EVALUATION OF SWEETPOTATO (*Ipomoea batatas* (L.) Lam.) GENOTYPES FOR VINE MULTIPLICATION IN SANDPONICS SYSTEM USING OPTIMIZED NUTRIENT MEDIA

BY

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DECLARATION

Declaration by the Candidate

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To my brother Makokha Madini Kiand Cleophas

ABSTRACT

Sweetpotato (*Ipomoea batatas* (L.) Lam.) is one of the most affordable and nutrient rich food crops in sub-Saharan Africa (SSA). However, the production of the crop is constrained by several biotic and abiotic stresses. Sweetpotato breeding has continuously developed cultivars to overcome some of these constraints. Unfortunately, insufficient planting materials limit the adoption and utilization of these improved cultivars. Availability of sufficient pre-basic seed as the starting material for bulking sweetpotato planting material, usually from research institutes is crucial. One of the critical deterrence for pre-basic sweetpotato seed multiplication is the high cost of sterilizing soil substrate. This study aimed at using sand substrate with fertigation also called 'sandponics' to produce pre-basic sweetpotato seed for selected genotypes instead of the conventional soil substrate method. Two experiments were conducted at Kenya Plant Health Inspectorate Service – Plant Quarantine and Biosecurity Station, Muguga Kenya between March 2018 to March 2019: to optimize the nutrient media for sweetpotato seed multiplication in the sandponics and to assess the cost-effectiveness of the sandponics system. Nutrient omission pot experiments were conducted to optimize the nutrient media for sweetpotato seed multiplication in the sandponics in the screenhouse and vine growth using cultivar Kabode. Five levels of each nutrient were replicated four times and the effect of N, P, Ca, S and B on sweetpotato vegetative growth parameters were measured 45 days after planting. Results showed that application of 200, 60, 200, 120 and 0.3 ppm of N, P, Ca, S and B respectively recorded the highest vegetative growth for sweetpotato. To assess the cost-effectiveness of the sandponics system, seed multiplication of virus indexed 3-node cuttings of genotypes Irene, Kabode, Ejumula and Gweri in the sandponics and conventional soil substrate method were compared. Vines were harvested at 42-day intervals in a crop calendar year of nine months. A significant ($p<.0001$) increase of 21.8% in vine multiplication rate was observed in the sandponics system compared to the conventional soil substrate method. The cost of producing one sweetpotato node in sandponics system was significantly ($p<.0001$) lower by 0.9 KSH (US$ 0.009) compared to conventional soil substrate method. Ejumula was the most cost-effective genotype to produce in sandponics system with a significant ($p<.0001$) reduction in the cost of producing one node by 1.2 KSH (US$ 0.012) compared to the conventional soil substrate method of production. Sandponics system has shown high potential for increasing the availability of pre-basic seed in the sweetpotato seed systems in SSA.

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ACRONYMS AND ABBREVIATIONS

C – Cost Per Cutting

CIP – International Potato Center

DFT – Deep Film Technique

FAO – Food and Agriculture Organization

FAOSTAT – Food and Agriculture Organization Statistics

GI – Gross Income

GLM – General Linear Model

IRR – Internal Rate of Return

KALRO – Kenya Agricultural and Livestock Research Organization

KEPHIS – PQBS - Kenya Plant Health Inspectorate Service – Plant Quarantine and Biosecurity Station

LSD – Least Significance Difference

NaOCl – Sodium hypochlorite

NARI – National Agricultural Research Institutes

NARS – National Agricultural Research Systems

NFT – Nutrient Film Technique

NPV – Net Present Value

OFSP – Orange Fleshed Sweetpotato

ppm – parts per million

SPVD – Sweetpotato Virus Disease

SSA – Sub-Saharan Africa

VMR – Vine Multiplication Rate

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Sweetpotato (*Ipomoea batatas* (L.) Lam) has many diverse uses ranging from human food, animal feed as well as an industrial product (Byju and George, 2005). In Kenya, sweetpotato is an important crop grown widely by small scale farmers, mainly women, and plays an important role, both as a source of household food security, and a source of family cash income (Carey *et al*., 1996; Ndolo *et al*., 2001). Besides, research has demonstrated that the Orange Fleshed Sweetpotato (OFSP) genotypes can play an important role in tackling vitamin A deficiency through biofortification (Low *et al*., 2017). Sweetpotato has an annual worldwide production of 112.8 million metric tons (MT) (FAOSTAT, 2017). Currently (2012 – 2017average), there are 30.0 million MT of sweetpotato production annually in Africa with East Africa accounting for 65% (FAOSTAT, 2017). The area under sweetpotato production has been expanding faster than maize over the past 20 years, albeit from a much lower base (Low *et al*., 2017). The production of sweetpotato in Kenya remains low at an average of 667274 MT per year and a national average farm yield of 9.4 t ha^{-1} (FAOSTAT, 2017) compared to 30 - 50 t ha^{-1} observed under experimental conditions (Kivuva *et al*., 2014; Ndolo *et al*., 2001). The large gap in the yield is as a result of biotic and abiotic stresses. Limited access to disease-free planting materials and improved varieties are the major factors contributing to low yield as well as reduced varietal diffusion (Andrade *et al*., 2009; Gibson *et al*., 2009, 2011) thus limited adoption and utilization of improved varieties. Further research demonstrated that use of disease-free planting material increased storage root yield by 20 – 30% (Fuglie *et al*, 1999). This increase in storage root yield was reported to be even higher with farmers in

Rwanda and Tanzania, who were found to achieve up to 40 – 50% higher yields (McEwan, 2016).

The International Potato Center (CIP), National Agricultural Research Institutes (NARIs) and other partners confronted conventional wisdom concerning food-based approaches and institutional barriers, to build the evidence base and bred Orange Fleshed Sweetpotato (OFSP) varieties adapted to farmer needs and preferences (Low *et al*., 2017). However, ensuring farmers have timely access to adequate quantities of quality planting materials of these improved varieties still remains a challenge (McEwan *et al*., 2015).

There have been ingenuities to strengthen sweetpotato seed systems driven from research and breeders focusing on varietal testing and systems to deliver new improved varieties but then bulking large quantities of quality planting material in a short time has always been a limitation in providing sufficient planting materials because of low multiplication rates (McEwan, 2016). Also, a key challenge has been to increase 'pre-basic seed' multiplication rates in the screenhouse at an affordable cost (Rajendran *et al*., 2017) for systems serving resource-poor farmers. This study thus aimed at optimizing nutrient media for pre-basic sweetpotato seed multiplication in the sandponics system and examining the economic and agronomic performance of selected sweetpotato genotypes with regard to vine yields in sandponics system compared to conventional soil substrate method.

1.2 Statement of the problem

The production of sweetpotato is constrained by lack of access to quality planting material and improved varieties (Gibson *et al*., 2009; Gibson *et al*., 2011b; Kivuva *et al*., 2014) at the right time and in the right quantities. This is mainly due to infection of planting materials with the sweetpotato virus disease (SPVD) and prolonged

droughts that either compromise the quality or availability of vines from the previous season's crop.

Also, insufficient planting materials limit the adoption and utilization of improved sweetpotato varieties (Andrade *et al*., 2009). Multiplication of clean (disease-free) pre-basic sweetpotato vines in screenhouses is possible in either sterilized soil substrate or sand. Sterilizing soil with either diesel or firewood translates to very high running costs and requires a lot of labor. While using sand with fertigation system also called 'sandponics system' might require a high initial investment that necessitates high seed yields for the multiplier to break even. To ensure high pre-basic seed yields, the nutrient media in the sandponics system must be optimized to maximize vegetative growth.

1.3 Justification of the study

Optimizing nutrient media for sweetpotato pre-basic seed multiplication using sandponics system will result to maximum growth in sweetpotato vines, increased vine multiplication rate, therefore increasing seed yields. Furthermore, a cost-effective sandponics system for sweetpotato pre-basic seed multiplication will lower the cost of seed and subsequently resulting to cheap cost of certified seed generations thereby increasing access to quality (disease-free) planting materials unclocking the adoption and utilization of improved varieties.

1.4 Objectives

1.4.1 Overall Objective

Improve sweetpotato yields through production of improved quality planting materials by use of sandponics system

1.4.2 Specific objectives

i. To determine optimal nutrient media for sweetpotato pre-basic seed multiplication in sandponics system.

ii. To compare agronomic and economic analysis for multiplication of sweetpotato pre-basic seed in sandponics system and conventional soil substrate method.

1.5 Hypotheses

a) Null hypotheses

i. Sweetpotato pre-basic seed multiplication in sandponics system is not affected by sequentially increasing levels of Nitrogen, Phosphorus, Sulfur, Calcium and Boron from fertilizer applications.

ii. Sweetpotato pre-basic seed multiplication is agronomically and economically better in the conventional soil substrate method compared to the sandponics system

b) Alternative hypotheses

i. Sweetpotato pre-basic seed multiplication in a sandponics system is affected by sequentially increasing levels of Nitrogen, Phosphorus, Sulfur, Calcium and Boron from fertilizer applications.

ii. Sweetpotato pre-basic seed multiplication is agronomically and economically better in the sandponics system compared to the conventional soil substrate method.

CHAPTER TWO

LITERATURE REVIEW

2.1 Importance of sweetpotato

Sweetpotato (*Ipomoea batatas* (L.) Lam.) which belongs to the family Convolvulaceae is a herbaceous, dicotyledonous plant (2n=90) native to Central America (Byju and George, 2005) and is widely grown throughout the tropics and subtropics. It is the seventh most important crop in the world in terms of production (FAOSTAT, 2017) although the bulk of the production is in China (Low *et al*., 2017). It is a staple food for smallholder farmers in much of Sub-Saharan Africa (SSA).

The crop is regarded as the most important root crop of the tropics because of its flexibility in a number of production aspects including short cropping season, use of non-edible parts as planting material, non-trellising growth habit as well as low requirement for soil nutrients (Motsa *et al*., 2015).

Sweetpotato is a food security crop (Ebregt *et al*., 2007; Lebot, 2008; Low *et al*., 2017; Motsa *et al*., 2015) as it survives where staple crops totally fail. It therefore contributes to food availability by providing high output per unit of land. In the densely populated semi-arid plains of eastern Africa, sweetpotato is often referred to as *cilera abana*, "protector of the child" (Byju and George, 2005) which alludes to the vital role it fulfils in thousands of villages where people depend on the crop to combat hunger.

According to Lebot (2008), sweetpotato has often been a lifesaver, for example it saved the Japanese nation when the typhoons destroyed all their rice fields just before world war I. During the early 1960s, China was plagued by famine and the availability of sweetpotato saved millions of the population from starvation. The Orange Fleshed Sweetpotato (OFSP) varieties played a major role in addressing

hunger and drought mitigation after biotic stresses in different parts of the world, including after the floods in Mozambique in 2000. Its use as a lifesaver is evidence that sweetpotato is indeed a food security crop (Amajor *et al*., 2014; Bovell-Benjamin, 2007; Ebregt *et al*., 2007).

The crop is one of the most affordable and nutrient rich food crops in Sub-Saharan Africa which possess carbohydrates, vitamin A, vitamin C, fibre, iron, potassium and protein (Motsa *et al*., 2015; Woolfe, 1992). Bovell- Benjamin (2007) reported that sweetpotato produces more edible energy than any other major food crop.

Research findings have also shown that OFSP play an important role in combating vitamin A deficiencies in SSA particularly the OFSP varieties which contain high amounts of β-carotene, a precursor for vitamin A (Low *et al*., 2017; Motsa *et al*., 2015).

Research has also demonstrated that sweetpotato vines and non-commercial roots are important animal feed. The vines are reported to contain high protein content (16% crude protein) making them an ideal dairy and pig feed (Kabirizi *et al*., 2017; Low *et al*., 2017; Peters, 2008).

2.2 Sweetpotato production constraints

Although sweetpotato crop is vegetatively propagated, certain particularities related to seed production are somewhat different than with the potato crop. In most developing countries Kenya being no exception, there is no formal seed system. The crop in most parts of the world is propagated by stem cuttings. These cuttings are usually obtained from mature plants for the following season. In some parts of Sub-Saharan Africa where unimodal patterns of rainfall exist, seed availability is a serious constraint (Gibson *et al*., 2009). Foliar cuttings can only be available for a short period of time and will be useless for a following dry season in which there is no cropping.

Sweetpotato has had low productivity in Kenya because of susceptibility of local varieties to sweetpotato viral disease (SPVD) and weevils (Kivuva *et al*., 2014). Lack of clean vines is also one of the major yield limiting factors in sweetpotato production. FAOSTAT (2017) shows sweetpotato hectarage in Kenya to have remained and constantly oscillated from 58509 ha in 2013 to 61067 ha in 2014, 72162 ha in 2015 and 47,184 ha in 2016 and 70821 in 2017 (Table 2.1).

Table 2: 1: Sweetpotato production trend in Kenya (2013 – 2017).

Year	Harvested area (ha)	Production quantity (tons)	Yield (t/ha)
2013	58509	729645	12.5
2014	61067	763643	12.5
2015	72162	1232332	17.1
2016	47184	697364	14.8
2017	70821	667274	9.4

Source: FAOSTAT (2017)

Research has demonstrated that lack of sustainable seed systems is one of the major constraints to improving sweetpotato productivity in SSA. A CIP survey of National Agricultural Research Systems (NARS) priority (Gibson *et al*., 2011b; Fuglie, 2007) reported that "virus management, seed quality and supply systems," was ranked as the highest priority for future research and development. CIP pro-poor research targeting further indicates that research on virus control in sweetpotato through provision of clean planting material alone could yield rates of return of between 56 – 84 % depending on rate of adoption and adoption ceiling.

2.3 Sweetpotato varietal development, seed multiplication and diffusion

International Potato Center (CIP) in collaboration with National Agricultural Research Institutes (NARIs) in SSA develops and releases new germplasm including Orange Fleshed Sweetpotato (OFSP). The breeding programmes have led to the development of new improved varieties adapted to farmer needs and consumer

preferences (Low *et al*., 2017; McEwan, 2016). They include elite cultivars that are resistant to biotic and abiotic stresses as well as nutritionally improved cultivars. However, with no strong linkages to seed multiplication and dissemination efforts, these varieties may not quickly benefit large numbers of smallholder poor resource farmers and consumers (McEwan, 2016).

Seed standards and inspection protocols for clonally propagated crops such as sweetpotato developed by Food and Agriculture Organization (Fajardo *et al*., 2010) advocate for multiplication of clean (disease–free) plantlets in laboratories then in screenhouses for further field multiplication. In SSA, the National Agricultural Research Institutes (NARIs) use tissue culture micro-propagation as one stage in the production of pathogen tested pre-basic seed (cuttings). Tissue culture plantlets are hardened and then multiplied under screen house conditions to produce pre-basic seed. This then is sold as starter seed for basic seed production, either under protected structures (mini-screen houses, net tunnels), or open field production (in low virus pressure areas).

Millions of farmers are losing 4 – 6 weeks of the excellent growing period at the beginning of the season while they re-establish sufficient vine production for planting, obtaining initial limited planting material from residual plants, re-sprouting roots or secondary growth of harvested fields (Gibson *et al.*, 2009, 2011*;* Gibson *et al.*, 2011b). The limited availability of clean planting material might explain why sweetpotato production area and yields are low. Gibson *et al*. (2009, 2011b) and Andrade *et al*. (2009) reported that successful releases of new sweetpotato varieties in Sub-Saharan African countries to combat vitamin A deficiency in children population will depend on seed availability. Furthermore, use of quality sweetpotato planting material can significantly improve the yields the way it was demonstrated in

Shandong province in China, where this intervention caused a great economic impact (Fuglie *et al*., 1999). Research has also shown a yield increase of 160% (40.8 t ha^{-1}) due to use of virus indexed planting material (Kivuva *et al*., 2014). Sweetpotato research and development activities have been focusing mainly on the generation and phytosanitary improvement ensuring an adequate supply of planting material at the right time especially in areas normally experiencing longer dry seasons and on the health benefits of OFSP. Lack of sufficient quantity and quality seed in SSA has long been a bottleneck to improved sweetpotato productivity, improved varietal diffusion and ability to control SPVD and weevil infestation through integrated management approaches (Namanda, 2012).

2.4 Nutritional requirements for sweetpotato vine growth

Generally, biomass in sweetpotato is partitioned as storage roots (66%), foliage (32%) or fibrous roots (2%), (Hozyo *et al*., 1971; Somasundaram and Mithra, 2008). However, this biomass accumulation is divided into three phases, namely 1) the initial phase of extensive growth of fibrous roots with limited vine growth 2) the middle phase where vines grow extensively and fast. Storage roots are initiated and there is a tremendous increase in green leaf area and 3) the final phase where bulking of storage roots occurs with very little growth of vines and fibrous roots. In this phase, initially the green leaf area stays constant and then decreases.

Nutrients play a major role in the growth and development of higher plants. Sixteen elements are essential in plants and can be divided into two groups: the macronutrients (those required in relatively large quantities) including carbon, hydrogen, oxygen, Nitrogen, Phosphorus, potassium, Calcium, magnesium and Sulfur and the micronutrients (those required in small quantities) including iron, chlorine, manganese, Boron, zinc, copper and molybdenum. Usually only a small proportion of

the total nutrient is available for uptake by the plant. Availability of many essential nutrients is affected by the pH. For instance, at high pH (alkaline nutrient solution), the solubility of P and many micronutrients (e.g. Fe, Mn, Zn and Cu) is greatly reduced, and the crop may experience deficiencies of these nutrients. At low pH (acid nutrient solution), the solubility of some elements, particularly P and Mo, is reduced, while that of Al and Mn may be increased to toxic levels. The plant's requirement of essential nutrients will increase as the plant accumulates more biomass. Nutrient omission pot experiments have revealed that sweetpotato vine yields were only limited to Nitrogen, Phosphorus, Sulfur, Calcium, Boron and Molybdenum (Taraken *et al*., 2010).

2.4.1 Nitrogen

Nitrogen is a key essential element affecting plant growth and crop yields. It is a mobile element in the plants as a constituent of amino acids, proteins, coenzymes, nucleic acids and chlorophyll. Nitrogen deficiency symptoms will develop first on lower leaves as the Nitrogen is removed for use in new developing leaves. The older leaves become chlorotic (turn yellow) and eventually die. Plants take up Nitrogen in nitrate (NO_3^{-1}) or ammoniacal (NH_4^{+1}) form. A proper balance between the nitrate form and ammonium form is required for plant growth and provides some degree of pH control. A ratio of 75% nitrate to 25% ammonium is satisfactory for nutrient solutions and should not exceed a ratio of 50/50 or ammonium toxicity may result (Bergman, 1985; Jones, 2016). Success in hydroponic growing systems depends on the management of Nitrogen (Jones, 2016). Most formulas call for the total N concentration in the nutrient solution to range from 100 to 200 parts per million (ppm).

2.4.2 Phosphorus

Phosphorus is a constituent of ATP, nucleic acids, phospholipids and certain coenzymes. It is very important in the plants energy transfer system and a deficiency can slow growth considerably (Bergman, 1985; Jones, 2016; Joiner, 1983; Resh, 1983). Phosphorus overfertilization may be a problem with soilless culture. Phosphorus toxicity may occur, interfering with the normal function of other elements such as iron, manganese and zinc (Bergman, 1985; Joiner, 1983; Jones, 2016). While Phosphorus deficiency reduces growth and older leaves develop a purplish color as anthocyanin pigments accumulate. Phosphorus uptake is influenced by temperature and a deficiency may be induced by cool nutrient solution temperatures (Bergman, 1985; Joiner, 1983; Jones, 2016). Most formulas call for 30-50 ppm of Phosphorus in the form of mono- or all-hydrogen phosphate anions (HPO_4^- or $H_2PO_4^{-1}$) or as phosphoric acid (H_3PO_4).

2.4.3 Calcium

Calcium is required to maintain membrane integrity and is found in cell walls as Calcium pectate which cements together adjacent cell walls (Resh, 1983). Calcium deficiency is generally a result of an imbalance with potassium and magnesium. It primarily affects leaf size and shape (Bergman, 1985; Joiner, 1983; Jones, 2016; Resh, 1983). A concentration of 200 ppm of Calcium is common for most nutrient solution formulae. Since Calcium is common in many natural water sources, a water analysis is necessary, so adjustments can be made to avoid overfertilization which would lead to an imbalance with potassium and magnesium (Bergman, 1985; Jones, 2016; Joiner, 1983; Resh, 1983).

2.4.4 Sulfur

Sulfur is a constituent of some amino acids and proteins, coenzyme A, thiamine and biotin (Bergman, 1985; Joiner, 1983; Jones, 2016; Resh, 1983). The ratio of Sulfur to Nitrogen may be a better measure of the sufficiency of Sulfur in the plant rather than total Sulfur concentration. Deficiency symptoms appear like Nitrogen deficiency symptoms as an overall plant yellowing or chlorosis. However, Sulfur deficiency symptoms start in new leaves (because it is not translocated out of old leaves) where Nitrogen deficiency symptoms, appear first in older leaves as Nitrogen is easily translocated to new leaves. Most nutrient solution formulas call for approximately 50 ppm Sulfur in the form of the sulfate anion (SO_4^{-2}). High concentration of SO_4^{-2} ions generally do not cause any harm.

2.4.5 Boron

The role of Boron in plants is not well understood although there is evidence that it is important in carbohydrate synthesis and transport. Minute quantities (<0.5 ppm) are usually required by plants, and many are sensitive to higher levels of this element (Bergman, 1985; Joiner, 1983; Resh, 1983). Boron deficiency will slow growth often stunting the whole plant. Boron toxicity from excess Boron in the nutrient solution or Boron in the water supply results in discoloration and eventual death of the leaf margins (Bergman, 1985; Joiner, 1983; Jones, 2016; Resh, 1983). Nutrient solution formulas usually call for about 0.3 ppm Boron commonly in the form of borate anion (BO_3^{-3}) or boric acid (H_3BO_3), (Bergman, 1985; Jones, 2016; Joiner, 1983; Resh, 1983).

2.5 The history of hydroponics

Hydroponic techniques started to be used in agriculture during the last century, especially in horticultural crops and flower industry. Difficulties in obtaining proper

substrate, its sterilization, fertilization, transport and storage, forced experiment stations first and then the private sector to use more and more hydroponics for agricultural production. Hydroponics use aerated nutrient solutions instead of conventional soil substrates used in greenhouses. Inclusion of sand, gravel and other inert elements provided improvements and more elasticity to the system. Later, the arrival of plastic industry allowed hydroponics to cut down production costs significantly. In the potato industry hydroponic technique were used very recently. Seemingly, several hydroponic techniques have been used in the horticultural industry as described below.

2.5.1 Deep Flow technique (DFT)

This system was initially designed for lettuce production (Jensen, 1997). A rectangular container 30 cm deep is covered with plastic. Once the nutrient solution is filled, a floating plastic sheet is placed with holes at regular space intervals in which plants are fitted. Nutrient solution is re-circulated and aerated. This system was used for seed potato production and compared to other hydroponic techniques (Kang *et al*., 1996). The DFT produced good results with the Irish Cobbler cultivar (Table 2.2). Most of the minitubers obtained were less than 1 g. The basic limitation of this technique is that the root system of the plants is poorly oxygenated. It is also electricity dependent.

Table 2.1: Number of minitubers / plant produced with three hydroponic systems in two potato cultivars

Hydroponics system	Cultivar Superior	Cultivar Irish Cobbler
Aeroponics	74.4^{a}	43.7^{c}
Deep Flow Technique (DFT)	62.3^{ab}	53.9^{bc}
Nutrient Film Technique (NFT)	55.9^{bc}	39.4^{c}

Different letters within the same column denote significant differences at $p \leq 0.05$

Source: Kang *et al*., 1996

2.5.2 Nutrient Film Technique (NFT)

Boersig and Wagner (1988) started to use this technique for seed potato production. Later, others followed (Muro *et al*., 1997; Rolot and Seutin, 1999; Soffer, 1986; Wheeler, 2006). Compared to conventional soil substrate method using regular greenhouse substrate, NFT produced better results as average number of minitubers per plant. At CIP, this technique was adapted using simple materials (Chuquillanqui *et al*., 2008). The system uses a 0.5 HP pump that makes recirculate a nutrient solution to a tank. Plants are placed in a bench with 6 channels, covered with a black plastic film to ensure darkness to the root system. In an experiment to compare the effectiveness of NFT to the conventional soil substrate method bed and pot system using 4 Peruvian potato cultivars, it was shown that by using NFT more minitubers per plant was produced. Compared to DFT, NFT uses less amount of nutrients solution and oxygenation of the root system is improved especially if inert material such as gravel is used. However, this technique has disadvantages. Space for root and tuber development is limited. The black plastic sheet that covers the root system can concentrate heat especially during sunny days causing unwanted rise in temperature of the nutrient solution. In a recirculating system such as this, pathogens like pectobacterium (Erwinia) can prosper and contaminate the whole system.

2.5.3 Aeroponics

Aeroponics is a recently developed hydroponic technique presently being used in Asia, Africa and Latin America. The root systems of the plants are suspended in the air, within a dark box. The foliage is supported by a wire screen or stakes. A pump is turned on intermittently to provide nourishment and water to the plants. For this purpose, a pipe is installed in the upper part of the boxes with nebulizers every 60 cm; so, when the pump is on, a fog provides to the root system an ideal condition for plant

growth and development. Therefore, production of minitubers is much greater than in the other described hydroponic techniques (Otazu, 2008, 2010). The main constraint of this technique is its electricity dependence.

2.5.4 Hydroponics with aggregates

Aggregates are inert materials useful in hydroponics to provide a supporting mechanism to the plants or improve the aeration of the root system. The cheapest aggregates are natural mineral substrates such as sand, gravel and volcanic rock. Treated mineral substrates are usually more expensive and not readily available. These include perlite and vermiculate. There are some others like coconut pith which is a by-product of the coconut fiber industry and comes as compressed bricks. They are mostly used in the flower industry. The following table summarizes the main properties of some materials used in hydroponics (Table 2.3).

Table 2.2: Properties of some materials used as substrates in hydroponics

Substrate	Density	Porosity	Aeration	Water retention	CCI(a)s	pH	Stability
Black peat	0.2–0.5	High	Medium	Good	> 20	4–7	Limited
Coarse sand	1.5–1.8	High	Good	Low	> 20	-	Limited
Pozzolans	0.8–1.3	High	High	Low	< 20	6.5	High
Volcanic rock	0.7–1.3	High	Good	Good	> 20	7	High
Perlite	0.08-0.12	High	High	Good	< 20	7–7.5	Low
Rockwool	0.0–0.09	High	Good	High	< 20	7	High
Expanded clay	0.75	High	High	Good	< 20	5–7	High
Vermiculate	0.9-0.14	High	Good	Good	> 20	7	Low

Source: Bures *et al*., 1997

Large size (30 g to 40 g) of seed tubers were obtained from plants grown in a hydroponic system with coconut pith in Kenya. Minitubers of 2 g to 4 g obtained from aeroponics that could not be planted in the field because of their small size were used

as seed. Coconut is expensive, so a cheaper alternative such as sand which is always available could be more convenient for most places.

Sand is an inert granular material composed of finely divided rock on mineral particles. The composition of sand depends on the local rock resources, although in inland continental settings, the main constituent is silica (silicon dioxide), in the form of quartz (*htt://en.wikipedia.org/wiki/sand*). The color of sand may give us an indication of its constituent. White sands in tropical and sub-tropical coastal settings may contain coral and shell fragments in addition to other organic and inorganic materials.

Sands rich in magnetite are dark to black and are derived from volcanic basalts and obsidian. Green sands are derived from basaltic material and have high content of olivine. Light brown sand, common in river beds have mostly quartz particles with angular edges and are preferred for the concrete industry. This sand is also used in agricultural activities as soil amendments to correct the texture of heavy soils.

In Sub-Saharan African rivers where mining activities are not as extensive as in Andes, there are no recorded deposits or mining of heavy metals (Mbiri *et al*., 2015) and probably biological contaminations would be more important. In these places we should be aware of *Erwinia* and *Ralstonia* contaminations.

Sterilization of conventional soil substrate is troublesome. When this is done using steam, temperature has to be monitored inside the chamber. If the inside temperature doesn't reach 82^{o}C for at least 30 min, then most probably unwanted microorganisms will not be eliminated. If we exceed this temperature above 82^{o}C, the organic matter contained in the substrate will release toxic manganese. When sterilization is done using bleach also referred to as sodium hypochlorite (NaOCl), then the various organic components of the substrate will react with Na and Cl ions of bleach forming

new compounds. This results in salt accumulation which is inconvenient for the plant growth.

Sand sterilization is easier and cheaper. It can be sterilized by heat or chemically. Sand can be “overcooked” with no toxic releases and now is regularly used for initial plant growth in aeroponics. Invitro plantlets are placed in sand trays for root development (Otazu, 2008) before planting, usually this sand is treated with boiling water to eliminate potential pathogens. Sodium hypochlorite is widely available as bleach and can also be used to treat sand. This product is affordable and efficient as disinfectant. Different tests have proved that sand can be safely disinfected using bleach (Mbiri *et al*., 2015; Otazu, 2010).

2.6 Nutrient media for sweetpotato pre-basic seed multiplication in sandponics system

Otazu, V., Chuquillanqui, C., Low, W.J., and Figueroa, E.S. (2011, unpublished) used aeroponics seed potato formulation nutrient solution to test sandponics as a better alternative to improve production of disease-free sweetpotato cuttings in the greenhouse with less cost as compared with the conventional soil substrate method and their findings indicated that sandponics system can be advantageously used over the conventional soil substrate method. However, they recommended further research to clarify nutrient dosis, frequency of application and cultivar responses.

Jones (2016) indicated that success in hydroponic growing systems depends on the management of Nitrogen. Other reports showed that Nitrogen is the key macro element for sweetpotato vine production although Nitrogen requirement that maximizes vine production for various sweetpotato varieties was not found in literature (Chen, 2013). However, most formulas call for 100 ppm – 200 ppm of Nitrogen -nutrient solution in the form of NO_3^- (Jones, 2016). Studies by Chen (2013)

reported a range of 100 ppm – 300 ppm Nitrogen to favor sweetpotato vine growth in hydroponics.

Wanjala, W.B., Srinivasulu, R., Makokha, P., Ssali, R.T., McEwan, M., Kreuze, J.F., and Low, J. (2019, unpublished) tried to adapt the nutrient media that was originally for seed potato minituber production for sweetpotato vine multiplication in hydroponics by only adjusting the Nitrogen levels to 213 ppm (Table 2.4). They then compared sweetpotato pre-basic seed production in sandponics system and conventional soil substrate method and found out that VMR was 33% higher in the sandponics system compared to the conventional soil substrate method but the cost-effectiveness analysis indicated that the conventional soil substrate method was more cost-effective than the sandponics system. They recommended for further studies to investigate the nutrient dosis for other elements that play key roles in sweetpotato vine growth along Nitrogen, varietal responses in the sandponis system and nutrigation frequency.

Table 2.3: Prototype nutrient media for sweetpotato pre-basic seed multiplication using sandponics system (modified from nutrient media for seed potato) at KEPHIS-PQBS, Muguga, Kenya (2017 – 2018).

Seed potato aeroponics nutrient media (Otazu, 2010)		**Modified sweetpotato pre-basic seed sandponics system nutrient media**	
Nutrient	g/1000 l	Nutrient	g/1000 l
Calcium nitrate (17%Ca 12%N)	295 (35.4 ppm N)	Calcium nitrate (17%Ca 12%N)	576 (69.1 ppm N)
Potassium phosphate (29%K 23%P)	170	Potassium phosphate (29%K 23%P)	170
Potassium nitrate (13K% 13%NO_3)	630 (81.9 ppm N)	Potassium nitrate (13K% 13%NO_3)	1111.1 (144.4 ppm N)
Magnesium sulfate (10% 13%)	615	Magnesium sulfate (10% 13%)	615
Boron	1.75	Microsol B	1.75

CHAPTER THREE

OPTIMIZATION OF NUTRIENT MEDIA FOR SWEETPOTATO PRE-BASIC SEED MULTIPLICATION USING SANDPONICS SYSTEM

ABSTRACT

Sweetpotato, being a vegetatively propagated crop, is very prone to seed degeneration as virus accumulation overtime results in reduced yield potential. A continuous source of high quality sweetpotato seeds (also known as pre-basic seed), is therefore necessary. Sweetpotato pre-basic seed production maintains pure disease-free seed through cleaning, multiplication and dissemination of seeds. In most countries, breeders in the National Agricultural Research Institutes (NARIs), are using tissue culture facilities to produce a limited quantity of pre-basic sweetpotato seed. This pre-basic sweetpotato seed is then used as starting material to maintain and produce high quality basic seed in mini-screen houses, net tunnels or open field multiplication in low-virus pressure areas by either the private seed companies or vine multipliers. Soil is the predominant substrate for pre-basic seed multiplication in most Sub-Saharan Africa (SSA) countries. Multiplying pre-basic sweetpotato seed in sand with fertigation, also known as 'sandponics' is a possible opportunity towards sustainable production of pre-basic sweetpotato seed. It would be beneficial to examine the feasibility and the potential ability to replace soil substrate for growing pre-basic sweetpotato seed. This study was conducted to investigate the use of sandponics to produce pre-basic sweetpotato seed instead of soil substrate method 'conventional soil substrate method'. Greenhouse pot experiments were conducted at Kenya Plant Health Inspectorate Service – Plant Quarantine and Biosecurity Station (KEPHIS-PQBS), Muguga between March – June 2018 to evaluate how sweetpotato vine propagation is affected by sequentially omitting 5 nutrients (Nitrogen, Phosphorus, Calcium, Sulfur and Boron) from fertilizer applications on cv. Kabode. Five experiments were laid in a factorial arrangement in randomized complete block design with five levels of the factor fertilizer replicated four times with two blocks. The effect of fertilization of Nitrogen at (0, 100, 150, 200 and 250), Phosphorus at (0, 30, 60, 90 and 120), Calcium at (0, 100, 200, 300 and 400), Sulfur at (0, 30, 60, 90 and 120) and Boron at (0, 0.1, 0.2, 0.3 and 0.4) ppm on vegetative growth parameters of sweetpotato plants were measured 45 days after planting. The means of the measurements were plotted against the concentrations of the five elements recovered in the leaf blades as a percentage for each of the five treatment levels and optimal nutrient concentrations extrapolated. Results showed that application of 200, 60, 200, 120 and 0.3 ppm of N, P, Ca, S and B respectively recorded the highest values in sweetpotato vegetative growth parameters.

3.1 Introduction

Limited availability of sweetpotato disease-free planting materials and improved varieties largely accounts for the low production area and yields in most of SSA countries (Andrade *et al*., 2009). Similar sentiments were echoed by (Gibson *et al*., 2009; Kivuva *et al*., 2014).

In SSA sweetpotato seed systems starts off with varietal development (breeders seed), the breeders seed is virus indexed and micropropagated through tissue culture in the laboratory, the multiplied invitro plantlets are acclimatized in the screenhouses and multiplied into pre-basic seed. The pre-basic seed is then used as starting material to maintain and produce basic seed in net tunnels (basic seed) or open field multiplication (quality declared seed) in low-virus pressure areas by either the private seed companies or vine multipliers. The basic and quality declared seed is passed on to the sweetpotato root growers who maintain quality planting material by removing diseased plants as soon as they appear (positive and negative selection). Presently, conventional soil substrate method is predominant for pre-basic seed multiplication in the screenhouses, however multiplying pre-basic seed using conventional soil substrate method is expensive, unsustainable and with sub-optimal vine multiplication rate (VMR). Therefore, a key challenge is to increase pre-basic seed multiplication rates in the screenhouse at low costs (Rajendran *et al*., 2017). Gibson *et al*. (2009) reported that one way of increasing the use of sweetpotato quality seed and increased varietal diffusion of improved sweetpotato varieties among smallholder resource poor farmers in SSA countries is by lowering the cost of seed.

This study therefore aimed at optimizing the nutrient media to increase the pre-basic seed yield in sandponics system to have a more productive system that can sufficiently give the grower an economic advantage by considering levels of Nitrogen,

Phosphorus, Calcium, Sulfur and Boron which are reported to significantly favor growth of sweetpotato vines (Taraken *et al*., 2010).

3.2 Materials and methods

3.2.1 Experimental site

A screenhouse experiment was conducted between March and May 2018 at the Kenya Plant Health Inspectorate Service – Plant Quarantine and Biosecurity Station (KEPHIS-PQBS) Muguga, Kenya, located at 1° 11' 0" South, 36° 39' 0" East at an altitude of about 1950 m above sea level.

3.2.2 Sand sterilization

River sand was sifted using a screen to remove pebbles and twigs, then soaked for 10 min in 10% bleach and rinsed 3 times with running tap water to remove bleach residues (Mbiri *et al*., 2015; Otazu, 2010) then left overnight on a raised rack to drip and for any traces of bleach to evaporate before potting**.**

3.2.3 Preparation of nutrient media

Samples of irrigation water and sand substrate were collected and submitted to Crop Nutrition Laboratories, Kenya for nutrient analysis using colorimetric (Oser and Summerson, 1947) and spectroscopy (Fishman *et al*., 1966) methods prior to experiment set off and results from analysis (Table 3.1) were used to adjust final nutrient concentrations for the studied elements. All the elements tested in the sand substrate were below detectable levels. Calcium nitrate, magnesium nitrate, Calcium triple phosphate, magnesium sulfate, Calcium chloride and microsol B were nutrient donor fertilizers as indicated in Table 3.2. Nutrient elements in 'prototype nutrient media' (Table 2.4) were sequentially modified into 5 treatments for each of the five elements. This involved sequentially increasing levels of Nitrogen, Phosphorus,

Calcium, Sulfur and Boron on sweetpotato vine yields in sandponics system (Table 3.3). The first level was by omitting the nutrient under study, this involved substituting sources for some of the nutrients.

Table 3.1: Water analysis report for a water source from KEPHIS-PQBS, Muguga, Kenya used for nutrient solution preparation for sweetpotato pre-basic seed multiplication using sandponics system (2018)

Water (ppm)	N	P	Ca	S	B	Mo	Cl
	-	-	12.8	7.68	-	0.0015	0.06

Table 3.2*:* Sources of nutrients for nutrient media for sweetpotato pre-basic seed multiplication using sandponics system at KEPHIS – PQBS, Muguga, Kenya (2018)

Fertilizer	Composition	Supplier
Calcium Nitrate (Calcinit)	15.5%N, 19%Ca	Amiran
Calcium Triple Phosphate	46%P_2O_5	Amiran
Magnesium Sulfate	26%S	Amiran
Microsol B	2.5%B, 0.036%Mo	Amiran
Calcium Chloride	27.9%Ca	Amiran
Magnesium Nitrate	10%N 13%Mg	Amiran

Table 3.3: Formulations of varied nutrient levels for sweetpotato pre-basic seed multiplication using sandponics system at KEPHIS – PQBS, Muguga, Kenya (2018)

Nutrient concentration level (ppm)	Weight (g) dissolved in 50 L of water
$N_0 = 0$	0 ppm N = 0 g of N. 60 ppm P = 15 g of TSP (46% P_2O_5). 60 ppm S less 7.68 ppm S donated by H_2O = 60 – 23 = 52.32 = 10 g of Magnesium sulfate (26%S). 200 ppm Ca less 12.8 ppm Ca donated by H_2O = 200 – 12.8 = 187.2 ppm = 33.5 g of $CaCl_2$ (27.9%Ca). 0.2 ppm B = 0.4 g of microsol B (2.5%B, 0.036%Mo).
$N_1 = 100$	100 ppm N = 32.3 g of Calcium nitrate (15.5%N, 19%Ca) which also brings 123 ppm Ca leaving Ca still needed = 200 – 123 = 77 ppm. 77 ppm Ca less 12.8 ppm donated by H_2O = 77 – 12.8 = 64.2 ppm = 11.5 g of $CaCl_2$ (27.9%Ca). 60 ppm P = 15 g of TSP (46% P_2O_5).

	60 ppm S less 7.68 ppm S donated by H_2O = 60 – 23 = 52.32 = 10 g of Magnesium sulfate (26%S). 0.2 ppm B = 0.4 g of microsol B (2.5%B, 0.036%Mo).
N_2 = 150	150 ppm N = 48.4 g of Calcium nitrate (15.5%N, 19%Ca) which also brings 184 ppm Ca leaving Ca still needed = 200 – 184 = 16 ppm. 16 ppm Ca less 12.8 ppm Ca donated by H_2O = 3.2 ppm = 0.6 g of $CaCl_2$ (27.9%Ca). 60 ppm P = 15 g of TSP (46%P_2O_5). 60 ppm S less 7.68 ppm S donated by H_2O = 60 – 23 = 52.32 = 10 g of Magnesium sulfate (26%S). 0.2 ppm B = 0.4 g of microsol B (2.5%B, 0.036%Mo).
N_3 = 200	153 ppm N = 49.3 g of Calcium nitrate (15.5%N, 19%Ca) which also brings 187.2 ppm Ca leaving Ca still needed = 187.2 – 187.2 = 0 ppm Ca. N still needed = 200 – 153 = 47 ppm. 47 ppm N = 23.5 g of Magnesium nitrate (10%N) 60 ppm P = 15 g of TSP (46%P_2O_5). 60 ppm S less 7.68 ppm S donated by H_2O = 60 – 23 = 52.32 = 10 g of Magnesium sulfate (26%S). 0.2 ppm B = 0.4 g of microsol B (2.5%B, 0.036%Mo).
N_4 = 250	153 ppm N = 49.4 g of Calcium nitrate (15.5%N, 19%Ca) which also brings 187.2 ppm Ca leaving Ca still needed = 187.2 – 187.2 = 0 ppm Ca. N still needed = 250 – 153 = 97 ppm. 97 ppm N as NO3 = 48.5 g of Magnesium nitrate (10%N). 60 ppm P = 15 g of TSP (46%P_2O_5). 60 ppm S less 7.68 ppm S donated by H_2O = 60 – 23 = 52.32 = 10 g of Magnesium sulfate (26%S). 0.2 ppm B = 0.4 g of microsol B (2.5%B, 0.036%Mo).
P_0 = 0	0 ppm P = 0 g of TSP 150 ppm N = 48.4 g of Calcium nitrate (15.5%N, 19%Ca) which also brings 184 ppm Ca leaving Ca still needed = 200 – 184 = 16 ppm Ca 16 ppm Ca less 12.8 ppm Ca donated by H_2O = 3.2 ppm = 0.6 g of $CaCl_2$ (27.9%Ca). 60 ppm S less 7.68 ppm S donated by H_2O = 60 – 23 = 52.32 = 10 g of Magnesium sulfate (26%S). 0.2 ppm B = 0.4 g of microsol B (2.5%B, 0.036%Mo).
P_1 = 30	30 ppm P = 7.5 g of TSP (46% P_2O_5) 150 ppm N = 48.4 g of Calcium nitrate (15.5%N, 19%Ca) which also brings 184 ppm Ca leaving Ca still needed = 200 – 184 = 16 ppm Ca. 16 ppm Ca less 12.8 ppm Ca donated by H_2O = 3.2 ppm = 0.6 g of $CaCl_2$ (27.9%Ca). 60 ppm S less 7.68 ppm S donated by H_2O = 60 – 23 = 52.32 = 10 g of Magnesium sulfate (26%S). 0.2 ppm B = 0.4 g of microsol B (2.5%B, 0.036%Mo).
P_2 = 60	60 ppm P = 15 g of TSP (46% P_2O_5). 150 ppm N = 48.4 g of Calcium nitrate (15.5%N, 19%Ca)

	which also brings 184 ppm Ca leaving Ca still needed = 200 – 184 = 16 ppm Ca 16 ppm Ca less 12.8 ppm Ca donated by H_2O = 3.2 ppm = 0.6 g of $CaCl_2$ (27.9%Ca). 60 ppm S less 7.68 ppm S donated by H_2O = 60 – 23 = 52.32 = 10 g of Magnesium sulfate (26%S). 0.2 ppm B = 0.4 g of microsol B (2.5%B, 0.036%Mo).
P_3 = 90	90 ppm P = 22.5 g of TSP (46% P_2O_5) 150 ppm N = 48.4 g of Calcium nitrate (15.5%N, 19%Ca) which also brings 184 ppm Ca leaving Ca still needed = 200 – 184 = 16 ppm Ca 6 ppm Ca less 12.8 ppm Ca donated by H_2O = 3.2 ppm = 0.6 g of $CaCl_2$ (27.9%Ca) 60 ppm S less 7.68 ppm S donated by H_2O = 60 – 23 = 52.32 = 10 g of Magnesium sulfate (26%S) 0.2 ppm B = 0.4 g of microsol B (2.5%B, 0.036%Mo)
P_4 = 120	120 ppm P = 30 g of TSP (46% P_2O_5) 150 ppm N = 48.4 g of Calcium nitrate (15.5%N, 19%Ca) which also brings 184 ppm Ca leaving Ca still needed = 200 – 184 = 16 ppm Ca 16 ppm Ca less 12.8 ppm Ca donated by H_2O = 3.2 ppm = 0.6 g of $CaCl_2$ (27.9%Ca) 60 ppm S less 7.68 ppm S donated by H_2O = 60 – 23 = 52.32 = 10 g of Magnesium sulfate (26%S) 0.2 ppm B = 0.4 g of microsol B (2.5%B, 0.036%Mo)
Ca_0 = 0	0 ppm Ca = 0 g of Calcium nitrate 150 ppm N as NO_3 = 75 g of Magnesium nitrate (10%N) 60 ppm P = 15 g of TSP (46%P_2O_5) 60 ppm S less 7.68 ppm S donated by H_2O = 60 – 23 = 52.32 = 10 g of Magnesium sulfate (26%S) 0.2 ppm B = 0.4 g of microsol B (2.5%B, 0.036%Mo)
Ca_1 = 100	100 ppm Ca = 100 less 12.8 ppm Ca donated by H_2O = 100 – 12.8 = 87.2 ppm Ca = 22.9 g of Calcium nitrate (15.5%N, 19%Ca) which also brings N as NO_3 containing 71 ppm N leaving N still needed = 150 – 71 = 79 ppm 79 ppm N as NO_3 = 39.5 g Magnesium nitrate (10%N) 60 ppm P = 15 g of TSP (46%P_2O_5) 60 ppm S less 7.68 ppm S donated by H_2O = 60 – 23 = 52.32 = 10 g of Magnesium sulfate (26%S) 0.2 ppm B = 0.4 g of microsol B (2.5%B, 0.036%Mo).
Ca_2 = 200	184 ppm Ca = 48.4 g of Calcium nitrate (15.5%N, 19%Ca) which also brings N as NO_3 containing 150 ppm N leaving N needed = 150 – 150 = 0. Ca still needed = 200 – 12.8 – 187.2 – 184 = 3.2 ppm 3.2 ppm = 0.6 g of $CaCl_2$ (27.9%Ca) 60 ppm P = 15 g of TSP (46%P_2O_5) 60 ppm S less 7.68 ppm S donated by H_2O = 60 – 23 = 52.32 = 10 g of Magnesium sulfate (26%S) 0.2 ppm B = 0.4 g of microsol B (2.5%B, 0.036%Mo).
Ca_3 = 300	184 ppm Ca = 48.4 g of Calcium nitrate (15.5%N, 19%Ca) which also brings N as NO_3 containing 150 ppm N leaving Ca still needed = 300 – 12.8 – 287.2 – 184 = 103.2 ppm

	103.2 ppm = 18.5 g of $CaCl_2$ (27.9%Ca) 60 ppm P = 15 g of TSP (46%P_2O_5) 60 ppm S less 7.68 ppm S donated by H_2O = 60 – 23 = 52.32 = 10 g of Magnesium sulfate (26%S) 0.2 ppm B = 0.4 g of microsol B (2.5%B, 0.036%Mo)
Ca_4 = 400	184 ppm Ca = 48.4 g of Calcium nitrate (15.5%N, 19%Ca) which also brings N as NO3 containing 150 ppm N leaving Ca still needed = 400 – 12.8 – 387.2 – 184 = 203.2 ppm 203.2 ppm = 36.4 g of $CaCl_2$ (27.9%Ca) 60 ppm P = 15 g of TSP (46%P_2O_5) 60 ppm S less 7.68 ppm S donated by H_2O = 60 – 23 = 52.32 = 10 g of Magnesium sulfate (26%S). 0.2 ppm B = 0.4 g of microsol B (2.5%B, 0.036%Mo).
S_0 = 0	0 ppm S = 0 g of magnesium sulfate (26%S) 150 ppm N = 48.4 g of Calcium nitrate (15.5%N, 19%Ca) which also brings 184 ppm Ca leaving Ca still needed = 200 – 184 = 16 ppm Ca 16 ppm Ca less 12.8 ppm Ca donated by H_2O = 3.2 ppm = 0.6 g of $CaCl_2$ (27.9%Ca). 60 ppm P = 15 g of TSP (46%P_2O_5) 0.2 ppm B = 0.4 g of microsol B (2.5%B, 0.036%Mo).
S_1 = 30	22.2 ppm S = 4.3 g of magnesium sulfate (26%S) 150 ppm N = 48.4 g of Calcium nitrate (15.5%N, 19%Ca) which also brings 184 ppm Ca leaving Ca still needed = 200 – 184 = 16 ppm Ca 16 ppm Ca less 12.8 ppm Ca donated by H_2O = 3.2 ppm = 0.6 g of $CaCl_2$ (27.9%Ca) 60 ppm P = 15 g of TSP (46%P_2O_5) 0.2 ppm B = 0.4 g of microsol B (2.5%B, 0.036%Mo)
S_2 = 60	52.32 ppm S = 10 g of magnesium sulfate (26%S) 150 ppm N = 48.4 g of Calcium nitrate (15.5%N, 19%Ca) which also brings 184 ppm Ca leaving Ca still needed = 200 – 184 = 16 ppm Ca 16 ppm Ca less 12.8 ppm Ca donated by H_2O = 3.2 ppm = 0.6 g of $CaCl_2$ (27.9%Ca) 60 ppm P = 15 g of TSP (46%P_2O_5) 0.2 ppm B = 0.4 g of microsol B (2.5%B, 0.036%Mo)
S_3 = 90	82.32 ppm S = 15.8 g of magnesium sulfate (26%S) 150 ppm N = 48.4 g of Calcium nitrate (15.5%N, 19%Ca) which also brings 184 ppm Ca leaving Ca still needed = 200 – 184 = 16 ppm Ca 16 ppm Ca less 12.8 ppm Ca donated by H_2O = 3.2 ppm = 0.6 g of $CaCl_2$ (27.9%Ca) 60 ppm P = 15 g of TSP (46%P_2O_5) 0.2 ppm B = 0.4 g of microsol B (2.5%B, 0.036%Mo)
S_4 = 120	112.32 ppm S = 21.6 g of magnesium sulfate (26%S) 150 ppm N = 48.4 g of Calcium nitrate (15.5%N, 19%Ca) which also brings 184 ppm Ca leaving Ca still needed = 200 – 184 = 16 ppm Ca 16 ppm Ca less 12.8 ppm Ca donated by H_2O = 3.2 ppm = 0.6 g of $CaCl_2$ (27.9%Ca) 60 ppm P = 15 g of TSP (46%P_2O_5)

	0.2 ppm B = 0.4 g of microsol B (2.5%B, 0.036%Mo)
$B_0 = 0$	0 ppm B = 0 g of microsol B 150 ppm N = 48.4 g of Calcium nitrate (15.5%N, 19%Ca) which also brings 184 ppm Ca leaving Ca still needed = 200 – 184 = 16 ppm Ca 16 ppm Ca less 12.8 ppm Ca donated by H_2O = 3.2 ppm = 0.6 g of $CaCl_2$ (27.9%Ca) 60 ppm P = 15 g of TSP (46%P_2O_5) 60 ppm S less 7.68 ppm S donated by H_2O = 60 – 23 = 52.32 = 10 g of Magnesium sulfate (26%S)
$B_1 = 0.1$	0.1 ppm B = 0.2 g of microsol B 150 ppm N = 48.4 g of Calcium nitrate (15.5%N, 19%Ca) which also brings 184 ppm Ca leaving Ca still needed = 200 – 184 = 16 ppm Ca 16 ppm Ca less 12.8 ppm Ca donated by H_2O = 3.2 ppm = 0.6 g of $CaCl_2$ (27.9%Ca) 60 ppm P = 15 g of TSP (46%P_2O_5) 60 ppm S less 7.68 ppm S donated by H_2O = 60 – 23 = 52.32 = 10 g of Magnesium sulfate (26%S)
$B_2 = 0.2$	0.2 ppm B = 0.4 g of microsol B 150 ppm N = 48.4 g of Calcium nitrate (15.5%N, 19%Ca) which also brings 184 ppm Ca leaving Ca still needed = 200 – 184 = 16 ppm Ca 16 ppm Ca less 12.8 ppm Ca donated by H_2O = 3.2 ppm = 0.6 g of $CaCl_2$ (27.9%Ca) 60 ppm P = 15 g of TSP (46%P_2O_5) 60 ppm S less 7.68 ppm S donated by H_2O = 60 – 23 = 52.32 = 10 g of Magnesium sulfate (26%S)
$B_3 = 0.3$	0.3 ppm B = 0.6 g of microsol B 150 ppm N = 48.4 g of Calcium nitrate (15.5%N, 19%Ca) which also brings 184 ppm Ca leaving Ca still needed = 200 – 184 = 16 ppm Ca 16 ppm Ca less 12.8 ppm Ca donated by H_2O = 3.2 ppm = 0.6 g of $CaCl_2$ (27.9%Ca) 60 ppm P = 15 g of TSP (46%P_2O_5) 60 ppm S less 7.68 ppm S donated by H_2O = 60 – 23 = 52.32 = 10 g of Magnesium sulfate (26%S)
$B_4 = 0.4$	0.4 ppm B = 0.8 g of microsol B 150 ppm N = 48.4 g of Calcium nitrate (15.5%N, 19%Ca) which also brings 184 ppm Ca leaving Ca still needed = 200 – 184 = 16 ppm Ca 16 ppm Ca less 12.8 ppm Ca donated by H_2O = 3.2 ppm = 0.6 g of $CaCl_2$ (27.9%Ca) 60 ppm P = 15 g of TSP (46%P_2O_5) 60 ppm S less 7.68 ppm S donated by H_2O = 60 – 23 = 52.32 = 10 g of Magnesium sulfate (26%S).

All the fertilizers used in the study (Table 3.2) easily dissolved in water apart from Calcium triple superphosphate. Weighed fertilizers were dissolved separately in approximately one litre of water until they were completely dissolved. Calcium triple

superphosphate granules were placed in a 50-mesh insect-proof net from Amiran Kenya and soaked in a bucket of warm water overnight and the following day were squeezed until all granules disappeared. The solution was left to settle down and clear supernatant transferred discarding impurities at the bottom. The dissolved fertilizers were transferred into black buckets and the volume topped up to 50 L with water, finally the pH was adjusted to 5.8 using HI98107 pH meter (Hanna Instruments Ltd, UK) by adding 3 mL of 0.1 M phosphoric acid.

3.2.4 Trial establishment and experimental design

Pathogen tested plantlets of cultivar Kabode obtained from KEPHIS-PQBS were weaned and multiplied in the greenhouse to generate experimental planting materials. Ten cuttings of three nodes were planted in a plastic pot measuring 18 cm diameter and a slanting 20 cm height filled with 5.5 kg of sterilized river sand. Five experiments (Table 3.3) were laid in a factorial arrangement in randomized complete block design with five levels of the factor fertilizer replicated four times with two blocks.

3.2.5 Crop management practices

Plants were manually fertigated using graduated measuring jars at the base of the sweetpotato plants until all the pots started to leak the nutrient solution to the plate at the bottom of the pots. Fertigation frequency was scheduled based on an Irrometer SR 12´´ (Irrometer Company Inc., CA, USA) readings. Hanging yellow traps were used to detect for presence of insects and timely appropriate interventions instituted during crops growth cycle. An optimal temperature of 26±4^{o}C (Chen, 2013) suitable for vine growth was maintained by heat controllers, sensors and cooling air extract fans and this was monitored by HOBO U12-013 data logger (Onset Computer Corp., Bourne, MA, USA).

3.2.6 Data collection

Data on petiole length, internode length, vine length, vine girth, leaf area and nodes produced were recorded 45 days after planting. Petiole length, internode length and vine length were measured using a meter ruler.

a) **Petiole length (cm);** this was determined by measuring the point between leaf attachment to the main stem and the leaf, the measurements were done on the fifth leaf from the tip of the main stem.
b) **Vine length (cm);** this was determined by measuring the main stem length from the surface of the soil in the pot to the tip.
c) **Internode length (cm);** this was determined by measuring the fifth internode from the tip of the main stem.
d) **Leaf area (cm^2);** this was determined by measuring leaf length (L) and width (W) at the widest part of the 5^{th} leaf from the tip of the main stem and the product L × W was used to compute for leaf area (cm^2/plant).
e) **Vine girth (cm);** this was determined by measuring the fifth internode girth diameter from the tip of the main stem using Vernier caliper.
f) **Nodes produced;** these were counted on the main stem from the surface of the pot to the fully open leaf at the tip of the vine.
g) **Nutrient disorders;** nutrient disorders were visually observed and recorded.
h) **Shoot fresh and dry mass (g);** at harvesting, four vines from each replication for each treatment were sampled to constitute a composite sample for above ground biomass determination. Harvested fresh shoot samples were separated from roots for each treatment, weighed and then heated to a constant weight in an oven for 48h at 65ºC. These were re-weighed to determine the dry weight.

i) **Fresh and dry root mass (g);** composite samples for fresh root samples from four plants for each replication from each treatment were harvested, weighed and heated to a constant weight in an oven for 48h at 65ºC and these were then reweighed to determine the dry weight.

j) **Leaf tissue analysis;** the blades of the 7^{th} to 9^{th} youngest leaves from the shoot tip were randomly selected as the index tissue to form a composite sample (O'Sullivan *et al*., 1997) and taken to Crop Nutrition Laboratories, Kenya for tissue analysis. The nutrient values in the leaf samples were plotted against various measured growth parameters and results used to extrapolate the optimal nutrient concentrations for sweetpotato vine growth for the 5 elements.

3.2.7 Data analysis

General linear model procedure (GLM) was used for the analysis of variance using the SAS 9.4 version (SAS Institute Inc., 2013) and means were separated using least significance difference (LSD) at 0.05 level of probability. The statistical model was $Y_{ijk} = \mu + T_i + B_j + E_{ij}$ where;

μ = population mean

Y_{ij} – is the response variable measured

i – is the treatment factor (levels 0, 1, 2, 3, 4 and 5)

j – is the blocking factor

T_i – is the effect due to i^{th} rate

B_j – is the effect for being in block j

Data for response variables were fitted in the above statistical model and subjected to Analysis of Variance as summarized in Appendix I.

3.3 Results

3.3.1 Nitrogen rate

Plants in the N omitted (0 mg NL^{-1}) pots exhibited N deficiency symptoms two weeks after planting when the crop had two fully expanded leaves. Plants showed stunting with minimal expansion of the leaf area (Plate 3.1 (A), as compared to plants on receiving all nutrient (Plate 3.1 (B). There was reddening of basal leaf edges advancing to younger growing leaves.

Plate 3: 1:(A) Plate of Nitrogen deficient vines on the minus Nitrogen treatment against the all (B) nutrient control 30 days after planting. (Source: Author, 2018)

Results from the experimental (Table 3.4) study showed that the means of internode length, leaf area, petiole length, vine girth, vine length and nodes production were significantly ($p<.0001$) affected by increasing N rates. When 0 ppm and 100 ppm N were applied internode length, leaf area, petiole length, vine length and nodes produced were significantly lower compared to 150, 200 and 250 ppm N application. The tissue N level recorded was below 4.0% N at 0 and 100 ppm treatments (Figure 3.1 (A).

The highest N rate (250 ppm) applied resulted in reduction but not significant growth of internode length, leaf area, petiole and vine length compared to plants grown at 200

ppm N (Table 3.4). Nitrogen levels in the leaf tissue increased logarithmically as fertilizer rate increased up to 200 ppm N fertilization (Figure 3.1 (A).

Table 3.4: Vegetative growth parameters of sweetpotato as affected by Nitrogen at different rates

N (ppm)	Vine internode length (cm)	Leaf area (cm^2)	Petiole length (cm)	Vine girth (cm)	Vine length (cm)	No. of nodes per vine	N leaf tissue concentration (%)	Above ground fresh biomass (g)
0	1.2^{c}	19.7^{b}	6.9^{b}	0.7^{b}	8.1^{c}	1.3^{c}	1.72	3.76
100	2.1^{ab}	39.5^{a}	10.7^{a}	0.9^{a}	27.4^{b}	3.6^{b}	3.71	16.1
150	2.2^{a}	46.8^{a}	12.6^{a}	1.0^{a}	33.3^{a}	4.3^{ab}	4.83	23.1
200	2.0^{ba}	49.7^{a}	12.0^{a}	0.9^{a}	31.7^{ab}	4.1^{ab}	5.01	20.2
250	1.7^{b}	48.9^{a}	11.4^{a}	0.9^{a}	30.6^{ab}	4.4^{a}	4.91	21.4
Mean	1.8	40.9	10.7	0.9	26.2	3.5		
LSD	0.4	12.3	2.3	0.1	5.0	0.8		
p	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001		

Different letters within the same column denote significant differences at $p \leq 0.05$

Results in the growth of internode length, leaf area, petiole length, nodes production, above ground fresh weight and N tissue accumulation suggest that optimal growth in these parameters can be achieved when N concentration is 200 ppm. This data showed that as N rate increased from 0 – 250 ppm, there was an increased significant growth in the vine length, vine internode length, leaf area, petiole length and nodes production. Increase in above ground fresh biomass accumulation was also noted (Table 3.4), however, a decline in the growth increase in vine length was observed as N rate exceeded 200 ppm (Figure 3.1 (a). The leaf tissue analysis report indicated (Figure 3.1 (a) that as N fertilization increased, N level in the plant tissue increased when its value was relatively lower than 5.01%. After N tissue level neared or exceeded 5.01%, the subsequent value, 4.91 % which is lower indicated that there was no further increment of N levels in the plant tissue. This information indicated that when N tissue was approximately 5.01% or above it might be toxic. This data further showed that significant growth in vine length, internode length, leaf area and petiole

length occurred as N fertilization increased until 5.01% N accumulation in plant tissue when no further increase was observed, an indication that 5.01% N tissue was the optimal nutrient concentration for sweetpotato vine growth. The minimal growth in internode length, leaf area, petiole length, vine length, nodes produced, above the ground fresh biomass and N tissue accumulation at 100 ppm fertilization (Table 3.4) shows that when tissue N was approximately 4.0%, it might be deficient an indication that this is the critical nutrient concentration for N deficiency.

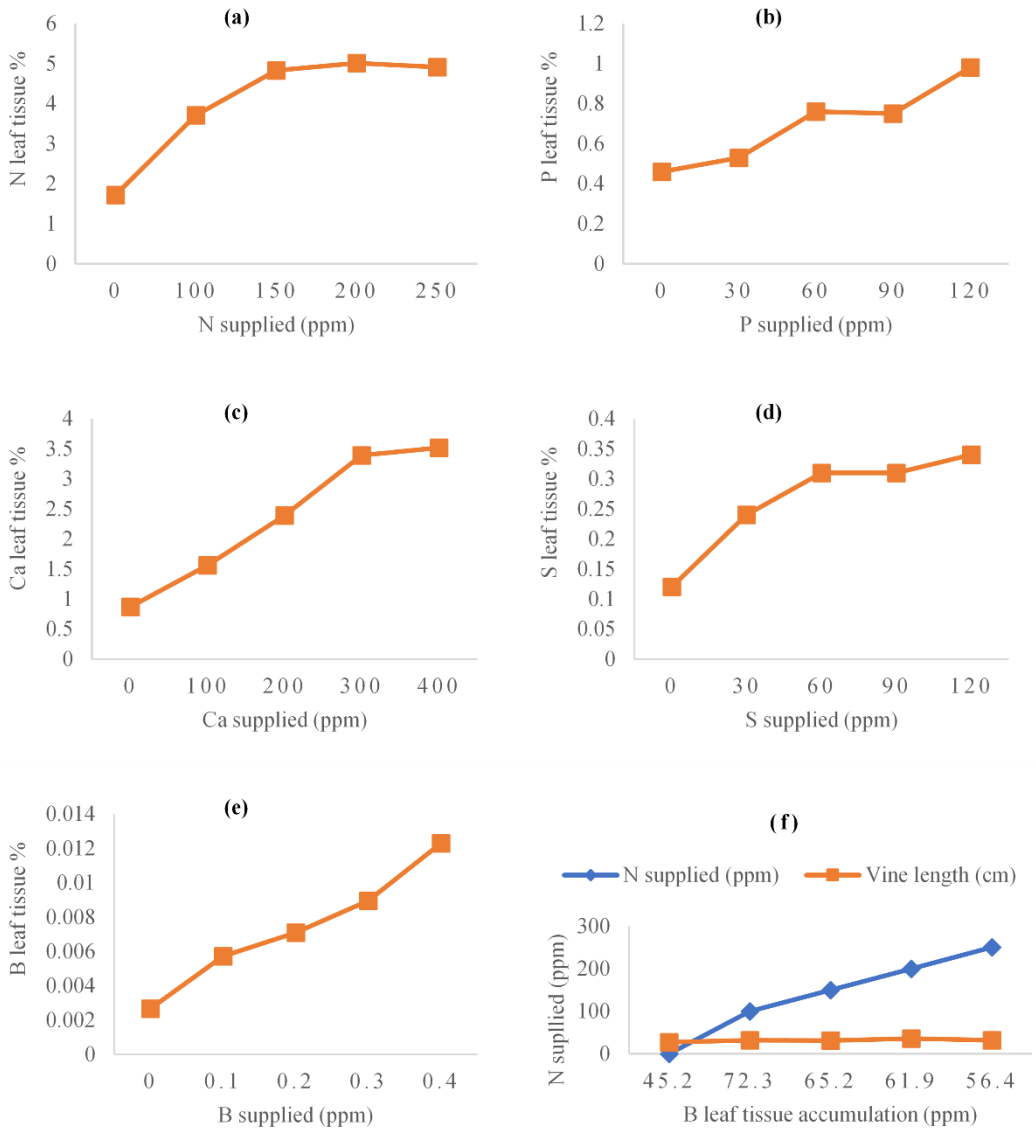

Figure 3: 1: Concentrations of (a) Nitrogen, (b) Phosphorus, (c) Calcium, (d) Sulfur and (e) Boron in the leaf index tissue across a range of supply levels. Critical concentrations were extrapolated using an exponential function model, regression and 'broken stick' procedures. (f) response of vine length to Nitrogen (N) Boron (B) interaction.

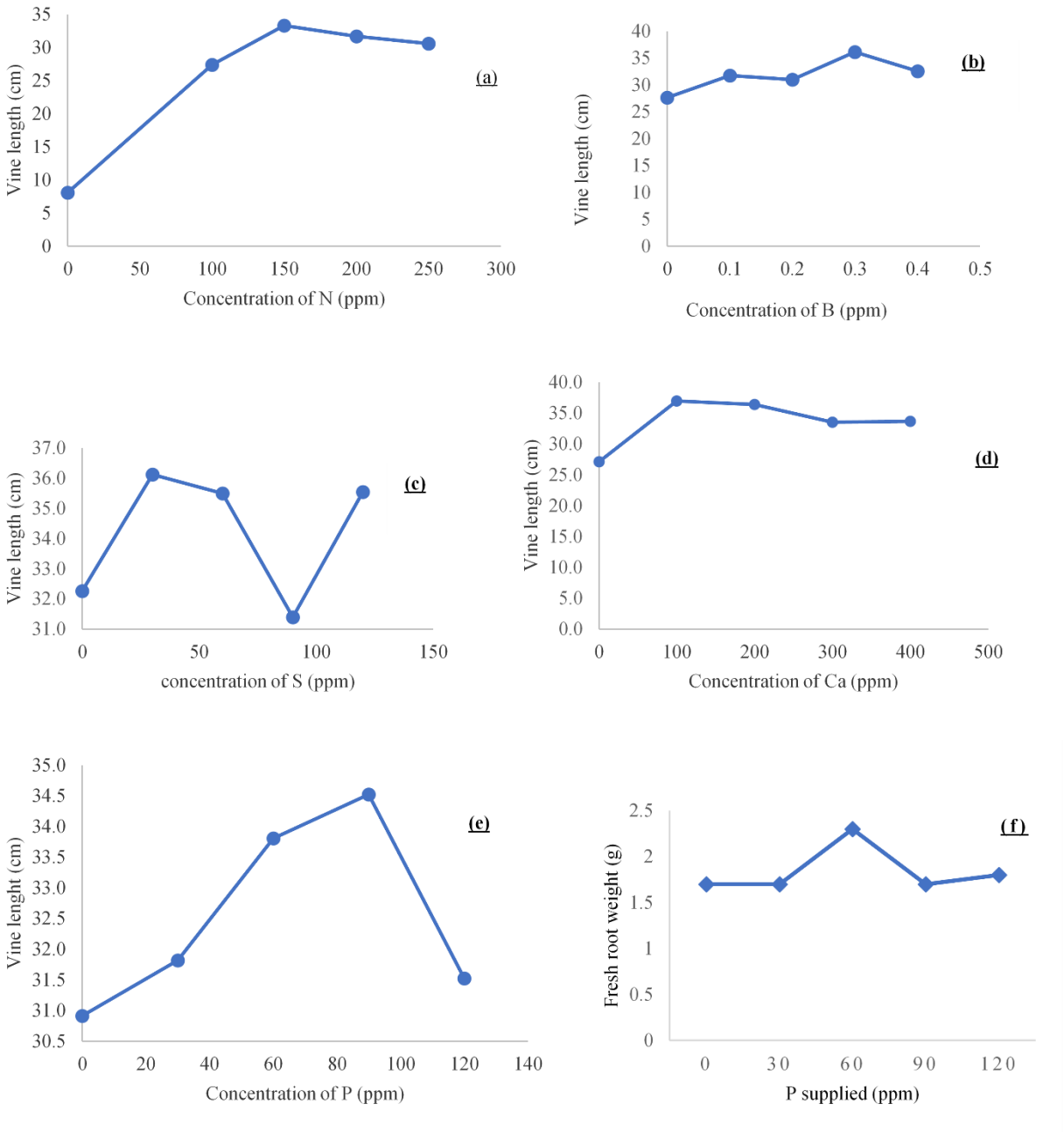

Figure 3: 2: Relationship between sweetpotato vine length and the supply of (a) N, (b) B, (c) S, (d) Ca and (e) P across a range of levels and (f) relationship between fresh root weight and the concentration of P supplied.

There was a sharp increase in Boron tissue concentration from 45.2 to 72.3 ppm at 0 and 100 ppm Nitrogen fertilization respectively, after which followed a successive decrease in Boron tissue concentrations to 65.2, 61.9 and 56.4 ppm when plants were fertilized with 150, 200 and 250 ppm Nitrogen respectively. The concentrations of Boron recovered in leaf blades as a percentage for each of the 5 treatment levels of

Nitrogen were plotted against the growth in vine length, the maximum growth in vine length was recorded at 200 ppm Nitrogen fertilization (Figure 3.2 (f).

3.3.2 Phosphorus rate

Pronounced visible deficiency symptoms were observed in plants with omitted Phosphorus as yellowing of older leaves spreading from discrete interveinal patches affecting half of the leaf blades surface (Plate 3.2 (A). Healthy vigorous sweetpotato vines were observed on all nutrient control (Plate 3.2 (B).

Plate 3: 2: (A) Plate of Phosphorus deficient vines on the minus Phosphorus treatment against the All (B) nutrient control 45 days after planting (Source: Author, 2018)

Phosphorus fertilization increase did not significantly (Table 3.5) affect growth in the means of vine internode length, leaf area, petiole length, vine girth, vine length and number of nodes produced per vine. However, the maximum mean leaf area and internode growth was recorded at 60 ppm Phosphorus fertilization.

Table 3.5: Vegetative growth parameters of sweetpotato plants as affected by Phosphorus at five rates

P (ppm)	Vine internode length (cm)	Leaf area (cm^2)	Petiole length (cm)	Vine girth (cm)	Vine length (cm)	No. of nodes per vine	P leaf tissue concentration (%)	Above ground fresh biomass (g)
0	2.1	47.2	12.3	0.9	31.2	3.9	0.46	19.3
30	2.2	50.0	14.1	0.9	31.8	3.6	0.53	20.0
60	2.2	53.4	12.7	0.9	33.8	4.0	0.76	23.7
90	2.0	52.6	13.5	0.9	34.2	3.8	0.75	25.4
120	2.1	51.7	13.2	0.9	31.5	3.4	0.98	23.5
Mean	2.1	51.0	13.2	0.9	32.5	3.7		
LSD	0.5	13.5	4.0					
p	0.9	0.6	0.3	0.4	0.2	0.1		

There was successive increase in Phosphorus levels in the leaf tissue as Phosphorus fertilization increased (Figure 3.1 (b). The threshold in the increase of P tissue levels was observed at 60 ppm Phosphorus fertilization. When Phosphorus tissue reached 0.76% a further increase in Phosphorus leaf tissue was not observed as Phosphorus fertilization increased, instead there was a non-significant decrease in growth parameters as Phosphorus leaf tissue exceeded 60 ppm (Table 3.5). Despite the decrease in growth of sweetpotato vegetative growth parameters due to increased P fertilization (Table 3.5), the highest growth in vine length was recorded at 90 ppm (Figure 3.2 (e) but was not significant ($p>0.05$).

3.3.3 Calcium rate

Chlorosis, curling, cupping and distortion of younger growing apical leaves was also observed (Plate 3.3 (A) against all nutrient control in which plants were vigorous and healthy (Plate 3.3 (B). Plants exhibited detrimental effects of advanced root rot in the Calcium omitted nutrient media treatment 45 days from planting (Plate 3.3 (D), while plants in the all nutrient control exhibited no root growth anormalies (Plate 3.3 (C).

Mild chlorosis and misshapen apical leaves were noted when plants were fertigated with 100 ppm Calcium.

Plate 3: 3: Calcium deficient vines on the minus Calcium treatment (A), sweetpotato vines on all nutrient control (B), (C) sweetpotato roots on all nutrient control against Calcium deficient sweetpotato roots on minus Calcium treatment (D) sampled 45 days from planting (Source: Author, 2018)

Increased Calcium fertilization resulted in significant (Table 3.6) increase in the means of internode length (p=0.005), leaf area (p=0.02), petiole length (p=0.01), vine girth (p=0.02) and vine length (p=0.001). Treatments with Calcium omitted resulted in vines with reduced internode length, leaf area, vine length, fewer nodes and low above ground fresh biomass accumulation, as well as low Calcium concentrations in the leaf tissue.

Table 3.6: Effect of Calcium fertilization on vegetative growth parameters of sweetpotato plants 45 days from planting

Ca (ppm)	Vine internode length (cm)	Leaf area (cm^2)	Petiole length (cm)	Vine girth (cm)	Vine length (cm)	No. of nodes per vine	Ca leaf tissue concentration (%)	Above ground fresh biomass (g)
0	1.7^{b}	35.8^{b}	9.3^{b}	0.9^{b}	27.0^{b}	3.7	0.87	17
100	2.0^{ba}	46.1^{ba}	12.4^{a}	0.9^{b}	37.0^{a}	4.5	1.56	27
200	2.4^{a}	47.1^{a}	11.8^{a}	0.9^{b}	36.4^{a}	4.2	2.39	27.1
300	2.3^{a}	44.8^{ba}	11.9^{a}	1.0^{a}	33.5^{a}	4.4	3.39	20.6
400	2.1^{ab}	45.5^{ba}	11.2^{ba}	1.0^{a}	33.6^{a}	4.2	3.52	25.5
Mean	2.1	43.9	11.3	0.9	33.6			
LSD	0.4	9.6	2.2	0.04	5.6	0.7		
p	0.005	0.02	0.01	0.02	0.001	0.08		

Different letters within the same column denote significant differences at $p \leq 0.05$

The maximum significant (Table 3.6) increase in leaf area, vine length and internode length were recorded at 200 ppm. Maximum accumulation in above ground fresh biomass accumulation was also observed at 200 ppm Ca fertigation (Table 3.6). These results show that increased Calcium fertilization results in increased growth of leaf area, plant height, petiole and internode length and fresh biomass accumulation as Calcium accumulation in the leaf tissue increased up to 2.39%. Further increase in the Calcium fertigation rate resulted in the decline in growth of the measurable parameters above (Table 3.6). There was no significant difference in petiole length and nodes production because of increased Calcium fertigation. The highest growth in the vine length was recorded at 100 ppm and 200 ppm which was 37 and 36.4 cm respectively, but not significantly different (Figure 3.2 (d).

3.3.4 Sulfur rate

Yellowing of middle growing leaves was visualized one month after planting followed by entire yellowing of the whole plant on the minus S treatments (Plate 3.4 (B) whereas healthy vigorous plants were observed on the all nutrient treatments (Plate 3.4 (A).

There was a significant increase in growth of vine internode length and petiole length at $p=0.03$ and $p=0.02$ respectively.

Table 3.7: The effect of sequentially increasing Sulfur fertilization rate on sweetpotato vegetative growth parameters

S (ppm)	Vine internode length (cm)	Leaf area (cm^2)	Petiole length (cm)	Vine girth (cm)	Vine length (cm)	No. of nodes per vine	S leaf tissue concentration (%)	Above ground fresh biomass (g)
0	2.2^{b}	39.6	12.5^{ab}	0.9	32.3	4.1	1.2	24.8
30	2.1^{b}	44.1	12.2^{ab}	1.0	36.1	4.5	2.4	23.6
60	2.3^{ba}	51.0	13.2^{ab}	0.9	35.5	4.4	3.1	23.9
90	2.1^{b}	45.7	11.3^{b}	0.9	31.4	4.1	3.1	22.6
120	2.5^{a}	43.8	14.3^{a}	0.9	35.5	4.3	3.4	23.0
Mean	2.2	44.8	12.7	0.9	34.2	4.2		
LSD	0.3	7.5	2.5	0.08	5.3	1.0		
p	0.03	0.08	0.02	0.5	0.1	0.6		

Different letters within the same column denote significance difference at $p \leq 0.05$

Plate 3: 4: (A) Plate of all nutrient control against the (B) Sulfur deficient vines on the minus Sulfur treatment showing entire yellowing of the whole plant representative of Sulfur deficiency sampled 45 days after planting (Source: Author, 2018)

There were no significant ($p>0.05$) differences in the means of vine length and vine girth because of increased Sulfur fertilization (Table 3.7). An increase in Sulfur tissue accumulation was recorded following consecutive Sulfur fertilization (Figure 3.1 (d) with the highest Sulfur rate applied (120 ppm) corresponding to 0.34% Sulfur tissue accumulation, which did not cause any significant growth of the measurable parameters. The highest growth in vine length were recorded at 30, 60 and 120 ppm S application which corresponded to 36.1, 35.5 and 35.5 cm respectively (Figure 3.2 (c), although not significant ($p>0.05$).

3.3.5 Boron rate

Boron deficiency symptoms were observed 21 days after planting in the Boron omitted nutrient media. Plants exhibited chlorosis in the apical leaves spreading to the basal foliage in the later stages of growth (Plate 3.5 (A). At advanced stage of vine growth, 45 days after planting, there was necrosis in the symptomatic leaves, death of the severely affected leaves and apical buds, eventually leading to premature plant

senescence (Plate 3.5 (B). Boron treated plants with 0.1 ppm exhibited chlorosis of apical buds and necrosis in older growing leaves, but the crops life cycle was not terminated.

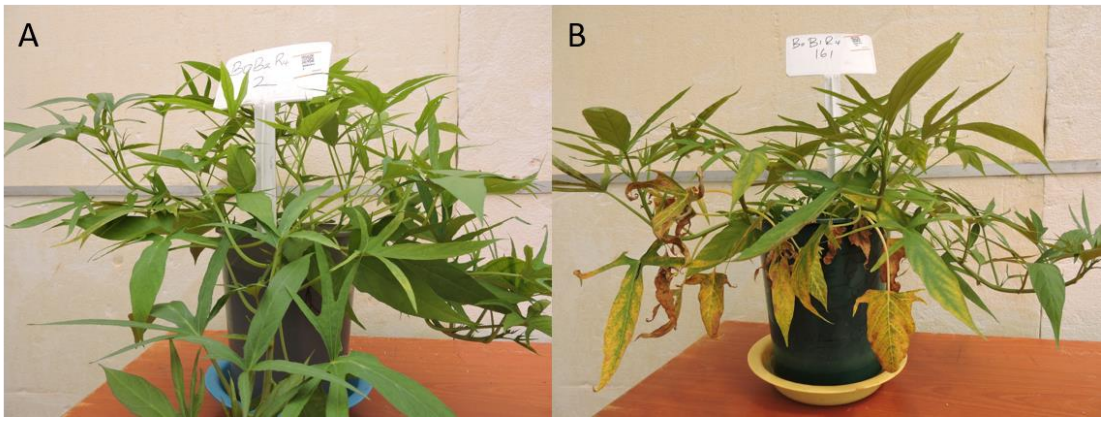

Plate 3: 5: (A) Early symptoms of Boron deficiency, (B) severe symptoms of Boron deficiency (Source: Author, 2018)

Successive increase in Boron fertilization resulted in a significant increase (Table 3.8) in growth of leaf area and vine length. The data also showed increased, but not significant ($p \leq 0.05$), growth in petiole length, vine girth, and nodes production. Leaf area and vine length were significantly ($p \leq 0.05$) reduced under Boron deficient treatments (Table 3.8). Vine length declined from 36.2 to 27.7 cm and leaf area dropped by 9.4 cm^2 $plant^{-1}$ at 0 and 0.3 ppm Boron application, respectively, indicating that Boron had a significant role on the growth of sweetpotato vines. Increase in above the ground fresh biomass and Boron tissue accumulation was also observed (Table 3.8) following successive increase in Boron fertilization.

Tissue analysis of the 7^{th} to 9^{th} open leaf blades from the shoot tip showed that Boron levels in the leaf tissue increased successively with increased Boron fertilization (Figure 3.1 (e), and this resulted in the increased growth of leaf area, vine length, nodes production and fresh biomass accumulation (Table 3.8). Maximum growth in

vine length was recorded at 0.3 ppm Boron application (Figure 3.2 (b), after Boron tissue level exceeded 0.00896% as Boron fertilization increased, growth increase in phenological measurable growth parameters declined.

Table 3. 8: The effect of increasing Boron fertilization rate on sweetpotato vegetative growth parameters

B (ppm)	Vine internode length (cm)	Leaf area (cm^2)	Petiole length (cm)	Vine girth (cm)	Vine length (cm)	No. of nodes per vine	B leaf tissue concentration (%)	Above ground fresh biomass (g)
0	1.8	40.4^{b}	9.8	0.9	27.7^{b}	3.9	0.00266	20.4
0.1	2.1	43.0^{ab}	12.2	0.9	31.8^{ab}	4.0	0.00573	23.8
0.2	2.3	48.1^{ab}	12.4	0.9	31.0^{ab}	4.0	0.00710	25.8
0.3	2.2	49.8^{a}	11.4	1.0	36.2^{a}	4.3	0.00896	28.8
0.4	2.1	46.9^{ab}	10.9	0.9	32.6^{ab}	4.0	0.01230	25.6
Mean	2.1	45.6	11.3	0.9	31.8	4.0		
LSD	0.4	8.5	2.6	0.07	5.6	0.8		
p	0.08	0.04	0.1	0.2	0.02	0.8		

Different letters within the same column denote significant differences at $p \leq 0.05$

3.4 Discussion

3.4.1 Nitrogen rate

Nitrogen fertilization at 200 ppm seemed to be the most favorable for vine growth. These findings are supported by previous Nitrogen studies conducted in greenhouse studies in other crops such as Texas mountain laurel (*Sophora secundiflora*), Anthurium (*Anthurium andraeanum* Lind.) and bell pepper (*Capsicum annum* L.), which all reported a similar range of Nitrogen fertilization rate for optimal haulm growth (Bar-Tal *et al*., 2001; Niu *et al*., 2011). A study conducted by (Chen, 2013) on Nitrogen fertilization rates and application timings on greenhouse sweetpotato production gave similar results.

It has been reported that growth reduction usually happens when a plant nutrient reaches a toxic range (Smith, 1962). In this study when Nitrogen tissue neared or exceeded 5.01% growth was retarded, and there was a reduction in the growth of

plants. This indicated that above 5.01% Nitrogen tissue might be the indicator of plant toxicity. A sufficient range for solution cultured sweetpotato 28 days from planting was reported between 4.2 – 5.0% when the 7^{th} to 9^{th} open leaf blades from the shoot tip were sampled (O'Sullivan *et al*., 1997). Mills *et al*. (1996) reported a sufficient range for field grown sweetpotato in the middle of the growing season to be between 3.3 – 4.5% when the most recent fully developed leaves were sampled.

Sufficiency ranges for nutrients usually vary considerably with phenological crop stage. Chen (2013) reported that the highest concentration of Nitrogen was found in new leaves, and the Nitrogen content became less with the age of the plant. Compared with field grown sweetpotato, leaves obtained from greenhouse shoot production were much younger, and thus should have been expected to have a higher Nitrogen content. This case has been documented in other crops. Cucumber plants grown in the greenhouse need a higher range of Nitrogen than those in the field, 4.5 – 6.0% versus 4.0 – 5.0% (Campbell and Plank, 2000). Greenhouse lettuce can tolerate an even higher Nitrogen level, from 4.5 – 6.5%. Based on this information, the relatively higher Nitrogen levels in this study seemed to be reasonable, while the drop in the Nitrogen tissue accumulation in the leaf samples was an indicator of optimal concentrations having been reached.

Increased levels of Nitrogen fertilization antagonizes Boron uptake, given that Boron plays an important role in sweetpotato growth, primarily in root development (Li *et al*., 2017; Miller and Nielsen, 1970; Nausbaum, 1946; O'Sullivan *et al*., 1997; Willis, 1943), consideration of Nitrogen rate that harmoniously interacts with Boron to favor vine growth is important and in this study, maximum vine length occurred at 200 ppm and 0.3 ppm Nitrogen application. Boron levels decreased significantly when Nitrogen rates exceeded 200 ppm Nitrogen fertilization.

3.4.2 Phosphorus rate

Phosphorus fertilization at the 5 levels did not result in significant variation at the 5% confidence level in all growth parameters measured. However, Phosphorus deficiency symptoms and decreased growth of leaf area which was not significant ($p>0.05$) and above ground fresh biomass in Phosphorus omitted pots was observed, this could have been attributed to the role Phosphorus plays in plant physiological processes as reported by (Baset-Mia, 2015; Hawkesford *et al*., 2012; Siose *et al*., 2018). There is further documented evidence that Phosphorus deficiency reduces leaf expansion (Fageria *et al*., 2003; Fredeen *et al*., 1989; Siose *et al*., 2018). The present data confirm these findings. According to Baset-Mia (2015), Phosphorus deficiency impairs photosynthetic activities in leaf, this is reflected in the low above ground biomass accumulation in this study. The increased growth in leaf area in the Phosphorus treated pots could have been a result of the beneficial effect of P on the activation of photosynthesis and metabolic processes of organic compounds in plants which increase the growth of plants (El Sayed Hameda *et al*., 2011; Purekar *et al*., 1992).

These results further indicated that 30 ppm can be approximated to be the lower critical Phosphorus concentration in sweetpotato vine growth, attributed to observed healthy plants. A concentration of 0.46% Phosphorus tissue was recovered from vine leaf blades fertilized at 30 ppm. O'Sullivan *et al*. (1997) reported a similar percentage to be within the sufficiency range. The non-significant ($p\leq0.05$) effects of increased Phosphorus fertilization on phenological growth parameters could be attributed to increased nutrient imbalance because of sequential Phosphorus fertilization (Kareem, 2013). Akinjoba (2014) reported that despite higher amount of Phosphorus released, recovery of Phosphorus fertilizer is about 15 - 30% while about 60% of the

Phosphorus fertilizer is absorbed. In this study 0.76% Phosphorus leaf tissue seemed to be the optimal level for absorption, then further fertilization did not result in increased Phosphorus-uptake. Furthermore, increased Phosphorus fertilization resulted in decreased growth in internode length, leaf area, petiole, vine length, nodes production, although this was not significant ($p \leq 0.05$). These data also showed a decline in fresh root biomass accumulation following increased Phosphorus fertilization corresponding with Rashid and Waithaka (1985) findings in their study of effect of Phosphorus fertilization on growth and tuberization of sweetpotato.

The increased fresh root biomass concurs with Kareem (2013), that root growth particularly development of lateral roots and fibrous rootlets is encouraged by Phosphorus in sweetpotato. It is reported that Phosphorus is one of the most important nutrients for many plant species including sweetpotato (El Sayed Hameda *et al*., 2011). The maximum increase in node production, above ground fresh biomass and fresh root biomass was recorded at 60 ppm Phosphorus fertilization. This indicates that 60 ppm was the approximate optimal concentration for sweetpotato vine growth.

3.4.3 Calcium rate

Chlorosis, curling and distortion of younger growing apical leaves in Calcium omitted nutrient media corroborated with report by Crasswell *et al*. (1995). Sweetpotato cultivars grown in the Pacific region on Calcium deficient soils exhibited similar symptoms (Crasswell *et al*., 1995). Generally, Calcium deficient plants recorded significantly reduced growth ($P \leq 0.05$) in internode length, leaf area and vine length. There was also decreased fresh weight biomass and limited Calcium tissue accumulation, this is because the root tips of Calcium deficient sweetpotato become rotten and fail to grow making it impossible for absorption of other nutrients to occur (Bautista-Tulin *et al*., 2018). In this study plants in the Calcium omitted treatment

further exhibited detrimental effects of advanced root rot 45 days after planting confirming the reports of O'Sullivan *et al*. (1997) and Ila'ava (1997). Miyasaka *et al*. (2002) also reported similar results in taro (*Colocasia esculenta*). The pronounced detrimental effect of root die back is attributed to inadequate iron uptake resulting from poor root function. Further documented work reported that iron deficiency may be induced by Calcium nutrition disorder resulting in adverse effects on roots (Craswell *et al*., 1996).

The present data additionally shows a significant increase in internode length, leaf area and vine length with increased Ca fertigation up to 200 ppm, after which no further growth was recorded. Maximum growth in leaf area, internode length, vine length and above the ground fresh weight was also recorded at 200 ppm Ca. These results confirm documented work by Hassan *et al*. (2014).

The positive effect of Calcium on the significant growth of sweetpotato vegetative internode length, leaf area, vine girth and vine length might have been due to the Calcium functions as a second messenger in the signal conduction between environmental factors and plant responses in terms of growth and development (Bothwell and Ng, 2005; Delian *et al*., 2014; Harper *et al*., 2004; Hetherington and Brownlee, 2004; Hirschi, 2004; Reddy, 2001; Reddy and Reddy, 2004). Moreover, Calcium ions play a pivotal role in membrane stabilization and in the regulation of enzymes synthesis (Schmitz-Eiberger *et al*., 2002).

The superior effects of Calcium at 200 ppm in enhancing the growth parameters described above may also be due to its physiological effects on sweetpotato plants. The positive effects of Calcium on vine yield and its components might be due to Calcium being a component of the middle lamella and is essential for intracellular membrane transport. Likewise, Calcium is known to act as a signaling molecule that

regulates metabolism, controlling respiration and reducing ethylene production in plants (Hassan *et al*., 2014; Marschner, 2012). Therefore, 200 ppm Calcium can be approximated to be the optimal concentration for sweetpotato vine growth.

3.4.4 Sulfur rate

The increased linear non-statistical growth in leaf area, vine girth, petiole length, vine length and nodes production could be as result of Sulfur acting as a signaling molecule involved in root formation, abiotic defense, and senescence (Hu *et al*., 2012; Jin *et al*., 2011; Shan *et al*., 2014; Zhang *et al*., 2011, 2009). The Sulfur application rates 0, 30, 60 and 90 ppm seemed to be lower based on the corresponding leaf tissue Sulfur accumulation that was recovered in the leaf tissue as 0.12, 0.24, 0.31 and 0.31 ppm respectively and apparently did not have considerable significant effects on the linear increase of sweetpotato phenological growth parameters, which conforms to the finding of (Alu *et al*., 2012). O'Sullivan *et al*. (1997) quoted an approximate critical value of 0.34% extractable Sulfur leaf tissue, below which Sulfur deficiency is likely in sweetpotato, the latter findings conform with this study. A plot of the concentration of Sulfur recovered in the 7^{th} to 9^{th} open leaf blades from the shoot tip as a percentage of each of the five treatment levels resulted in a luxury consumption within the plateau region of the curve relating Sulfur tissue accumulation to increased Sulfur fertilization. The concentrations of the index tissues remained approximately constant as the Sulfur tissue neared 0.34% indicating the plant had been satisfied. Furthermore, no significant increase in phenological growth parameters was observed. Similar results were reported by (O'Sullivan *et al*., 1997). These results indicated that 0.34% Sulfur tissue occurred with 120 ppm Sulfur fertilization, suggesting this is the approximate optimal concentration in sweetpotato vine growth. Thus, Sulfur

fertilization rates that had extractable Sulfur content in the leaf tissues below 0.34% were identified as deficient.

3.4.5 Boron rate

Li *et al.* (2017) reported that Boron not only affects formation and development of reproductive organs of plants, but also plays an essential role in the vegetative growth of plants and participates in the structural composition of cell walls and membranes. The observed premature senescence and plant growth cycle termination could have been due to root elongation inhibition that affected haulm growth and development (Dell and Huang., 1997; Han *et al*., 2008; Miwa *et al*., 2007). An important reason is that the root and leaf are vital organs of plant to acquire nutrients (Li *et al*., 2017).

Similar results were documented by preceding Boron studies in other crops like cotton (*Gossypium hirsutum* L.) which reported that a transient deficiency of Boron can lead to irreversible damage thus seriously affecting yields (Rosolem and Costa, 2000).

It is further reported that Boron deficiency indirectly affects the metabolism of proteins and nucleic acids and mediates the levels of hormones and phenolic substances in the plant body (Beato *et al*., 2010; Zhou *et al*., 2015). This confirms the advanced chlorosis and premature senescence of plants that was observed. The percentage of Boron concentration recovered in the 7^{th} to 9^{th} leaf blades increased linearly from 26.6 ppm to 123 ppm as the concentration of Boron fertilization increased from 0 ppm to 0.4 ppm respectively. Leaf tissue Boron concentration plotted against vine yield and its components showed that maximum growth in leaf area, vine girth, vine length, nodes produced, and accumulation of fresh biomass was achieved at 0.3 ppm Boron fertilization, corresponding to 89.6 ppm Boron leaf tissue accumulation. (O'Sullivan *et al*., 1997) reported a sufficiency range of 50 – 200 ppm measured in the 7^{th} to 9^{th} open leaf blades from the shoot tip. In this study fertilization

of plants with 0.4 ppm resulted in B tissue accumulation of 123 ppm Boron culminating in decreased growth of vine internode, leaf area, petiole length, vine girth, vine length, nodes produced and fresh biomass. This data points out that in sweetpotato, when Boron leaf tissue exceeds 89.6 ppm it becomes toxic to plant, indicating 0.3 ppm is the optimal Boron fertilization in sweetpotato vine production.

This study also identified nutrient deficiency symptoms for the five studied elements (N, P, Ca, S, and B) that can be used to guide sandponics system operations in correcting for nutrient deficiencies (Table 3.9).**Table 3.9: Optimized nutrient media and nutrient deficiency symptoms for sweetpotato pre-basic seed multiplication using sandponics system**

Element	Optimal Application rate (ppm)	Probable source	Nutrient deficiency symptoms
Nitrogen	200	Calcium nitrate, Magnesium nitrate	Stunted plants with minimal expansion of leaf area. Reddening of basal leaf edges advancing to younger leaves.
Phosphorus	60	Calcium triple phosphate	Yellowing of older leaves spreading from discrete interveinal patches affecting half of the blades.
Calcium	200	Calcium nitrate	Chlorosis, curling, cupping and distortion of younger growing apical leaves. Plants exhibit detrimental effects of root rot.
Sulfur	120	Magnesium sulfate	Yellowing of middle growing leaves succeeded with entire yellowing of the whole plant.
Boron	0.3	Microsol B	Chlorosis in the apical leaves spreading to the basal foliage in the later stages of growth. Necrosis in the symptomatic leaves at advanced stage of vine growth, death of severely affected leaves, apical buds eventually leading to premature.

3.5 Conclusions and recommendations

3.5.1 Conclusions

i. Optimal nutrient concentrations for sweetpotato pre-basic seed multiplication in sandponics are 200, 60, 200, 120, and 0.3 ppm of N, P, Ca, S, and B respectively.

3.5.2 Recommendations

i. Although, this optimized nutrient media has been formulated using cultivar 'Kabode' it could easily be extended for multiplying other sweetpotato varieties with some slight modifications. A follow up study is recommended to adapt the nutrient media for other sweetpotato varieties.

ii. Sandponics system is a promising technology for breaking the limited supply of pre-basic seed in sweetpotato cropping systems. It is vital to optimize critical factors to maximize vine production in sandponics system. Other results have indicated that despite 33% increase in vine multiplication rate in sandponics system, pre-basic seed production by the conventional soil substrate method was still more cost-effective. Therefore, a follow up study to compare the cost-effectiveness of the two substrates using this optimized sandponics system media is recommended.

CHAPTER FOUR

COMPARATIVE ANALYSIS FOR PRODUCTION OF SWEETPOTATO PRE-BASIC SEED USING SANDPONICS SYSTEM AND CONVENTIONAL SOIL SUBSTRATE METHOD

ABSTRACT

A sustainable seed system for sweetpotato crop will fulfil critical roles of ensuring the timely provision of planting material of appropriate quality for smallholders, efficient dissemination of new improved varieties from breeding programs and the provision of replacement planting material following natural disasters or in times of crisis or unrest. However, in Sub-Saharan African countries, one of the major bottlenecks in the sweetpotato seed system is the multiplication of sufficient pre-basic seed to be passed on to subsequent bulking stages by Decentralized Vine Multipliers. Currently, the dominant "conventional soil substrate method" practice is for pre-basic seed to be multiplied in the screenhouses using pots or boxes with a sterilized soil substrate. With the banning of the chemical methyl bromate, sterilizing soil has now to be done with heat. The use of sand substrate with a fertigation system also referred to as 'sandponics system' has been proposed to be an alternative to the conventional soil substrate method for sweetpotato pre-basic seed generation but its cost-effectiveness compared to the conventional soil substrate method approach is unknown. A study was conducted at Kenya Plant Health Inspectorate Service – Plant Quarantine and Biosecurity Station (KEPHIS-PQBS), Muguga, Kenya to determine the cost-effectiveness of sweetpotato pre-basic seed generation in the two distinct vine propagation systems. The experiment was laid down following a randomized complete block design in split plot. Hardened virus indexed cuttings of 20 – 30 cm for genotypes Irene, Ejumula, Kabode and Gweri were planted in 3 litre pots filled with sterilized sand and soil and subjected to fertigation (sandponics system) and irrigation (conventional soil substrate) during the growing season. Optimized nutrient media was used for fertigation in the sandponics system. Vine harvesting was done at 42-day intervals for the entire crop calendar of 9 months. Data from the experiment showed a significant ($p<.0001$) increase in the vine multiplication rate (VMR) in the sandponics system by 21.8% compared to the conventional soil substrate method. The cost of producing one sweetpotato node in sandponics system was significantly ($p<.0001$) lower by 0.9 KSH (US$ 0.009) compared to conventional soil substrate method. The cost-effectiveness of producing pre-basic seed in a sandponics system varied among the genotypes, with Ejumula being the most cost-effective genotype to produce in the sandponics system. The cost of producing one node of Ejumula significantly ($p<.0001$) reduces by 1.2 KSH (US$ 0.012) when compared to the cost of producing a similar node using conventional soil substrate method. These results indicated that sandponics system was cost-effective compared with the conventional soil substrate method. The reasons for this include: cost of inputs (substrate; sand) were cheaper compared to the conventional soil substrate and (ii) the VMR was higher in the sandponics system compared to the conventional soil substrate method.

4.1 Introduction

Sweetpotato (*Ipomoea batatas* (L.) Lam.) is an important crop in Sub-Saharan Africa (SSA). It plays a critical role as an income and food security crop for many households (Amajor *et al*., 2014; Byju and George, 2005; Lebot, 2008; Motsa *et al*., 2015). Other advantages of sweetpotato are: flexible planting dates, a short maturity period (3-4 months), suitable for distribution as part of post conflict and disaster relief programs, it requires minimum inputs and can be grown on infertile soils where grain crops may fail, once established it is drought tolerant and many varieties have potential for piece meal harvesting over an extended period of time (Carey, *et al*., 1996; Ndolo *et al*., 2001). The crop has a high root yield potential of 20-50 t ha^{-1} (Kivuva *et al*., 2014). However, this yield potential is not realized in SSA, where productivity is less than 10 t ha^{-1} (FAOSTAT, 2017). Assessment of sweetpotato production constraints in SSA shows that limited access to disease-free planting materials and improved varieties are the major factors contributing to low yields (Andrade *et al*., 2009; Gibson *et al*., 2009; Gibson *et al*., 2011b). These findings underline that a sustainable seed system is vital in improving sweetpotato productivity in SSA, as has been demonstrated in Shandong province, China (Fuglie *et al*., 1999). A functional sweetpotato seed system should provide timely and affordable access for different types of farmers to adequate quantities of quality planting material of preferred varieties (Gibson *et al*., 2009). However, in SSA, a major bottleneck in the sweetpotato seed system has been the availability of sufficient quantities of pre-basic seed to supply commercial sweetpotato seed producers. Currently, the dominant practice is for pre-basic seed to be multiplied in screenhouses in pots or boxes using a sterilized soil substrate. The use of sterilized soil is expensive, unsustainable, and may not achieve optimal vine multiplication rates (VMR) (Wanjala, W.B., Rajendran, S.,

Makokha, P., Ssali, R.T., McEwan, M., Kreuze, J.F., and Low, J.W. 2019, unpublished).

In the past, methyl bromate was used to sterilize soil, however this has been banned and the alternative of sterilizing soil using steam is very costly. The use of sand substrate with a fertigation system, also referred to as "sandponics" has been proposed as an alternative to the conventional soil, manure, gravel substrate mix ("conventional soil substrate type") used in screenhouse production. Previous work has optimized the nutrient media for sweetpotato vine multiplication using the sandponics system (Makokha *et al*., 2018). However, the cost effectiveness of using the sandponics system compared to the conventional soil substrate method has not been established. Wanjala, W.B., Srinivasulu, R., Makokha, P., Ssali, R.T., McEwan, M., Kreuze, J.F., and Low, J. (2019, unpublished) found that although the use of a sandponics system and trellising increased the VMR by 33%, use of the conventional soil substrate was still more cost effective. However, that experiment was based on the results for two vine harvests and therefore the optimal production period may not have been reached. Therefore, this study was conducted to compare the use of a sandponics system with an optimized nutrient media formula with the conventional soil substrate to establish which method was more cost effective.

4.2 Materials and methods

4.2.1 Experimental site

A screenhouse experiment was conducted between July 2018 – March 2019 at the Kenya Plant Health Inspectorate Service – Plant Quarantine and Biosecurity Station (KEPHIS-PQBS) Muguga, Kenya, located at 1° 11' 0" South, 36° 39' 0" East at an altitude of about 1950 m above sea level.

4.2.2 Sand and soil substrate sterilization

Sand was sterilized by sifting using a screen, soaked in 10% NaOCl, rinsed 3 times with running tap water and dried on a raised rack for two days to allow NaOCl residues to evaporate (Otazu, 2010; Mbiri *et al*., 2015). Soil substrate was composed of top forest soil, cow manure and gravel in the ratio of 5:2:1 was sterilized by steaming for 30 min using a steam boiler at 82^{o}C with diesel as source of energy.

4.2.3 Preparation of nutrient media and substrate

Samples of irrigation water, sterilized sand and soil substrates were taken to Crop Nutrition Laboratories, Nairobi, Kenya for analysis before the experiment started. The pH of the sand substrate was 6.8 but the nutrient elements were below detectable levels. The chemical and physical properties of the soil substrate are indicated in Table 4.1. The laboratory water analysis report (Table 4.2) was used to adjust the nutrient concentrations in the optimized sweetpotato pre-basic seed multiplication media (Table 3.9) and optimal nutrient media worked out from fertilizer formulations (Table 4.3). Optimization of sandponics system nutrient media was limited to N, P, Ca, S and B which are the key elements reported to favor sweetpotato vine growth (Taraken *et al*., 2010; Makokha *et al*., 2018) and potassium was deliberately omitted given that its role in the growth of sweetpotato comes in later, at least seven weeks after planting (Bourke, 1985; Taraken *et al*., 2010).The pH of the final solution was adjusted to 5.8 using HI98107 pH meter (Hanna Instruments Ltd, UK) by adding 5 mL of 0.1 M phosphoric acid.

Table 4.1: Chemical and physical properties of sterilized soil substrate sampled from screenhouse pots at KEPHIS-PQBS, Muguga, Kenya (July 2018) prior to planting of sweetpotato pre-basic seed under conventional soil substrate

Parameter	Unit	Result	Description*
Sampling depth	m	0.3	
pH (H_2O)		7.52	High
EC (salts)	uS/cm	1250	High
Phosphorus (Olsen)	**(ppm)**	**28.6**	**Low**
Potassium	**ppm**	**2060**	**Low**
Calcium	**ppm**	**3780**	**Low**
Magnesium	ppm	547	Low
Sulfur	**ppm**	**106**	**Low**
Iron	ppm	77.5	Optimum
Manganese	ppm	318	Optimum
Boron	**ppm**	**2.16**	**Low**
Copper	ppm	1.35	Low
Zinc	ppm	16.5	Optimum
C.E.C	Mq/100q	31.4	High
Total N	**%**	**0.21**	**Low**
Organic matter	%	5.83	Optimum
C/N ratio		16.1	Optimum

* Recommendations based on O'Sullivan *et al*., 1997

Table 4.2: Water source from KEPHIS-PQBS, Muguga Kenya, its composition and nutrient adjustment for sweetpotato pre-basic seed nutrient media in sandponics system (2018 – 2019)

	N (ppm)	P (ppm)	Ca (ppm)	S (ppm)	B (ppm)
Water	0.91	0.059	4.29	1.86	<0.01
Makokha *et al*. (2018)	200	60	200	120	0.3
Adjustment	199.1	59.9	195.71	118.1	-

Table 4.3: Workings for nutrient media concentrations for sweetpotato pre-basic seed multiplication in sandponics system at KEPHIS-PQBS, Muguga, Kenya (2018 – 2019)

Element	Source	Concentration and weight (g) in 1000 L
Calcium	Calcium nitrate (15.5%N, 19%Ca)	195.71 Ca = 1030.05 g of Ca $(NO_3)_2$ which also comes with 159.66 ppm N leaving N still needed = 199.1 – 159.66 = 39.44 ppm
Nitrogen	Magnesium nitrate 10%Mg, 10%N) and Calcium nitrate	39.44 ppm of N = 394.3 g of Mg $(NO3)_2$
Phosphorus	Calcium triple super phosphate (46%P_2O_5)	59.9 ppm of P = 298.5 g of TSP
Sulfur	Magnesium sulfate (26.3%S)	118.1 ppm = 449.2 g of $MgSO_4$
Boron	Microsol B (2.5%B)	Microsol B (2.5%B)

4.2.4 Experimental design and trial establishment

The experiment was subjected to a randomized complete block split plot design (RCBSPD) with repeated measures. Two substrate types were used for the study i.e., sand substrate and conventional soil media. Each treatment combination (substrate type × variety) was replicated five times in four blocks. The substrate type was a whole plot factor while each variety was a sub-plot factor. Genotypes Irene, Kabode, Ejumula and Gweri were used in the study selected based on their growth morphology (Table 4.4) as erect, semi-erect, spreading and extremely spreading, respectively (Huamán, 1991; Tumwegamire *et al*., 2014).

Plastic pots measuring 18 cm diameter and 20 cm slanting height were filled with 5.5 kg and 4.0 kg of sterilized sand or sterilized soil media, respectively. Planting material of the four sweetpotato genotypes were obtained by taking three-node cuttings from hardened pathogen tested plants maintained at KEPHIS-PQBS,

Muguga, Kenya. Prior to planting, pots were irrigated and fertigated in the conventional soil substrate method and sandponics system, respectively, to moisten the substrates and avoid injuring cuttings during planting. Irrigation water and fertigation nutrient media was supplied from elevated tanks connected to drip lines in the sandponics system and conventional soil substrate. Manual valves allowed the distribution of water and nutrients by gravity through surface pipes and drippers.

Ten plants were planted per pot approximately 3 cm apart from each other with two nodes buried in the substrate and one node above the surface. Three grams of diammonium phosphate (18:46:0) was applied per pot at planting in the conventional soil substrate.

Table 4.4: Sweetpotato vine morphological traits for genotypes Irene, Kabode, Ejumula and Gweri used in the trial during pre-basic seed multiplication using sandponics system and conventional soil substrate method at KEPHIS-PQBS, Muguga, Kenya (2018 – 2019)

	Growth morphology				
Genotype	**Canopy or plant type**	**Leaf**	**Vine**	**Flowering ability and habits**	**Sprouting ability**
Irene	Erect (<75 cm)	Green when mature, light green and purple edges when young, purple veins at top and under surfaces; with 5 deep lobes	Purple mature sections and green meristem tops, short (3.5-5.0 cm) internodes, thin (4-6 mm) diameter	Late and sparse	Prolific sprouting
Kabode	Non-twining and semi-erect (<150 cm)	Green when mature, and slightly purple when young, 7 moderate deep lobes	Green, with purple tip, short (3-5 cm) internodes, thin (<4 mm) diameter	Late and sparse	Prolific sprouting
Ejumula	Spreading (<250 cm vine length)	Green when mature, 3-4 moderately deep lobes	Green, short (3-5 cm) vine internodes, intermediate (7-9 mm) diameter	Late and sparse	Weak sprouting
Gweri	Extremely spreading (>250 cm vine length)	Green when young and mature, with light purple midrib at the back; heart shaped single lobes	Light green when mature, green when young, very short (<3 cm) internodes, thick (7-9 mm) diameter	Does not flower at high altitudes	

4.2.5 Crop management practices

Subsequent irrigation (conventional soil substrate) and fertigation (sandponics system) were guided by Irrometer SR 12" (Irrometer Company Inc., CA, USA). Leaching of nutrients following two fertigation was done as described by (Chen, 2013) to avoid accumulation of salts to toxic levels in the sandponics system. Heat controllers, sensors and cooling air extract fans maintained a mean temperature range of 26 ± 4 °C which is optimal for sweetpotato vine growth (Chen, 2013) and this was monitored by HOBO U12-013 data logger (Onset Computer Corp., Bourne, MA, USA). For the conventional soil substrate method, Calcium ammonium nitrate (27% N) fertilizer was applied two weeks after each harvest at the rate of three grams per pot.

The vines were harvested six times at 42-day intervals, therefore, over the nine-month crop calendar, one vine harvest and five ratoons (subsequent grow outs) were carried out. The number of harvests was based on findings from earlier studies using a trellising technique and sandponics system (Wanjala, W.B., Srinivasulu, R., Makokha, P., Ssali, R.T., McEwan, M., Kreuze, J.F., and Low, J. 2019, unpublished) where after two harvests the VMR had increased by 33% in the sandponics system compared to the conventional soil substrate method, but the latter conventional soil substrate was more cost effective. At harvest, 20 – 30 cm cuttings with at least three nodes were harvested starting from the vine tip and leaving two nodes above the surface for regrowth. At 42, 84, 126 and 210 days after planting (DAP) plants for all four genotypes in the two distinct substrates were randomly sampled. From each sampled plant, leaves were selected from the 7^{th} to 9^{th} open leaf blades from the shoot tip, and samples from the same genotype and substrate system bulked as one composite sample for analysis (O'Sullivan *et al.*, 1997). Analysis was conducted for

key nutrients for deficiency, toxicity and for recommended range of concentration sampled. The leaf tissue analysis was done at Crop Nutrition Laboratories, Nairobi, Kenya.

4.2.6 Data collection

The data collection tools in the experiment were used between June 2018 and March 2019 to capture key agronomic and production cost variables for screenhouse production of sweetpotato pre-basic seed using the two different substrates systems.

i. **Sweetpotato vine yield traits**

The following data on sweetpotato vine morphological and yield traits were collected. Average leaf area was determined by measuring leaf length (L) and width (W) at the widest part of the fifth leaf from the tip of the main stem and the product L × W was used to compute for leaf area (cm^2/plant). Average petiole length was deduced by measuring the point between leaf attachment to the main stem and the leaf, and the average vine internode length. The measurements for leaf area, petiole and vine internode length were done on the fifth leaf from the tip of the main stem. Data on average vine length were determined by measuring the main stem length from the surface of the substrate in the pot to the tip. All the aforementioned measurements were done using a meter ruler on 50% plant population per pot at each harvest.

Also, at harvest, the total number of nodes on all vines per pot were counted and recorded. Vine multiplication rates in the two different substrate methods were calculated by dividing the total number of nodes produced by three (a three-node cutting constitutes a unit of planting material) which is the ideal “seed” for sweetpotato. Harvested vines from each pot were also weighed using an electronic digital LCD scale SF–400 (5 kg) and total fresh weight determined.

ii. **Cost data**

For the cost data, the study hypothesized that in a respresentative production period, the production cost per node in the sandponics system would be lower than in the conventional soil substrate method. The hypothesis was tested using cost effectiveness or least-cost combination method. This method is part of constant effect method and is normally used in low income settings to deal with intangible benefits. The intangible benefits were determined on a present worth basis and the least expensive alternative combination of tangible costs that would realize the same intangible benefits (Gittinger, 1985). The cost effectiveness analysis was used to identify the most cost effective substrate method to produce sweetpotato pre-basic seed. Since the study was based on experimental basis, the study collected cost data in the sandponics system and conventional soil substrate vine propagation methods based on real-time basis.

The production cost calculation in the experiment was carried out over a crop calendar period of nine months and hence the cost estimates were restricted to activities carried out during this period. The following procedure was used to gather information on costs for the two different substrate methods; (i) selection of team members who were directly involved in the production activities, (ii) preparation of the crop calendar, (iii) mapping out operational activities and inputs, and (iv) mapping out costs information and share of allocation of inputs. Data collection questionnaires were prepared as micro-log and macro-log sheets. The input cost template and labor cost template micro-log sheets (Appendix II and Appendix III, respectively) are daily record sheets which monitor daily amounts of input usage and activities in the experiment for each laborer in that order. After data were recorded in the micro-log sheet for each laborer, the information was then transferred to the input template and labor cost template macro-log sheets (Appendix IV and Appendix V, respectively)

and later transferred to the cost calculation sheet developed in MS office excel program (Appendix VI). The data for each production activity in the sandponics system and conventional soil substrate method were collected and reported separately using the micro and macro-log sheets.

The costs were classified into variable and fixed costs. Variable costs included labor, inputs and consumable costs. The cost of labor was estimated based on the daily wage rate and the number of man-days used by each laborer for each production activity. The input costs were calculated using data on the quantity and prices of inputs used. Finally, the costs for consumables were also included as part of variable costs. Fixed costs are defined as those costs that occur regardless of quantity produced. The team identified the types of equipment that were used for producing sweetpotato pre-basic seed during the experimental period. Once each type of equipment was identified, the team identified the life (years) of the equipment and the fixed cost was estimated by adding-up depreciation, interest on average investment and insurance and taxes. Summing both variable and fixed costs, the total cost of production was then estimated. In addition to total production costs, 10% overhead was included for both substrate methods to consider costs for water and electricity, which were paid directly by the government institution. The study also monitored pre and post-harvest losses which were then accounted for in the total costs. The study estimated the cost of producing sterilized sand and soil substrate separately and included these into the cost calculations for the sandponics system and conventional soil substrate, respectively. The detailed fixed, variable costs and consumables used to calculate the total cost of production in the two substrate methods are as shown in Appendix VI. The cost of producing sterilized sand is shown in Appendix VII. The cost of sand per kilogram is inclusive of transport cost. Since sand was readily

available close by, the cost of sand per kilogram is relatively lower. The sterilized soil was bought from KEPHIS-PQBS, Muguga, Kenya, so, this price was used in the cost estimation (i.e., US$ 0.20 or KSH 20.0 per kg). The exchange rate for converting Kenyan shillings (KSH) into US dollar (US$) was 1 US$ equivalent to 100 KSH.

4.2.7 Data analysis

Statistical analyses for the agronomic data on vine yield and traits were conducted using SAS 9.4 version (SAS Institute Inc., 2013) and Stata version 14.1 (STATA 14.1 version, 2015). Data for the two substrate methods were analyzed using the proc t-test to compare vine productivity in the sandponics system and the conventional soil substrate method. The effects of treatments on varietal response and their interactions were evaluated at $p \leq 0.05$ using the general linear model procedure.

Statistical model was as shown below;

$$Y(ij) = f'(W_i, S_{ij})\beta + \gamma_i + E_{ij}$$

where W = whole plot factor, S = sub plot factor, γ = whole plot effect, E = random error, i = block effect, j = runs within the block and ij = j^{th} response in the i^{th} block.

Node data for vine production were fitted into a model:

$$Y(ijkl) = var_i + sub_j + REP_k + (var \times sub)_{ij} + (var \times REP)_{ik} + (sub \times REP)_{jk} + Ei_{jkl}$$

where Y = the number of nodes, var = sweetpotato varieties, sub = substrate (sandponics system and conventional soil substrate method), REP = replication (1,2,3,4,5), E = errors generated in repeated measures. Among them, effects written by lower case letters are fixed effects, and effects written by upper case letters are random effects.

A detailed cost effectiveness analysis was conducted for the two methods of sweetpotato vine production based on all relevant indicators as described by Mateus-

Rodriguez *et al*. (2013). Total production cost (TPC, Kenyan Shillings (KSH) per crop calendar) involved fixed and variable costs (Table S8). These costs were considered for the production cycle (nine months) and amortized over the same period. It was assumed that all pots in the system received an equal share of the inputs required under each substrate method, therefore, to calculate the cost of production per pot (C, KSH per pot) in each substrate method, the total cost of production (TPC, KSH per substrate method) for each system was divided by the total number of pots in each system to get average cost of production per pot. The average cost per node (C, KSH per node) was then determined using the formula C = Cost per pot/Q, where Q is the total quantity of nodes produced per pot. The continuous variable 'cost per node' was then subjected to statistical analysis using SAS 9.4 version (SAS Institute Inc., 2013) to compare the cost effectiveness of producing one node for the four genotypes in the two substrate methods using the t-test procedure. A one-way analysis-of-variance (ANOVA) model was performed and multiple comparison tests were also conducted. Further, we also used Bartlett's test for equal variance to understand homogeneity in the variances as ANOVA assumes that the variances are homogenous. Since the distribution curve for the production cost per node may have a different shape and may not be identical, the study also used Kruskal-Wallis H test to compare the mean value of cost per node in the two substrate systems. The labour intensity could not be measured using the current experimental design due to lack of information on the amount of labor required to cultivate one hectare of a specific crop. As a proxy for labour intensity, the study estimated the ratio of the cost of labor as a proportion of the total cost of producing a good. The higher the ratio, the higher the labor intensity. The cost per square meter was also estimated by dividing total costs by area size to understand efficiency of resource use per square meter. The

screenhouse total area was 32 m^2 and each substrate method used half of the area with 80 observations (pots) for each substrate method.

4.3 Results

4.3.1. The effect of substrate type, genotype and interaction of genotype and substrate type on sweetpotato vine morphological and yield traits

The Analysis of Variance (ANOVA) in Table 1 shows that the variation attributable to the substrate method (sandponics system and conventional soil substrate) was significant ($p<.0001$) for the following vine yield characteristics: VMR, number of cuttings per vine and biomass. Morphological traits of petiole length and the vine length were not significantly different (Appendix VIII) and therefore are not discussed. However, the substrate method significantly affected vine internode length ($p\leq0.01$) and leaf area ($p\leq0.05$) (Appendix VIII). Table 4.5 shows that the means of vine internode length and leaf area were 2.5 / 2.7 cm and 53.4 / 56.1 cm^2 for the sandponics system and conventional soil substrate method, respectively, in which the conventional soil substrate produced significantly increased growth in the vine internode and leaf area compared to the sandponics system. Table 4.5 shows that there was also a significant increase in the means of: VMR, number of cuttings per vine and biomass in the sandponics system (204.2; 13.6 and 121.6 g) compared to the conventional soil substrate method (163.7; 11.2 and 90.0 g).

The ANOVA also indicates that the genotypes varied significantly ($p<.0001$) for vine internode length, leaf area, petiole length and vine length but the significant variations in the vine internode length between the two substrate methods (Table 4.6) were only exhibited by genotypes Irene and Kabode ($p=0.005$ and $p=0.003$, respectively). Among the four genotypes, only the genotype Irene showed significant variation in the leaf area between the two substrate methods at $p=0.02$ (Table 4.6). In general,

genotype Irene recorded the highest mean for vine internode length (3.3 cm) and vine length (25.3 cm) compared to the other three genotypes (Table 4.5). Genotype Gweri had the highest mean for the leaf area (63.7 cm^2) while genotype Irene recorded the lowest leaf area (49.3 cm^2). Genotypes Ejumula and Gweri had the highest means for petiole length which were 12.9 cm and 12.6 cm, in that order (Table 4.5). Significant variations were also observed between genotypes for vine yield traits such as number of vines harvested, VMR, number of three-node cuttings per vine, and biomass at $p<.0001$ (Appendix VIII). Considering vine yield traits (Table 4.5), genotype Irene had the highest mean VMR (252.2) for the nine month period, number of vines harvested (20.4 vines per pot) followed by genotypes Kabode and Gweri which recorded 12.7 and 12.2 vines per pot, respectively. Genotypes Gweri, Kabode and Irene recorded the highest means for number of cuttings per vine (12.9; 12.9 and 12.8, in that order), subsequently, genotypes Kabode, Irene and Gweri also had the highest means for biomass (109.8 g; 108.6 g and 105.5 g, respectively).

Table 4.5: Means of morphological and yield characteristics of vines for four sweetpotato genotypes produced using sandponics system and conventional soil substrate at KEPHIS-PQBS, Muguga, Kenya (2018 – 2019)

Vine morphological traits	Substrate type	Genotype				Mean*
		Irene	Kabode	Ejumula	Gweri	
Vine internode length (cm)	Sandponics system	3.1	2.1	2.6	2.1	2.5b
	Conventional soil substrate	3.5	2.4	2.6	2.2	2.7a
	Mean*	3.3a	2.2c	2.6b	2.1c	Mean*
Leaf area (cm^2)	Sandponics system	47.1	53.8	49.9	62.8	53.4b
	Conventional soil substrate	51.5	56.3	52.0	64.7	56.1a
	Mean*	49.3c	55.1b	50.9c	63.7a	
Petiole length (cm)	Mean*	10.7c	11.9b	12.9a	12.6a	
Vine length (cm)	Mean*	25.3a	17.8c	20.2b	16.9c	
Vine yield traits						
Number of plants harvested	Mean*	20.4a	12.7c	16.8b	12.2c	
Vine multiplication rate	Sandponics system	282.2	172.4	206.5	155.6	204.2a
	Conventional soil substrate	222.2	139.4	155.6	137.6	163.7b
	Mean*	252.2A	155.9c	181.1b	146.6c	
Number of cuttings per vine	Sandponics system	13.7	13.1	12.1	15.5	13.6a
	Conventional soil substrate	12.0	12.7	9.9	10.2	11.2b
	Mean*	12.8a	12.9a	11.0b	12.9a	
Biomass (g)	Sandponics system	127.0	125.2	115.9	118.3	121.6a
	Conventional soil substrate	90.2	94.4	82.9	92.6	90.0b
	Mean*	108.6a	109.8a	99.4b	105.5a	

*: different letters within and across the column indicate means differed at the $p \leq 0.05$ level

The interaction between genotype and substrate type was significant for vine yield traits for number of vines harvested ($p \leq 0.01$), VMR ($p < .0001$) and number of cuttings per vine ($p \leq 0.01$). A detailed comparison of sweetpotato vine morphological and

yield traits for the four genotypes in sandponics system and conventional soil substrate using a t-test is shown in Table 4.6. In general, the increase in VMR, number of cuttings per vine and vine weight per pot was significant ($p<0.0001$) for all the four genotypes in the sandponics system when compared to the conventional soil substrate type (Table 4.6).

Table 4.6: Comparing sweetpotato pre-basic seed production of four genotypes under sandponics system and conventional soil substrate using a t-test for 9-month crop calendar at KEPHIS-PQBS, Muguga, Kenya (2018 – 2019)

Variety yield traits	Variety	Sandponics system	Conventional soil substrate	t	p
Vine Internode length (cm)	Irene	3.1±0.2	3.5±0.2	-3.0	0.005
	Kabode	2.0±0.1	2.4±0.2	-3.4	0.003
	Ejumula	2.6±0.2	2.6±0.2	-0.2	0.9
	Gweri	2.1±0.2	2.2±0.2	-0.2	0.9
Leaf area (cm^2)	Irene	47.1±2.3	51.5±2.8	-2.5	0.02
	Kabode	53.8±3.4	56.3±2.9	-1.1	0.3
	Ejumula	49.9±2.9	52.0±2.8	-1.0	0.3
	Gweri	62.8±3.4	64.7±4.7	-0.6	0.5
Vine multiplication rate	Irene	282.2±19.5	222.2±12.4	5.2	<.0001
	Kabode	172.4±8.2	139.4±7.8	5.8	<.0001
	Ejumula	206.5±8.0	155.6±7.5	9.3	<.0001
	Gweri	155.6±7.0	137.6±6.6	3.7	0.0006
Number of cuttings per vine	Irene	13.7±1.2	12.0±1.0	2.2	0.03
	Kabode	13.1±1.4	12.7±1.4	0.4	0.7
	Ejumula	12.1±0.7	9.9±0.8	4.0	0.0003
	Gweri	15.5±1.4	10.2±0.7	6.7	<.0001
Vine weight per pot/g	Irene	127.0±4.1	90.2±6.4	9.7	<.0001
	Kabode	125.2±4.3	94.4±3.8	10.7	<.0001
	Ejumula	115.9±4.5	82.9±3.9	11.0	<.0001
	Gweri	118.3±3.2	92.6±4.4	9.5	<.0001

4.3.2 The effect of ratooning on sweetpotato vine morphological and yield traits

The ANOVA (Appendix IX) further showed that: the effect of ratooning; interaction of variety and ratooning; and combination of substrate type and ratooning on VMR

were significant at p<.0001. Moreover, the effect of interaction between variety × substrate type × ratooning on VMR was also significant at p=0.05.

Pairwise comparison by Dunnett test of the five ratoons (84, 126, 168, 210, and 252 days) after planting (DAP) compared to the first harvest (42 DAP) as the control showed that the highest significant difference was between 252 DAP and 42 DAP (Table 4.7) indicating that there was significant increase in VMR in the later stages of vine propagation when using ratooning technique.

Also, results showed that interaction of sandponics system × ratooning resulted to significantly increased VMR by 21.8% compared to the conventional system (Table 4.8). Among the four genotypes, Irene was the most advantageous genotype for ratooning while Kabode the least (Table 4.7). There was a significant increase in VMR across the six harvests in the two substrate types, however, VMR was higher by 21.8% in favor of the sandponics system (Table 4.8)

Table 4.7: Pairwise multiple comparison of sweetpotato vine multiplication rate due to interaction between genotype and ratooning under sandponics system and conventional soil substrate during pre-basic seed production at KEPHIS-PQBS, Muguga, Kenya (2018 – 2019

Comparison of harvest 6th , 5th , 4th , 3rd & 2nd to the 1st harvest done at 42-day intervals	VMR (difference between means)			
	Irene	Ejumula	Kabode	Gweri
252-42	19.3*	10.7*	5.3*	5.9*
210-42	16.2*	4.8*	1.0	1.8
168-42	8.7*	-1.8	-3.3	-1.1
126-42	9.5*	0.7	-0.7	2.1
84-42	-3.6	-2.3	-4.9*	-3.4

*Significant at 0.05 level of probability confidence according to Dunnett test.

Table 4.8: Comparison of sweetpotato pre-basic seed production under sandponics system and conventional soil substrate over six harvests at KEPHIS-PQBS, Muguga, Kenya (2018 – 2019)

Days after planting	Vine multiplication rate		t	p
	Sandponics system	Conventional soil substrate method		
42	27.6±1.2	28.3±1.3	-0.8	0.4
84	28.2±1.6	20.7±1.2	7.5	<.0001
126	35.9±2.4	25.7±1.7	6.9	<.0001
168	34.8±2.6	22.4±1.8	7.8	<.0001
210	36.3±3.1	31.6±2.3	2.4	0.02
252	41.4±3.3	35.1±2.4	3.1	0.002
Average	**34.0±1.1**	**27.3±0.9**	**9.6**	**<.0001**

4.3.3 The effect of substrate type on leaf tissue nutrient accumulation

The findings on nutrient analysis of leaf samples from plants growing under both the sandponics system and the conventional soil substrate showed that the mean nutrient concentration for five elements (N, P, Ca, S, and B) was within the recommended range for vine propagation; but that the concentrations were significantly higher ($(p\leq0.05)$ for samples from the sandponics system for all the above nutrients, with the exception of Potassium and Sulphur (Table 4.9). Higher levels of potassium were

extracted from leaves sampled from conventional soil substrate production method compared to the sandponics system (3.7% / 0.7%, in that order).

Table 4.9: Means of sweetpotato leaf tissue nutrient analysis for composite leaf samples from the sandponics system and conventional soil substrate during pre-basic seed production at KEPHIS-PQBS, Muguga, Kenya (2018 – 2019)

Substrate type	Mean leaf tissue nutrient concentration					
	N (%)	P (%)	K (%)	Ca (%)	S (%)	B (ppm)
Sandponics system	4.9a	0.6a	0.7b	2.4a	0.3a	82.3a
Conventional soil substrate method	4.1b	0.4b	3.7a	1.7b	0.3a	50.7b

Different letters within the same column denote significant differences at $p \leq 0.05$

4.3.4 Cost-effectiveness analysis

The cost effectiveness analysis results (Table 4.10) indicated that the cost per node produced from sandponics system was 3.5 KSH (US$ 0.035) as compared to 4.4 KSH (US$ 0.04) per node produced from conventional soil substrate method. Therefore, the cost of producing one sweetpotato node in sandponics was significantly ($p<.0001$) lower by 0.9 KSH (US$ 0.009), (22.7%) compared to conventional soil substrate system. To validate these results, the study also conducted regression analysis (Appendix X) to understand the causation of each substrate method on cost per node by genotype. The results also validated one-way ANOVA results with strong causation effects and overall fitness of the estimated models through R^2. The study conducted Bartlett's test and the results were insignificant which means we cannot reject the assumption that the variances are homogenous and hence data were normally distributed.

Table 4.10: Average cost (KSH) of producing one sweetpotato node at KEPHIS-PQBS, Muguga, Kenya (2018 – 2019) in sandponics system compared with conventional soil substrate method after 6 harvests for four genotypes and test of equality using one way test

Genotype	Sandponics system	Conventional soil substrate method	Difference	p value	Bartlett's test	Kruskal-Wallis equality-of-populations rank test
Irene	2.4	3.1	-0.7	<.0001**	0.845	-
Kabode	3.9	5.0	-1.0	<.0001**	0.299	-
Ejumula	3.3	4.5	-1.1	<.0001**	0.020**	0.0001**
Gweri	4.4	5.0	-0.7	0.0002**	0.175	-
Overall (all genotypes)	**3.513**	**4.413**	**-0.9**	**<.0001****	**0.331**	**<.0001**

[1] Exchange rate 1 US$ = 100 KSH in year 2019; *, ** indicates 5% & 1% level significant respectively

Further, the one-way analysis of variance and regression analysis were conducted within genotypes as well. The results showed that among the four genotypes, Ejumula was the most cost effective to produce in the sandponics system compared to the other three genotypes. The cost of producing one node of Ejumula in sandponics system was significantly ($p<.0001$) lower by 1.2 KSH (US$ 0.012) compared to the conventional soil substrate method. Therefore, for each node of Ejumula produced in the sandponics system, 1.2 KSH (US$ 0.012) is saved compared to the conventional soil substrate method. The Bartlett's test for Ejumula showed that the results are significant which means we reject the assumption that the variance are homogeneous and hence data were not normally distributed. We then conducted non parametric tests (by Kruskal-Wallis H test using STATA 14.1 version) to determine whether this statistical difference is true or not. The ANOVA results showed that the statistical

differences between the two distinct substrate methods are true. A similar approach was also carried for the other three genotypes.

The Bartlett's test was not significant and hence the Kruskal-Wallis H test was not required, and interpretation could be done using the one-way test directly. In sum, sandponics is cost effective compared to the conventional soil substrate method but the use of sandponics system should be validated for specific genotypes.

For example, in our case, it is more advantageous to use the sandponics system to produce pre-basic seed for genotype Ejumula. Genotype Irene was found to have the lowest production cost but the difference in cost per node between the sandponics system and the conventional soil substrate was highest for the genotype Ejumula (i.e., 1.2 KSH or US$ 0.012). Therefore, use of sandponics system was cost effective for the case of genotype Ejumula as compared to other three genotypes and least cost effective for genotype Gweri for which there was a significant ($p<.0001$) reduction in production cost but only of 0.7 KSH (US$ 0.007) per node compared to the conventional soil substrate type. Considering labor intensity, sandponics system is more labor intensive than using the conventional soil substrate (i.e., labor intensity ratio in terms of cost ratio was 0.023 for sandponics system and 0.017 for conventional soil substrate).

4.4 Discussion

4.4.1 The effect of substrate type, genotype and interaction of genotype and substrate type on vine morphological and yield traits

The highly significant ($p<.0001$) 21.8% increase in the VMR under the sandponics system compared to the conventional soil substrate could be attributed to more efficient use of fertilizers and water throughout the vine propagation period. The significant increase in yield (VMR) could be attributed to uninterrupted and optimal

nutrient and water supply in sandponics system (Sardare, 2015; Wahome *et al*., 2011). This could also be the reason why the sandponics system significantly ($p<.0001$) outperformed the conventional soil substrate by 31.6% considering biomass accumulation. Our findings corroborate previous work where sandponics systems have also been used successfully in the production of high quality pre-basic seed potato (Mbiri *et al*., 2015; Mateus-Rodriguez *et al*., 2013; Tessema and Dagne, 2018). Similarly, soil-less production systems for different crops have shown several benefits compared to conventional production systems (Wahome *et al*., 2011). One of the chief merits is that sandponics system produces higher yields (Tessema and Dagne, 2018).

The significant differences in the growth of vine and petiole length were influenced by genotypes as described by (Huamán, 1991) in his studies on descriptors of sweetpotato where Huamán indicated that growth in vine and petiole length are varietal controlled. However, the means in the vine and petiole length could not be a true reflection given that Huaman's measurements were on field grown sweetpotato crop. In the present study genotypes Kabode and Gweri had significantly lower means for the vine internode length recorded as 2.2 cm and 2.1 cm, respectively compared to 3.3 cm for genotype Irene. However, considering the number of nodes produced per vine, the means for genotypes Irene (12.8), Kabode (12.9) and Gweri (12.9) were not significantly different. These data showed that reduction in vine internode length increases VMR and this is a varietal characteristic. Our data further showed that above ground biomass accumulation is also genotype dependent, agreeing with Bhagasari and Ashley (1990) findings.

The increased VMR for the four genotypes was controlled by the increased numbers of stems (stem density) in the subsequent ratoons. For instance, each pot was planted

with 10 cuttings and by the 6th harvest the stem density had significantly increased and was recorded as 20.4, 16.8, 12.7 and 12.2 for genotypes Irene, Ejumula, Kabode and Gweri respectively. However, our data further showed that sprouting ability is genotype dependent, agreeing with Tumwegamire *et al*. (2014).

4.4.2 The effect ratooning on sweetpotato vine morphological and yield traits

The mean VMR was 33.6% higher ($p \leq 0.05$) between the first harvest (42 DAP) and last (252 DAP) harvest. This could be attributed to regrowth of vines from multiple regenerating sprouts following subsequent harvests. Ratoon cropping technique in hydroponically grown pepper (*Capsicum annuum* L.) showed increased marketable fruit yields (Riga, 2013). The increased fruit yields were due to a greater number of stems, 4 to 6 new re-grow stems per plant compared to newly planted plants having from 2 to 3 stems above the first fork. In this study, the 21.8% increase in VMR rates based on the interaction of the sandponics system and ratooning could be as a result of consistent supply of optimal nutrient to the multiple regenerating sprouts throughout the growing season. Ratooning technique has also been used in the production of Amaranthus (*Amaranthus cruentus* L.) which showed the total numbers of leaves and branches of Amaranthus developed was greater, gaining a higher total fresh weight yield, and the total dry weight of various plant parts and resulting in more profit at the optimum commercial stage (Fu, 2008). Our results gave similar findings.

The increased regrowth translated into an increase in stem density and subsequently, VMR in the later ratoons. There seems to be a positive correlation between ratooning and VMR which has implications for the production cost of seed with subsequent ratoons. The increased VMR reduces the unit production cost and thereby possible options for increasing profit margin. This helps seed producers to develop pricing

strategies using different price points for different types of customers which will attract more clients and increase revenue (Rajendran *et al*., 2017). However, the current recommended practice for sweetpotato pre-basic seed production using conventional soil substrate in screenhouses is to only ratoon three times due to concerns about the seed quality. Greater benefits will be realized from using later ratoons. Therefore, subsequent studies should investigate the effect ratooning on seed quality under sandponics system multiplication.

4.4.3 The effect of substrate type on leaf tissue nutrient accumulation among sweetpotato genotypes

The adequate nutrient levels of N, P, Ca, S and B which were within the recommended ranges (O'Sullivan *et al*., 1997) for sweetpotato vine growth in favor of sandponics system could be attributed to continued uninterrupted supply of optimal nutrients to vines during the entire growth cycle. Higher levels of K extracted from leaf index tissues from the conventional soil substrate method was as a result of high K levels in the soil substrate. The deliberate omission of potassium (K) in the optimized sweetpotato sandponics media which resulted in low levels of K in the leaf index tissues seems to have led to an increased number of nodes based on the significant reduction in vine internode length for genotypes Irene and Kabode. The vine internode length for genotypes Irene and Kabode in the sandponics system was 3.1 cm and 2.0 cm, respectively compared to the vines grown in the conventional soil substrate which recorded 3.5 cm and 2.4 cm, respectively. This was attributed to high levels of K (0.21%) in the conventional soil substrate method. This was later reflected in the 3% significantly higher levels of K extracted from leaf samples grown in the conventional soil substrate compared to leaf samples sourced from the sandponics system. The high K-levels contributed to the increased growth in the vine internode

length as well as leaf area size at the expense of number of nodes produced translating into lower VMR in the conventional soil substrate vine production method. The early stage of vine propagation is reported to be less K-demanding than the storage root production stage in mature crops (Taraken *et al*., 2010). Other studies have also shown that the effect of K on the growth of sweetpotato occurred at least 7 weeks after planting (Bourke, 1985; Byju and George, 2005). However, our present data indicates that sweetpotato genotypes differ in K-demand during the early stages of vine propagation as exhibited by genotypes Irene and Kabode which had increased significant growth of vine internode length and leaf area in favor of the conventional soil substrate method in which the soil substrate had higher levels of K compared to the sandponics system . These results corroborate with Byju and George (2005) and Ila'ava (1997) who reported that sweetpotato cultivars differ in their tolerance to low levels of nutrients, indicating that early stages of growth for genotypes Ejumula and Gweri are less K-demanding. These findings further indicated that the growth morphology of sweetpotato genotypes seems to also play key roles in dictating the amount of K uptake, given that genotypes Irene and Kabode exhibit erect and semi-erect growth habit respectively, large amount of K is needed by these genotypes to build cellulose, increase stalk strength and reduce lodging one of the major roles played by K (Byju and George, 2005). Reduced vine internode length 'rosetting' is also often associated with K deficiency (Gerardeaux *et al*., 2010; Hasanuzzaman *et al*., 2018).

4.4.4 Cost-effectiveness analysis

Turning to the analysis of the cost-effectiveness of the sandponics system and the conventional soil substrate, the significant reduction of 0.009 US$ (22.7%) in the unit production cost in the sandponics system was due to the increased VMR which was

21.8% higher compared to the conventional soil substrate although only for selected genotypes. The highly significant ($p<.0001$) reduction in the cost of producing one node of genotype Ejumula by US$ 0.012 which was the most cost effective genotype to produce in sandponics is attributed to its increased VMR in sandponics compared to the conventional soil substrate. These results indicate that sandponics technology is cost effective compared with to the conventional soil substrate for selected genotypes. The increased labor intensity in sandponics is attributed to more labor time required to measure precisely the optimal soluble inorganic fertilizers during nutrient media preparation. However with the optimization of a nutrient media for sweetpotato pre-basic seed multiplication using sandponics system (Makokha *et al*., 2018) development of a pre-mixed soluble inorganic fertilizer will reduce the labor and increase the efficiency of sandponics technology. Although our results have indicated that sandponics technology is cost effective compared to the use of conventional soil substrate, sandponics system can be more effective for specific genotypes rather than all genotypes. The reasons for this include (i) the current nutrient media mix is more suited for some genotypes for example in our case Ejumula, (ii) purchase, transport and sterilization of sand is cheaper (0.035 US$ Kg^{-1}) since it was readily available and the cost involved in sterilizing is low compared to the soil substrate (0.2 US$ Kg^{-1}) cost, (ii) increased VMR in the sandponics compared to the conventional system.

In the principle of economics, a change in technology in the production system will have an impact on demand and supply which influences prices in the market (Gittinger, 1985). For example, when a new technology is discovered in a production system and allows the system to produce at lower costs, this will lead to a larger quantity to be produced at a lower price which will increase the economies of scale and overall revenue will also increase. Thus, sandponics system (new technology)

increases the pre-basic seed production efficiency attributed to an increased VMR compared to the use of conventional soil substrate and provides a lower price to end-users. Research has shown that if pre-basic seed is cheaper (Mbiri *et al*., 2015) then, the production cost for the following certified generations will also be cheaper.

The major impediment to using sandponics system is that soluble inorganic fertilizers are not readily available in some areas of SSA countries, therefore, further studies are required to explore alternative sources of nutrients that are locally available for example manure and compost filtrates.

4.5 Conclusions and recommendations

4.5.1 Conclusion

1. This study found out that sandponics system is a cost-effective technology for pre-basic seed multiplication compared to the use of conventional soil substrate method. However, sandponics system is more-effective for selected genotypes.

4.5.2 Recommendations

i. This study recommends genotype Ejumula the most cost-effective to multiply using sandponics system. However, sandponics system could as well be used to multiply sweetpotato pre-basic seed for other genotypes depending on varietal preferences across regions given that it’s cost-effective compared to the conventional soil substrate.

CHAPTER FIVE

GENERAL DISCUSSION

5.1 Optimal nutrient rates for sweetpotato vine multiplication using sandponics system

The study demonstrated that nutrient media composition is very critical to the multiplication of sweetpotato pre-basic seed using the sandponics system. By sequentially increasing the application rate of Nitrogen, Phosphorus, Calcium, Sulfur and Boron the variations observed in both the vine growth parameters and the accumulation of nutrients in the leaf tissue have been used to identify the optimal application rates for each element in the nutrient media for the sandponics system (Table 3.9). The differences in growth parameters like vine internode length, leaf area, petiole length, vine girth, vine length, nodes produced, and fresh biomass were readily attributed to the application rate of nutrients (Ning *et al*., 2013).

5.1.1 Nitrogen rate

These results have shown that sweetpotato vines consume large amounts of Nitrogen. Chen (2013) reported an adequate range of 100 – 300 ppm of Nitrogen in sweetpotato storage root production in hydroponics. However, in this study, 200 ppm seemed to be the optimal rate given that this rate favored growth of most vegetative growth parameters. Nitrogen has been documented to favor foliage growth in plants (Gojon *et al*., 2017) which was the economic yield in this study. Since sweetpotato is a higher source of proteins (Motsa *et al*., 2015), the crop needs to consume large amounts of Nitrogen necessary for the formation of amino acids (Kraiser *et al*., 2011) and this could be the reason why a higher rate of 200 ppm favored growth of most vine yield traits. Stevens *et al*. (2002) in their studies of crop nutrient deficiencies and toxicities indicated that management of Nitrogen Calcium interaction is vital in achieving

optimal crop yields. They further indicated that a ratio of 1:1 Nitrogen to Calcium harmoniously interacts and favors growth of most plants. This study gave similar results. Accumulation of Nitrogen in the sand substrate occurs with subsequent nutrigation and therefore irrigation of vines with water periodically after two fertigations will be necessary leach the accumulated Nitrogen to avoid build up to toxic levels (Chen, 2013) as well as antagonizing uptake of other nutrients like Calcium and Boron.

5.1.2 Phosphorus rate

Growth modelling studies have shown that Phosphorus plays a key role in the growth of adventitious and lateral roots in sweetpotato (Shen *et al*., 2011) which is the first phase in sweetpotato growth cycle (Somasundaram and Mithra, 2008). This could be the reason attributed to increased uptake of Phosphorus by sweetpotato vines. Phosphorus uptake is influenced by temperature and a deficiency may be induced by cool nutrient solution temperatures (Yan *et al*., 2012). In cool areas where temperatures go below 22^{o}C, it will be necessary to install screenhouses with heaters and HOBO data loggers to monitor and regulate the optimal temperature that favor sweetpotato vine growth (26 ± 4^{o}C) as demonstrated by Chen (2013).

5.1.3 Calcium rate

The 200 ppm Calcium rate which seemed to favor growth for most of the sweetpotato vegetative growth parameters lies within the adequate range reported to be called by most of the formulae (White and Broadley, 2003). This rate (200 ppm Calcium) is also within the adequate ranges as reported by O'Sullivan *et al*. (1997) in their studies of nutrient disorders for sweetpotato. Calcium has been documented to play key roles in the formation of calcium pectate which gives shape to plant organs (Reddy and Reddy, 2004). This could be the reason why it's consumed in large

amounts. Stevens *et al*. (2002) indicated that interaction of Calcium and Nitrogen at 200 ppm and 200 ppm, respectively was synergistic and favored growth of plants. Further studies by Rene *et al*. (2017) showed that uptake of Calcium is antagonized by higher rates of Nitrogen and therefore the ratios of these two nutrients in the nutrient media should be carefully monitored through analysis of sand substrate, water, nutrient solution, and plant tissues.

5.1.4 Sulfur rate

Turning to Sulfur rate, results showed that sweetpotato vines seems to also consume large amounts of Sulfur (120 ppm). Research has demonstrated that sweetpotato is highly rich in proteins (Motsa *et al*. (2015); Loebenstein and Thottappilly, 2009). Sulfur is documented to be one of the key elements involved in the formation enzymes and assist in the formation of plant proteins (Zhang *et al*., 2011) and this explains why sweetpotato is a heavy consumer of Sulfur. It will be important to manage Sulfur rates in the nutrient media for multiplication of sweetpotato vines using sandponics system given that Sulfur combines with Calcium to form Calcium Sulfate which is an insoluble compound (Rene *et al*., 2017).

5.1.5 Boron rate

Boron is regarded as a micro-nutrient and therefore it's consumption by plants is in minimal rates (Ganie *et al*., 2013). However, in this study, Boron seems to be a very important nutrient and led to premature senescence under low critical levels as it was reflected in plants growing in Boron omitted pots. Similar results were reported in cotton (*Gossypium hirsutum*) where premature senescence was observed as a result of Boron deficiency (Li *et al*., 2017). Since high levels of Nitrogen and Calcium antagonize uptake of Boron (Rene *et al*., 2017), nutrient solution media should be monitored periodically to ascertain concentration rates of Nitrogen and Calcium to

ensure they are within adequate ranges that don't inhibit the uptake of Boron by growing vines.

5.1.6. Diagnostic testing procedures in sandponics system

Success with any plant growing system is pegged on considerable degree on the ability to effectively evaluate and diagnose the conditions of the crop at all times particularly for the hydroponics (Jones, 2016). Therefore, to optimize vine yields when using sandponics system, it will be important to get into the habit of routinely analyzing the water source, nutrient solution, growing media (sand), and crop. Interpretations and recommendations based on assay results are designed to assist the grower to avoid crop losses and reduced yields. The following procedures described by Jones (2016) ought to be conducted periodically to ensure vines are continuously supplied with optimal nutrient solution.

i. Water analysis

Water available for making a nutrient solution or for irrigation may not be of sufficient quality (i.e. free from inorganic as well as organic substances) to be suitable for use. The only way to determine what is in the water is to have it assayed. Knowing what is in the water will determine whether it is acceptable with or without treatment and whether adjustments would be required to compensate for constituents that are present. If a sample is to be collected for a laboratory analysis, it is best to contact the laboratory beforehand to obtain their recommended sampling (volume of solution required) procedure.

ii. Nutrient solution analysis

Errors in the preparation of a nutrient solution as well as in the functioning of doses are not uncommon. Hence, do remember to check on the final nutrient concentrations prior to use. Knowing the nutrient composition of the nutrient solution allows for

adjustments in the composition of the nutrient solution to compensate for the "crop effect," not only for the current crop stand but for future ratoon crop as well. Nutrient analysis prior to use increases precision of optimal nutrient rates to ensure good crop growth.

iii. Nutrient analysis of the growth medium (sand)

Nutrient analysis of plant growth medium is an important part of the total evaluation of the nutrient status of the medium-crop system. When coupled with a plant analysis, it allows the grower to determine what nutrient stresses exist and how best to bring them under control. A comprehensive test is more valuable as a means of pinpointing possible nutrient problems than just a determination of the electrical conductivity (EC). A test of the sand substrate measures the accumulation of salts that will significantly affect the nutrient composition of the nutrient solution being fertigated. By knowing what is accumulating in the growth medium, it becomes possible to alter the nutrient solution composition sufficiently to utilize the accumulated elements or to begin to adjust in the nutrient solution formula, with the idea of reducing the rate of accumulation while partially utilizing those elements already present in the medium.

iv. Plant analysis

The objective of a plant or leaf analysis is to monitor the nutrient content of the plant to ensure that all the essential elements are being supplied in sufficient quantity to satisfy the crop requirement, as well as ensure against nutrient imbalances and excesses. Growers can use visual observation to detect for nutrient deficiencies and excesses in growing vines. However, many symptoms of nutrient stress are quite similar and can fool the best-trained grower or advisor. In addition, some stress conditions can be due to the relationship between or among the nutrients and

therefore, may require more than just a minor change in the nutrient solution formula to correct them. For optimal vine yields, the grower should develop a routine of sampling and analysis a week before harvesting (5 weeks after planting). A grower faced with a suspected essential element deficiency or imbalance should verify the suspected insufficiency by means of plant (leaf) analysis. Without an analysis result, a change could be made which would only further aggravate the problem. During sampling the 7^{th} to 9^{th} open leaf blades from the shoot tip should be sampled randomly to form a composite sample for laboratory analysis.

5.2 Comparative agronomic and economic analysis for sweetpotato pre-basic seed multiplication using sandponics and conventional systems

5.2.1 Effect of substrate type on agronomic performance of sweetpotato genotypes

These findings show that sand substrate seems to favor growth of most of vine yield traits compared to the conventional soil substrate. This could be attributed to: efficient use of supplied nutrients in optimal rates without interruption (Sardare, 2015). Sand substrate of coarse texture (recommended for sandponics) is well aerated and thus allows easy percolation of nutrients as well as roots enabling vines to access nutrients adequately (Mbiri *et al*., 2015). Generally, the use of sand aggregates in the hydroponics has been successful in other crops, for example production of seed potato minitubers in sandponics system (Mateus-Rodriquez *et al*., 2012). Vines growing in the conventional soil substrate face nutrient imbalances as reflected in the soil analysis report (Table 4.1 and 4.9) leading to sub-optimal VMR. Management of Potassium in the nutrient solution during sweetpotato vine multiplication is important in sandponics system since its role in sweetpotato comes in later at storage root formation stage (Taraken *et al*., 2010).

5.2.2 Effect of sweetpotato genotype on agronomic performance

Differences in the responses of sweetpotato genotypes in the two distinct vine multiplication systems was varietal controlled. This was as a result of differences in the growth morphology of genotypes as described to be: erect, semi-erect, spreading and extremely spreading (Tumwegamire *et al*., 2012) coupled with variances in genetic make-up of genotypes.

5.2.3 Effect of interaction between genotype and substrate type on agronomic performance of sweetpotato genotypes

The superior performance of all the vine yield traits in the sandponics system could be attributed to the optimal nutrient application throughout the growth cycle of vines (Mateus-Rodriquez *et al*., 2012; Mbiri *et al*., 2015). More so, the differences in the yields of vine traits could also have been marked by the genotypic differences of cultivars as reported in other crops like potato (Rostami and Mohavedi, 2016). Soroushzadeh (2012) also indicated that yield production of seed potato minitubers was higher in the aeroponics (soil-less culture) when compared to the conventional soil substrate method.

This was later be reflected in the leaf index tissue analysis which showed that sandponics system sourced leaf index tissues had adequate ranges of key nutrients (Nitrogen, Phosphorus, Calcium, Sulfur and Boron) that favor growth of vines. The inferior performance of sweetpotato genotypes in the conventional soil substrate considering vine yield traits is as a result of sub-optimal nutrient supply to vines during the growth cycle (Soroushzadeh, 2012).

5.2.4 Cost-effectiveness analysis

Further, these results showed that sandponics is a promising technology for breaking the limited supply of pre-basic seed in sweetpotato cropping systems. Other studies

have indicated that for a sustainable seed system, pre-basic seed has to be affordable (Gibson *et al*., 2011; Mbiri *et al*., 2015). This will ensure cheaper cost of seed in the subsequent generations at basic, certified and quality declared seed levels.

A follow up study to compare sweetpotato pre-basic seed multiplication using an optimized nutrient media has found out that sandponics system is more cost-effective compared to the use of conventional soil substrate. However, sandponics system was more cost-effective for selected genotypes and hence it is necessary to identify the appropriate genotypes for mass multiplication using sandponics system. In this experiment, although the production cost per node was lowest for genotype Irene, the difference in costs between the two methods was higher for genotype Ejumula and hence it was found to be the most cost-effective genotype of the four tested to use in sandponics system. Sandponics system is a feasible alternative technology for pre-basic sweetpotato seed multiplication.

CHAPTER SIX

GENERAL CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

i. Nutrient concentrations of 200, 60, 200, 120 and 0.3 ppm for Nitrogen, Phosphorus, Calcium, Sulfur and Boron, respectively are the optimized levels for sweetpotato pre-basic seed multiplication using sandponics system. These concentrations were most favorable for increased significant growth in vine morphological and yield traits.

ii. The study also identified nutrient deficiency symptoms for various elements that can be used to guide sandponics operations in correcting for nutrient deficiency (Table 3.9).

iii. Sandponics is a cost-effective system for sweetpotato pre-basic multiplication.

iv. Some genotypes are more cost-effective to multiply using sandponics system than others. In this experiment, although the production cost per node was lowest for genotype Irene, the difference in costs between the two substrate methods was higher for genotype Ejumula and hence it was found to be the most cost-effective genotype of the four tested to use in sandponics system.

6.2 Recommendations

i. Since this optimized nutrient media was formulated using cultivar ‘Kabode’ it could easily be extended for multiplying other sweetpotato varieties with some slight modifications. Therefore, further studies to adapt the nutrient media for other sweetpotato varieties is recommended.

ii. It is necessary to identify appropriate genotypes for mass multiplication using sandponics system given that some are more cost-effective than others.

iii. More studies are required on: (i) evaluating the vigor and quality of subsequent basic seed production using starter materials sourced from the sandponics system, (ii) assessing the maximum number of ratoons that can be

reached taking into account both quality as planting material and timing of seed availability in relation to market demand, (iii) evaluating planting in benches and troughs vs. pots to optimize on plant density, (iv) effect of ratooning on vine quality and (v) Sweetpotato breeding is a relatively slow and laborious process that involves multiple stages of evaluation of candidate varieties in target population environment(s). However, there is uncertainty of the target population environments for future sweetpotato production systems in SSA due to the effect of climate change. Sandponics system could as well be adapted for high throughput phenotyping platforms or assays for some traits that are either difficult to measure under field conditions or are likely to be the suitable for cropping models accounting for the effects of climate change. These could include traits like moisture stress resistance, nutrient use efficiency, cold stress tolerance or heat stress tolerance among others.

REFERENCES

Akinjoba, U. (2014). Outcome of Phosphorus fertilizer on tuber yields vegetative growth and Phosphorus uptake of sweet potato (*Ipomoea batatas*). *International Journal of Manures and Fertilizers*, *3*(7), 558–560.

Alu, Kapah., Rao, Rajashekhar., and Bailey, J.. (2012). Effects of sulfur fertilization on growth response of sweetpotato vines. *Niugini Agrisaiens*. 4. 52-57.

Amajor, J.U., Oti, E., Ekeledo, N., Omodamiro, R., Amajor, E.E., and Aniedu, C. (2014). Studies on the Characteristic Properties of Fermented, Sun-Dried Orange Fleshed Sweet Potato Flour. *Nigerian Food Journal*, 32(1), 45 – 53.

Andrade, M., Barker, I., Cole, D., Dapaah, H., Elliott, H.,…. and Thiele, G. 2009. *Unleashing the potential of sweetpotato in Sub- Saharan Africa: Current challenges and way forward*. International Potato Center (CIP), Lima, Peru. Working Paper 2009-1. 197 p.

Bar-Tal, A., Aloni, B., Karni, L., and Rosenberg, R. (2001). Nitrogen Nutrition of Greenhouse Pepper. II. Effects of Nitrogen Concentration and NO3 : NH4 Ratio on Growth, Transpiration, and Nutrient Uptake. *Hortscience*, 36(7), 1252–1259.

Baset-Mia, M. A. (2015). Nutrition of crop plants – *Plant science, research and practices.* Nova Science Publisher, Inc. NY. pp. 69-74.

Bautista -Tulin, A., Asio, V. B., Pardales, J. R., and Campilan, D. M. (2018). *Nutrient Deficiency Symptoms of Sweetpotato Varieties Planted in Degraded Uplands of Pinabacdao, Samar and in Commercial Areas of Leyte and Samar A. Vegetative Parts*.

Beato, V. M., Rexach, J., Navarro-Gochicoa, M. T., Camacho-Cristóbal, J. J., Herrera-Rodríguez, M. B., … and González-Fontes, A. (2010). A tobacco asparagine synthetase gene responds to carbon and Nitrogen status and its root expression is affected under Boron stress. *Plant Science*, 178(3), 289–298.

Bergman, E. (1985). *Nutrient Solution Culture of Plants*. The Pennyslyvania State University College of Agriculture, Extension Hort. Mimeo Series, II:160.(3), 21.

Bhagasari, A.S., and Ashley, D. A. (1990). Bhagasari, A.S. and Ashley, D.A. Relationship between photosynthesis and harvest index to sweetpotato yield. *Journal of the American Society of Horticultural Sciences*, 115, 288–293.

Boersig, M.R., and Wagner, S. A. (1988). Hydroponic system for production of seed potato tubers. *Am Potato J*, *65*, 470-471.

Bothwell, J. H. F., and Ng, C. K.-Y. (2005). The evolution of Ca2+ signalling in photosynthetic eukaryotes. *New Phytologist*, *166*(1), 21–38.

Bourke, R. M. (1985). Influence of nitrogen and potassium fertilizer on growth of sweet potato (*Ipomoea batatas* (L.) Lam) in Papua New Guinea. *Field Crops Research*, *12*(C), 363–375.

Bovell- Benjamin, A. C. (2007). Sweet Potato: A Review of its Past, Present, and Future Role in Human Nutrition. In *Advances in food and nutrition research* (Vol. 52, pp. 1–59).

Bures S., Gago MC., and Martinez, F.X. (1997). Water characterization in granular materials. *Acta Hort*, *450*(ISHS), 389–396.

Byju, G., and George, J. (2005). Potassium nutrition of sweet potato. *Advances in Horticultural Science*, *19*(4), 221–239.

Campbell, C.R., and Plank, C.O. (2000). *Corn. In Reference sufficiency ranges for plant analysis in the southern region of the United States*. Southern Cooperative Series Bulletin #394. North Carolina Department of Agriculture.

Carey, E.E., Gichuki, S.T., Ndolo, P.J., Turyamureeba, G., and Teri, J. M. (1996). In:

Collaborative sweetpotato breeding in eastern, central and southern Africa. CIP Program Report 1995-1996. Lima Peru; 1997;49-57.

Chen, J. (2013). *Sweetpotato Root Quality in Response to Abiotic Factors and Maximizing Greenhouse Plant Production by Adjusting Fertilizer Application Rates*. PhD thesis, North Carolina State University, Raleigh, USA.

Chuquillanqui, C., Tenorioy, J., and Salazar, L. F. (2008). *Producción de semilla de papa por hidroponía. En: "Alternativas al uso del bromuro de metilo en la producción de semilla de papa de calidad."Documento de trabajo.* Lima-Perú.

Crasswell, E.T., Asher, C.J., and O'Sullivan, J. N. (1995). *Mineral Nutrient Disorders of Root Crops in the Pacific*. 17-20 April. Nuku'alofa, Kingdom of Tonga.

Craswell, E. T., Asher, C. J., Q'sullivan, J. N., Asher, C., and O'Sullivan, J.N. (1996). *Mineral Nutrient Disorders of Root Crops in the Pacific* (Vol. 86320).

Delian, E., Chira, A., Bdulescu, L., and Chira, L. (2014). Calcium Alleviates stress in plants: Insight into Regulatory Mechanisms. *AgroLife Scientific Journal* , *3*(2), 2285–5718.

Dell, B., and Huang, L. (1997). Physiological response of plants to low Boron. *Plant and Soil*, *193*(2), 103–120.

Ebregt, E., Struik, P. C., Odongo, B., and Abidin, P. E. (2007). Piecemeal versus one-time harvesting of sweet potato in north-eastern Uganda with special reference to pest damage. *NJAS - Wageningen Journal of Life Sciences*, *55*(1), 75–92.

El Sayed Hameda, E. A., Saif El Dean, A., Ezzat, S., and El Morsy, A. H. A. (2011). Responses of productivity and quality of sweet potato to Phosphorus fertilizer rates and application methods of the humic acid. *Journal of Biological Sciences*, *13*(3), 112–122.

Fageria, N., Slaton, N., and Baligar, V. (2003). Nutrient Management for Improving Lowland Rice Productivity and Sustainability. *Advances in Agronomy*, *80*, 63–152.

Fajardo, J., Lutaladio, N., Larinde, M., Rosell, C., Roca, W., and Chujoy, E. (2010). *Quality declared planting material: protocols and standards for vegetatively propagated crops*. FAO, Rome (Italia).

FAOSTAT. (2017). http://apps.fao.org-Food and Agriculture Organization of the United Nations, Rome, Italy.

Fishman, M. J., Downs, S. C., Udall, S. L., and Pecora, W. T. (1966). *Methods for analysis of selected metals in water by atomic absorption*. (No. 1540 C. U.S. Govern. Print. Office). Washington D.C.

Fredeen, A. L., Rao, I. M., and Terry, N. (1989). Influence of Phosphorus Nutrition on Growth and Carbon Partitioning in Glycine max. *Plant Physiology*, *89*(1), 225–230.

Fu, J. (2008). *Effects of different harvest start times on leafy vegetables (lettuce , pak choi and rocket) in a reaping and regrowth system*. PhD thesis,. Lincoln University, Oxford, Pennslavania, USA.

Fuglie, K.O. (2007). Research priority assessment for the CIP 2005-2015 strategic plan: Projecting impacts on poverty, employment, health and environment. *J of Potato Res*, 84: 353. https://doi.org/10.1007/BF02987182.

Fuglie, K.O., Zhang, L., Salazar, L.F., and Walker, T.S. (1999). *Economic impact of virus-free sweet potato planting material in Shandong Province, China*. International Potato Center Program Report for 1997-98, pp 249-254

Ganie, M., Akhter, F., Bhat, M., Malik, A., Junaid, J., Shah, M., . . . Bhat, T. (2013). Boron — a critical nutrient element for plant growth and productivity with reference to temperate fruits. *Current Science*, *104*(1), 76-85.

Gerardeaux, E., Jordan-Meille, L., Constantin, J., Pellerin, S., and Dingkuhn, M. (2010). Changes in plant morphology and dry matter partitioning caused by potassium deficiency in *Gossypium hirsutum* (L.). *Environmental and Experimental Botany*, *67*(3), 451–459.

Gibson, R.W, Namanda, S., Sindi, K. (2011b). Sweetpotato seed systems in East Africa. *J Sustain Agric* 35:870–844

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

Gibson, R.W., Namanda, S., and Kirimi, S. (2011). *Sweetpotato seed systems in East Africa*. African Crop Science Conference Proceedings, 10, 449–451.

Gittinger, J. P. (1985). *Economic analysis of agricultural projects* (English) | The World Bank. Unnumbered Series ; No. UNN 76. Washington, DC: World Bank., 1.

Gojon, A. A. (2017). Nitrogen nutrition in plants: rapid progress and new challenges. *Journal of Experimental Botany*, 68(1)2457–2462.

Han, S., Chen, L.-S., Jiang, H.-X., Smith, B. R., Yang, L.-T., and Xie, C.-Y. (2008). Boron deficiency decreases growth and photosynthesis, and increases starch and hexoses in leaves of citrus seedlings. *Journal of Plant Physiology*, *165*(13), 1331–1341.

Harper, J. F., Breton, G., and Harmon, A. (2004). Decoding ca $^{2+}$ signals through plant protein kinases. *Annual Review of Plant Biology*, *55*(1), 263–288.

Hasanuzzaman, M., Bhuyan, M., Nahar, K., Hossain, M., Mahmud, J., … Fujita, M. (2018). Potassium: A Vital Regulator of Plant Responses and Tolerance to Abiotic Stresses. *Agronomy*, *8*(3), 31.

Hassan, M. A., H Serg, S. M., Saif El-Deen, U. M., and Mohamed, M. A. (2014). Effect of Calcium, potassium and some antioxidants on growth, yield and storability of sweet potato: 2-Chemical composition and storability of tuber roots during storage period. *Annals of Agric. Sci* (Vol. 52).

Hawkesford, M., Horst, W., Kichey, T., Lambers, H., Schjoerring, J., … and White, P. (2012). Functions of Macronutrients. *Marschner's Mineral Nutrition of Higher Plants*, 135–189.

Hetherington, A. M., and Brownlee, C. (2004). The generation of ca $^{2+}$ signals in plants. *Annual Review of Plant Biology*, *55*(1), 401–427.

Hirschi, K. D. (2004). The Calcium conundrum. Both versatile nutrient and specific signal. *Plant physiology*, *126*(3), 1092–1104.

Hozyo, Y., Murata, T., and Yoshida, T. (1971). *Development of tuberous roots in grafting sweet potato plants*, (*Ipomoea batatas* Lam.) Tokyo Nat Inst Agr Sci Bull Ser D.

Htt://en.wikipedia.org/wiki/sand. 18th March 2018.

Hu, L.-Y., Hu, S.-L., Wu, J., Li, Y.-H., Zheng, J.-L., … and Zhang, H. (2012). Hydrogen Sulfide Prolongs Postharvest Shelf Life of Strawberry and Plays an Antioxidative Role in Fruits. *Journal of Agricultural and Food Chemistry*, *60*(35), 8684–8693.

Huamán, Z. (1991). *Descriptors for sweet potato*. CIP, AVRDC, IBPGR. International Board for Plant Genetic Resources, Rome, Italy.

Ila'ava, V. P. (1997). *Effects of soil acidity factors on the growth of sweet potato cultivars*. PhD thesis., The University of Queensland, Brisbane, Australia.

Jensen, M. H. (1997). *Principales sistemas hidropónicos: Principios, ventajas y*

desventajas. En: Hidroponía comercial. Una buena opción en agro negocios UNALM. Lima-Perú.

Jin, Z., Shen, J., Qiao, Z., Yang, G., Wang, R., and Pei, Y. (2011). Hydrogen sulfide improves drought resistance in Arabidopsis thaliana. *Biochemical and Biophysical Research Communications*, *414*(3), 481–486.

Joiner, J. . (1983). Nutrition and fertilization of ornamental greenhouse crops. *Horticultural Reviews*, *5*(Janick (ed.).IN:), 340–403.

Jones, B. Jr., 2016. *Hydroponics*: A Practical Guide for the Soilless Grower. St.-Lucie Press.

Kabirizi, J., Lule, P., Kyalo, G., Mayanja, S., Ojakol, J., … and Lukuyu, B. (2017). *Sweetpotato Silage Manual for Smallholder Farmers*, (February), 25.

Kang, J. G., Kim, S. Y., Kim, H. J., Om, Y. H., and Kim, J. K. (1996). Growth and tuberization of potato (*Solanum tuberosum* L.) cultivars in aeroponic, deep flow technique and nutrient film technique culture systems. *Korean Society for Horticultural Science*, *37*, 24–27.

Kareem, I. (2013). Growth , Yield and Phosphorus Uptake of Sweet Potato (*Ipomoea batatas*) Under the Influence Phosphorus Fertilizers. *Research Journal of Chemical and Environmental Sciences*, *1*(3), 50–55.

Kivuva, B.M., Yencho, C.G., Sibiya, J., Musembi, F.J., and Githiri, S.M. (2014). Assessment of Production Constraints and Farmers ' Preferences for Sweet Potato Genotypes. *Journal of Plant Breeding and Genetics*, *02*(01), 15–29.

Kraiser, T., Gras, D.E., Gutiérrez, A.G., González, B., and Gutiérrez, R.A. (2011). A holistic view of nitrogen acquisition in plants, *J Exp Bot*. 2011 Feb; 62(4): 1455–1466.

Lebot, V. (2008). Tropical root and tuber crops: cassava, sweetpotatoes, yams and aroids. *Crop Production Science in Horticulture* 17. CABI Publishing, Wallingford.

Li, M., Zhao, Z., Zhang, Z., Zhang, W., Zhou, J., … and Liu, X. (2017). Effect of Boron deficiency on anatomical structure and chemical composition of petioles and photosynthesis of leaves in cotton (*Gossypium hirsutum* L.). *Scientific Reports*, *7*(1), 1–9.

Loebenstein, G. and G. Thottappilly (eds.). 2009. The Sweetpotato. *Springer-media*, Houten, Netherlands.

Low, J. W., Mwanga, R. O. M., Andrade, M., Carey, E., and Ball, A. M. (2017). Tackling vitamin A deficiency with biofortified sweetpotato in sub-Saharan Africa. *Global Food Security*, *14*(January), 23–30.

Low, J., Lynam, J., Lemaga, B., Crissman, C., Barker, I., … and Andrade, M. (2009). Sweetpotato in Sub-Saharan Africa. In The Sweetpotato (pp. 359–390). Dordrecht: *Springer* Netherlands.

Makokha, P., Matasyoh, L. G., Ssali, R. T., Kiplagat, O. K., Wanjala, B. W., and Low, J. (2018). Optimization of nutrient media for sweetpotato (*Ipomoea batatas* L.) vine multiplication in sandponics: Unlocking the adoption and utilization of improved varieties. *Gates Open Research*, *2*, 59.

Marschner, P.. (2012). *Marschner's Mineral Nutrition of Higher Plants*. 10.1016/C2009-0-63043-9.

Mateus-Rodriguez, J. R., de Haan, S., Andrade-Piedra, J. L., Maldonado, L., Hareau, G., … and Benítez, J. (2013). Technical and Economic Analysis of Aeroponics and other Systems for Potato Mini-Tuber Production in Latin America. *American Journal of Potato Research*, *90*(4), 357–368.

Mbiri, D., Schulte-Geldermann, E., Otazu, V., Kakuhenzire, R., Demo, P., and

Schulz, S. (2015). An alternative technology for pre-basic seed potato production - sand hydroponics. In: Low, J., Nyongesa, M., Quinn, S., Parker, M. (eds). Potato and sweetpotato in Africa. Transforming the value chains for food and nutrition security. Oxfordshire (UK). *CABI International*. pp. 249-253.

McEwan, M. (2016). *Sweetpotato seed systems in sub- Saharan Africa: a literature review to contribute to the preparation of conceptual frameworks to guide practical interventions for root, tuber, and banana seed systems*. RTB Working Papers No. 2016–4. CGIAR Research Program on Roots, Tubers and Bananas. Lima, Peru: CGIAR.

McEwan, M., Almekinders, C., Abidin, P.E., Andrade, M., Carey, E.E.,… and Schulz, S. (2015). Can small still be beautiful? Moving local sweetpotato seed systems to scale in Sub-Saharan Africa. In: Low, J., Nyongesa, M., Quinn, S., Parker, M. (Eds.), Potato and Sweetpotato in Africa: Transforming the Value Chains for Food and Nutrition Securityeds.. *CABI*, Oxfordshire, United Kingdom.

Miller, C.H., and Nielsen, L. W. (1970). Sweet potato blister, a disease associated with Boron deficiency. *Journal of the American Society for Horticultural Science*, *95*, 685-686.

Mills, H. A., Jones, J. B., and Wolf, B. (1996). Plant analysis handbook II : *a practical sampling, preparation, analysis, and interpretation guide*. Micro-Macro Pub., Athens, GA.

Miwa, K., Takano, J., Omori, H., Seki, M., Shinozaki, K., and Fujiwara, T. (2007). *Plants tolerant of high Boron levels*. Science (New *York, N.Y.), 318*(5855), 1417.

Miyasaka, S.C., Hamasaki, R.T., and de la Pena, R.S. (2002). Nutrient Deficiencies and Excesses in Taro. *Soil and Crop Management*, SCM-4, CTAHR Cooperative Extension Service, Honolulu, HI. 14 p.

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*, *Volume 111*(11/12).

Muro, J.V., Goñi, J.L., and Lamsfus, C. (1997). Comparison of hydroponic culture and culture in a peat/sand mixture and the influence of nutrient solution and plant density on seed potato yields. *Potato Res* , *40*, 431–438.

Namanda, S. (2012). *Current and Potential Systems for Maintaining Sweetpotato Planting Material in Areas with Prolonged Dry Seasons*: A Biological, Social and Economic Framework. PhD thesis, University of Greenwich, London, UK.

Nausbaum, C. J. (1946). Internal brown spot, a Boron deficiency disease of sweet potato. *Phytopathology*, *36*, 164–167.

Ndolo, P. J., Mcharo, T., Carey, E. E., Gichuki, S. T., Ndinya, C., and Maling'a, J. (2001). Participatory on-farm selection of sweetpotato varieties in western Kenya. *African Crop Science Journal*, *9*(1), 41–49.

Ning, Y. W, Ma, H. B, Xu, X. J, Wang, J. D, Zhang, H., Xu, J. P, Chen, J., Zhang, Y. C. (2013). Effects of deficiency of N, P, or K on growth traits and nutrient uptakes of sweet potato at early growing stage. *Sci Agric Sin* (in Chinese) 46:486–495.

Niu, G., Rodriguez, D., and Gu, M. (2011). Response of *Sophora secundiflora* to Nitrogen Form and Rate. *Hortscience*, *46*(9), 1303–1307.

Nolte, K., and Ostermeier, M. (2017). Labour market effects of large-scale agricultural investment: conceptual considerations and estimated employment effects World Dev., 98 pp. 430-446

Oser, H., and Summerson (1947). *Practical Physiological Chemistry*, Churchill,

London. pp 839-844.
O'Sullivan, J.N., Asher, C.J., and Blamey, F.P.C. (1997). *Nutrient disorders of sweetpotato*. ACIAR Monograph No 48, 136p.
Otazu, V. (2008). Steam sterilization of greenhouse substrates (in Spanish). In: *Alternativas al uso del bromuro de metilo en la producción de semilla de papa de calidad*. In *Documento de trabajo 2007-2* (pp. 15–25). Lima, Peru: International Potato Center.
Otazu, V. (2010). *Manual on quality seed potato production using aeroponics*. International Potato Center (CIP), Lima, Peru. 44 p.
Peters, D. (2008). *Assessment of the Potential of Sweetpotato as Livestock Feed in East Africa*: Rwanda, Uganda, and Kenya. A report presented to The International Potato Center (CIP) in Nairobi, (July), 64.
Purekar, P.N., Singh, R.R., and Deshmukh, R. D. (1992). *Plant Physiology and Ecology.* (2nd ed). New Delhi, India: S Chand and Company.
Rajendran, S., Kimenye, L. N., and McEwan, M. (2017). Strategies for the development of the sweetpotato early generation seed sector in eastern and southern Africa. *Open Agriculture*, *2*(1).
Rashid, K., and Waithaka, K. (1985). The effect of Phosphorus fertilization on growth and tuberization of sweet potato (*Ipomoea batatas* L.) *Acta Hortic*, *153*(IX African Symposium on Horticultural Crops), 47.
Reddy, A. S. N. (2001). Calcium: silver bullet in signaling. Plant Science : *An International Journal of Experimental Plant Biology*, *160*(3), 381–404.
Reddy, V. S., and Reddy, A. S. N. (2004). Proteomics of Calcium-signaling components in plants. *Phytochemistry*, *65*(12), 1745–1776.
Resh, H.M. (1983). *Hydroponic Food Production*, 2nd Edition. Woodbridge Press Publishing Co., Santa Barbara, C. A. pp 335, 2nd Edition(3), 335.
Riga, P. (2013). Short communication. Ratoon cropping technique combined with pluriannual character improves soilless pepper (*Capsicum annuum* L.) fruit yield. *Spanish Journal of Agricultural Research*, *6*(3), 430–433.
Rolot, J. L., and Seutin, H. (1999). Soilless production of potato minitubers using a hydroponic technique. *Potato Research*, *42*(3–4), 457–469.
Rosolem, C. A., and Costa, A. (2000). Cotton growth and Boron distribution in the plant as affected by a temporary deficiency of Boron. *Journal of Plant Nutrition*, *23*(6), 815–825.
Rostami, M., and Z. Movahedi. (2016). 'Evaluation the effects of Naphthalene acetic acid (NAA) on morpho-physiological traits of valerian (*Valeriana officinalis* L.) in aeroponic system'. *Iranian Journal of Plant Physiology*, 6(3): 1751-1759.
Sardare, M. D. (2015). A Review on Plant Without Soil - Hydroponics. *International Journal of Research in Engineering and Technology*, *02*(03), 299–304.
SAS Institute Inc. (2013). *Statistical Analysis Software,* Version 9.4. Cary, NC, USA.
Schmitz-Eiberger, M., Haefs, R., and Noga, G. (2002). Calcium deficiency - Influence on the antioxidative defense system in tomato plants. *Journal of Plant Physiology*, *159*(7), 733–742.
Shan, C., Liu, H., Zhao, L., and Wang, X. (2014). Effects of exogenous hydrogen sulfide on the redox states of ascorbate and glutathione in maize leaves under salt stress. *Biologia Plantarum*, *58*(1), 169–173.
Shen, J., Yuan, L., Zhang, J., Li, H., Bai, Z.…., and Chen, X. (2011). Phosphorus dynamics. *Plant Physiol.* 2011 Jul; 156(3): 997–1005.
Siose, T., Kader, M., and Tulin, A. (2018). Determination of limiting nutrient to Sweetpotato (L.) growth on Samoa Oxisol using a *Ipomoea batatas* Nutrient

Omission Technique. *Annals of Tropical Research*, (June 2018), 105–119.
Smith, P. F. (1962). Mineral Analysis of Plant Tissues. *Annual Review of Plant Physiology*, *13*(1), 81–108.
Soffer, H. (1986). A device for growing plants aero-hydroponically: The E.G.S. (Ein Gedi System) mini unit. *Soilless Cult*, *2*(3–4), 45–52.
Somasundaram, K., and Mithra, V. S. S. (2008). Madhuram : A Simulation Model for Sweet Potato Growth. *World Journal of Agricultural Sciences*, *4*(2), 241–254.
Soroushzadeh, A. (2012). Comparison of aeroponics and conventional soil systems for potato mini-tubers production and evaluation of their quality characters. *Journal of Plant Physiology and Breeding*, Iran. 2(2): 13-25.
STATA 14.1 version. (2015). StataCorp. *Stata Statistical Software*: Release 14. College Station, TX: StataCorp LP.
Stevens, G., P. Motavalli, P. Scharf, M. Nathan, and D. Dunn. 2002. *Integrated pest management; crop nutrient deficiencies and toxicities*. UM Extension, Univ. Missouri-Columbia.
Taraken, I. T., Kapal, D., Sirabis, W., and Bailey, J. (2010). *Nutrient deficiencies limiting the growth of sweetpotato vines on important soil types in the highlands of Papua New Guinea*. In 19th World Congress of Soil Science, Soil Solutions for a Changing World, 1 – 6 August 2010, Brisbane, Australia. (pp. 90–93).
Tessema, L., and Dagne, Z. (2018). Aeroponics and Sandponics: Alternative Technologies for Pre-Basic Seed Potato Production in Ethiopia. *Open Agriculture*, *3*(1), 444–450.
Tumwegamire, S., Mwanga, R. O. M., Andrade, M., Low, J., Ssemakula, G. N., Laurie, S., … and Gruneberg, W. (2014). *Orange-fleshed Sweetpotato for Africa. Catalogue 2014* (Second Edition). International Potato Center (CIP), Lima, Peru. 74p.
Wahome, P. K., Oseni, T. O., Masarirambi, M. T., and Shongwe, V. D. (2011). Effects of Different Hydroponics Systems and Growing Media on the Vegetative Growth, Yield and Cut Flower Quality of Gypsophila (*Gypsophila paniculata* L.). *World Journal of Agricultural Sciences*, *7*(6), 692–698.
Wheeler, R. M. (2006). Potato and Human Exploration of Space: Some Observations from NASA-Sponsored Controlled Environment Studies. *Potato Research*, *49*(1), 67–90.
White, P.J., and Broadley, M.B. (2003. Calcium in Plants. *Ann Bot.* 2003 Oct; 92(4): 487–511
Willis, L.G. (1943). *Apply borax to improve quality of sweet potatoes*. North Carolina Agricultural Experiment Station Special Circular 1, 1943.
Woolfe, J. A. (1992). Sweet potato : *an untapped food resource*. Cambridge University Press.
Yan, Q., Duan, Z., Mao, J., Li, X., and Dong, F. (2012). Effects of root-zone temperature and N, P, and K supplies on nutrient uptake of cucumber (*Cucumis sativus* L.) seedlings in hydroponics, *Soil Science and Plant Nutrition*, 58:6, 707-717.
Zhang, H., Hu, S.-L., Zhang, Z.-J., Hu, L.-Y., Jiang, C.-X., … and Jiang, S.T. (2011). Hydrogen sulfide acts as a regulator of flower senescence in plants. *Postharvest Biology and Technology*, *60*(3), 251–257.
Zhang, H., Tang, J., Liu, X.-P., Wang, Y., Yu, W., … and Hu, L.Y. (2009). Hydrogen Sulfide Promotes Root Organogenesis in *Ipomoea batatas, Salix matsudana* and *Glycine max*. *Journal of Integrative Plant Biology*, *51*(12), 1086–1094.
Zhou, G.-F., Liu, Y.-Z., Sheng, O., Wei, Q.-J., Yang, C.-Q., and Peng, S.-A. (2015).

Transcription profiles of Boron-deficiency-responsive genes in citrus rootstock root by suppression subtractive hybridization and cDNA microarray. *Frontiers in Plant Science, 5*, 795.

APPENDICES

Appendix I: Analysis of Variance for response variables during nutrient media optimization for pre-basic seed multiplication using sandponics system at KEPHIS-PQBS, Muguga, Kenya (2018).

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Computed F
Treatment (5-1)	4	Treatment sum of squares (TSS)	TMS = TSS/4	F = TMS/RMS
Block (2-1)	1	Block sum of squares (BSS)	BMS = BSS/1	F = BMS/RMS
Residual	4	Residual SS	RMS = RSS/4	
Total	9	Total SS		

Appendix II: **Input cost template micro-log sheet for sweetpotato pre-basic seed multiplication using sandponics system and conventional soil substrate method at KEPHIS-PQBS, Muguga, Kenya (2018 – 2019).**

S. No	Date of use	Particulars (Items)	Experiment Name for used inputs (1=Sandponics system; 2=conventional soil substrate method)	1=Input; 2=Consumable good; 3=Service Costs; 4=Other costs	Quantity purchased	Unit Name for QTY purchased	Price per unit	Total Price paid	Currency Name	Qty Used	Unit Name for Qty used	Qty contained per purchased unit	Status of usage (1= Ongoing; 2=Completed)
1													
2													

Appendix III: Labor cost template micro-log sheet for sweetpotato pre-basic seed production using sandponics system and conventional soil substrate at KEPHIS-PQBS, Muguga, Kenya (2018 – 2019).

LABOUR COST

NAME OF THE STAFF _____

LOG SHEET FILLED BY FIELD STAFF

S.No	Activity (mentioned type of the input product used)	Work involved in the type of experiment (1=Sandponics system; 2=Conventional soil substrate method)	Date of application (dd/mm/yy)	Starting Time of application (HH/MM)	Ending time of application (HH/MM)	Status of usage (1=ongoing; 2=completed)
1						

Appendix IV: Input template macro-log sheet for sweetpotato pre-basic seed production using sandponics system and conventional soil substrate method at KEPHIS-PQBS, Muguga, Kenya (2018 – 2019)

Cost Summary																		
S. No	**APPLICATION DATE**	**Particulars (Items)**	**Quantity purchased**	**Unit Name for QTY purchased**	**Total Price paid**	**Currency Name**	**Quantity used**	**Unit Name for Qty used**	**conversion**	**local conversion unit**	**Per unit cost used**	**Total Cost for used qty**	**Exchange Rate (1 USD = in Local Currency) during the purchase time**	**Total Cost (in USD)**	**conventional ratio for sandponics**	**Total Cost of qty used for coventional soil substrate method**	**conventional ratio for CONVENTIONAL**	**Total Cost of qty used for coventional soil substrate method**
1																		

Appendix V: Labor cost macro-log sheet for sweetpotato pre-basic seed multiplication using sandponics system and conventional soil substrate method at KEPHIS-PQBS, Muguga, Kenya (2018 – 2019)

	Figures	Unit name
No of hours per day		hours
wage rate per day		DAY
Total Area Measurement		SQUARE METER

sweetpotato vine

Name of the laborer	Starting Date (DD/MM/YYYY)	Ending Date (DD/MM/YYYY)	Wage Rate in local currency per day	Total Hours worked during production cycle	Total	Estimated cost (Local Currency)	If there is a contract, then Contract labour cost	Estimated total cost (Local Currency)	Average Exchange rate during the production period	Total Cost in USD
					man-days					

Appendix VI: Detailed cost of production for sweetpotato pre-basic seed multiplication using sandponics system and conventional soil substrate method at KEPHIS-PQBS, Muguga, Kenya (2018 – 2019).

Cultivation technique	Sandponics system			
Structure under production	Screenhouse			
Local currency	KSH	Kenyan shillings		
	Size	Unit name		
Total area measurement (m^2)	16	Square metres (SQM)		
	Name of the unit	Measure		
Production unit	NODE	1		
	FROM	TO	Production Cycle	Units
Year of Calculation	June-2018	March-2019	9	Months

Varieties Name	Kabode, Irene, Ejumula, Gweri				
Number of Varieties	4				
Number of harvesting	6				
Irrigation / Fertigation method	Drip				
Yield	YIELD FOR SANDPONICS SYSTEM		YIELD FOR CONVENTIONAL SOIL SUBSTRATE METHOD		
	NODE		NODE		
	48996	16 SQM	39293	16 SQM	
PRODUCTION – SANDPONICS SYSTEM					
CROP NAME		Name of the Unit	Actual Quantity Produced	Wastages during production period (production unit)	
Sweetpotato vines (pre-basic)		Node	48996	2449.8	
PRODUCTION – CONVENTIONAL SOIL SUBSTRATE METHOD					
CROP NAME		Name of the Unit	Actual Quantity Produced	Wastages during production period (production unit)	
Sweetpotato vines		Node	39293	1964.65	
INPUT COSTS FOR THE PRODUCTION					
Variable Costs					
Labor costs	Unit	Unit Name	Total Man-days	SANDPONICS SYSTEM	CONVENTIONAL SOIL SUBSTRATE METHOD
Total Labor cost incurred – CONVENTIONAL SOIL SUBSTRATE METHOD			4.9		2823
DAILY OR CASUAL LABOR COST – SANDPONICS SYSTEM			6.6	3799	
Total			**11.5**	**3799**	**2823**
Variable costs				SANDPONICS SYSTEM	CONVENTIONAL SOIL SUBSTRATE METHOD
Input Cost[a]					
Chemicals / Fertilizers				11961	16113
Consumables				550	550
Total Input Costs				12511	16663
Total Variable Costs				**16310**	**19486**
Fixed Costs (Ownership costs or Capital costs)				SANDPONICS SYSTEM	CONVENTIONAL SOIL SUBSTRATE METHOD
Screen house				68,174	68,174
Water tank and pipe, drip, stand				67,018	67,018
Pots / plates				2,185	2,185

Wheel barrow				0.5	0.5
Spade				0.1	0.1
Sprayer				10.5	10.5
Secateurs				2.2	2.2
Weighing scale				32	0
Total Fixed Costs				137,421	137,390
Total Costs	Total variable costs + total fixed costs			**153,731**	**156,875**
Overhead Cost (water, electricity, maintenance, security and land)	10%			154	157
Total Costs	Include overhead and contingencies & exclude wastages			**153,885**	**157,032**
Unit Cost	Total costs / total quantity of Production (excluding wastage cost)			**3.1**	**4.0**
Total costs for wastage	Unit costs*total quantity wastage			**7694**	**7852**
Total Costs	Include overhead and contingencies & include wastages cost			**161,579**	**164,884**
BREAKEVEN COST TO TOTAL COSTS	INCLUDING WASTAGES			**3.3**	**4.5**
COST PER VARIETY	KSH			40395	41221
Ejumula	Number of nodes among all 4 blocks			12388	9338
Kabode	Number of nodes among all 4 blocks			10341	8364
Irene	Number of nodes among all 4 blocks			16933	13333
Gweri	Number of nodes among all 4 blocks			9334	8258

Note: 'a' inputs includes such as triple super phosphate, magnesium nitrate, magnesium sulphate, etc.

Appendix VII: Cost of producing sterilized sand over 5 days' time period for sweetpotato pre-basic seed multiplication using sandponics system at KEPHIS-PQBS, Muguga, Kenya (2018 – 2019).

S.NO	PARTICULARS	QUANTITY	LOCAL UNIT	COST PER UNIT (KSH)	TOTAL COSTS (KSH)
VARIABLE COSTS					
INPUT COSTS					
	SAND	480	kgs	1.5	720
	JIK	2	lit	80	160
Sub-total					880
LABOUR COSTS					
	Daily laborers cost	1.00	man-days	575	576
Sub-total					576
TOTAL VARIABLE COSTS					1456
FIXED COST					
	Drum	3	Drums	2.41	7.2
	Spade	3	Spade	0.2	0.6
	Wheel borrow	1	wheel borrow	2.0	2.0
	Shovel	2	Shovel	0.2	0.5
	Sieve	1	Sieve	2.9	2.9
TOTAL FIXED COSTS (After depreciation)					13.2
TOTAL COST EXCL. OVERHEAD & CONTIGENCY (KSH)					1469
TOTAL COST EXCL. OVERHEAD & CONTIGENCY (USD)					15
OVERHEAD COSTS (10 %)					147
RISK COSTS (5 %)					73
TOTAL COST INCL OVERHEAD & CONTIGENCY COSTS (KSH)					1689
EXCHANGE RATE	AS ON 8 APRIL 2019'				100
TOTAL COST INCL OVERHEAD & CONTIGENCY COSTS (USD)					17
TOTAL QTY PRODUCED (KG)					480
BREAK EVEN COST PER UNIT (KSH) (Total costs / Total Quantity produced)					3.5
BREAK EVEN COST PER UNIT (USD)					0.035

Note: Price of sterilized soil is 20 KSH (US$ 0.20) per Kg purchased from KEPHIS-PQBS, Muguga, Kenya.

Appendix VIII: F values of sweetpotato vine morphological and yield characteristics as affected by substrate type, genotype and interaction between substrate type and genotype during pre-basic seed multiplication at KEPHIS-PQBS, Muguga, Kenya (2018 – 2019).

Characteristic	Substrate type	Genotype	Genotype × Substrate type interaction
Morphological			
Vine Internode length (cm)	9.22**	62.06***	2.35^{ns}
Leaf area (cm^2)	5.68*	31.95***	0.27^{ns}
Petiole length (cm)	0.28^{ns}	18.79***	1.74^{ns}
Vine length (cm)	1.82^{ns}	56.26***	0.66^{ns}
Yield			
Number of plants harvested per pot	0.69^{ns}	38.36***	5.01**
Vine multiplication rate per pot	119.54***	167.04***	6.42**
Number of cuttings per vine	36.77***	5.45**	6.89**
Vine weight per pot (g)	410.9***	8.85***	2.21^{ns}

*: significant at p≤0.05 level
**: significant at p≤0.01 level
***: significant at p<.0001
ns: non-significant

Appendix IX: The F values for vine multiplication rate of the four sweetpotato genotypes as influenced by ratooning under sandponics system and conventional soil substrate method at KEPHIS-PQBS, Muguga, Kenya (2018 – 2019).

Yield trait	Ratoon	Ratoon × Substrate type	Variety × Ratoon	Variety × Substrate type× Ratoon
Vine multiplication rate	95.51**	21.07**	10.41**	1.69*
p value	<.0001	<.0001	<.0001	0.05

Appendix X: Regression analysis on measuring causation effect of sandponics system vs conventional soil substrate method on cost per node for each genotype during sweetpotato pre-basic seed production at KEPHIS-PQBS, Muguga, Kenya (2018 – 2019).

Genotype	Ejumula	Kabode	Irene	Gweri	Overall
Conventional (Base)	-	-	-	-	-
Sandponics	-1.18 (-9.24)**	-0.68 (-4.16)**	-0.69 (-5.06)**	-1.05 (-6.44)**	-0.90 (-6.45)**
R^2					
*, ** indicates 5% & 1% level significant respectively; in parenthesis is t-value					