004

SEASON*PB	2	104.2548	52.12741	5.14	0.0112
SEASON*CLONE	**2**	**105.5937**	**52.79685**	**5.21**	**0.0107**
PB*CLONE	4	57.68074	14.42019	1.42	0.2478
SEASON*PB*CLONE	4	47.32074	11.83019	1.17	0.3428
Error	34	344.8285	10.14202		
Corrected Total	53	1391.81			

PB = Planting bed

Appendix VIr: Effect of ornamental sweet potato variety on foliage cover (percent ground cover)

Source	DF	Sums of Squares	Mean Square	F Value	Pr > F
BLOCK	2	59.7037	29.85185	0.14	0.873
SEASON	1	10.66667	10.66667	0.05	0.8266
PBT	2	1369.926	684.963	3.13	0.0566
VAR	**2**	**12381.48**	**6190.741**	**28.28**	**<.0001**
SEASON*PB	2	0.44444	0.22222	0	0.999
SEASON*VAR	2	283.1111	141.5556	0.65	0.5301
PB*VAR	4	128.2963	32.07407	0.15	0.9633
SEASON*PB*VAR	4	513.7778	128.4444	0.59	0.6743
Error	34	7441.63	218.8715		
Corrected Total	53	22189.04			

PB = Planting bed

Appendix VIs: Interaction effect of season and method of planting on sweet potato vine length

Source	DF	Sums of Squares	Mean Square	F Value	Pr > F
BLOCK	2	264.2068889	132.1034444	11.32	<.0001
SEASON	1	30.3921111	30.3921111	2.60	0.1120
MOP	4	401.6011111	100.4002778	8.60	<.0001
CLONE	2	51.9628889	25.9814444	2.23	0.1171
SEASON*MOP	**4**	**477.2473333**	**119.3118333**	**10.22**	**<.0001**
SEASON*CLONE	2	45.9602222	22.9801111	1.97	0.1488
MOP*CLONE	8	43.9448889	5.4931111	0.47	0.8718
SEASON*MOP*CLONE	8	73.0386667	9.1298333	0.78	0.6199
Error	58	676.886444	11.670456		
Corrected Total	89	2065.240556			

MOP = Method of planting

Appendix VIt: Interaction effect of season and method of planting on size of nursery bed required to produce enough sweet potato vine to plant one hectare of land

Source	DF	Sums of Squares	Mean Square	F Value	Pr > F
BLOCK	2	39. 5726667	19.7863333	3.72	0.0301
SEASON	1	1.6810000	1.6810000	0.32	0.5759
MOP	4	124.4517778	31.1129444	5.86	0.0005
CLONE	2	15.1046667	7.5523333	1.42	0.2496
SEASON*MOP	**4**	**75.2051111**	**18.8012778**	**3.54**	**0.0119**
SEASON*CLONE	2	15.3206667	7.6603333	1.44	0.2448
MOP*CLONE	8	48.1775556	6.0221944	1.13	0.3551
SEASON*MOP*CLONE	8	32.4548889	4.0568611	0.76	0.6358
Error	58	308.1406667	5.3127701		
Corrected Total	89	660.1090000			

MOP = Method of planting

Appendix VIu: Effect of season on the number of sweet potato storage roots per plant

Source	DF	Sums of Squares	Mean Square	F Value	Pr > F
BLOCK (FARM)	4	0.85041667	0.21260417	1.59	0.1927
SEASON	**2**	**3.22170333**	**1.61085167**	**12.08**	**<.0001**

CLONE	3	1.77895333	0.59298444	4.45	0.0082
SEASON*CLONE	6	0.61417667	0.10236278	0.77	0.5994
Error	44	5.86778333	0.13335871		
Corrected Total	59	12.33303333			

Appendix VI v: Effect of sweet potato clone on the number of marketable sweet potato storage roots per plant

Source	DF	Sums of Squares	Mean Square	F Value	Pr > F
BLOCK (FARM)	4	0.85041667	0.21260417	1.59	0.1927
SEASON	2	3.22170333	1.61085167	12.08	<.0001
CLONE	**3**	**1.77895333**	**0.59298444**	**4.45**	**0.0082**
SEASON*CLONE	6	0.61417667	0.10236278	0.77	0.5994
Error	44	5.86778333	0.13335871		
Corrected Total	59	12.33303333			

Appendix VI w: Effect of season on sweet potato storage root yield per plant

Source	DF	Sums of Squares	Mean Square	F Value	Pr > F
BLOCK (FARM)	4	0.04512667	0.01128167	0.27	0.8953
SEASON	**2**	**1.54672333**	**0.77336167**	**18.56**	**<.0001**

CLONE	3	08531333	0.02843778	0.68	0.5675
SEASON*CLONE	6	0.02207667	0.00367944	0.09	0.9972
Error	44	1.83355333	0.04167167		
Corrected Total	59	3.53279333			