OPTIMIZATION OF NUTRIENT SOLUTIONS FOR ENHANCED YIELDS AND QUALITY OF POTATO (*Solanum tuberosum* L.) ROOTED APICAL CUTTINGS IN HYDROPONICS

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DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and has not been presented in this University or any other for the award of a degree

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DEDICATION

I dedicate this work to my family and seed potato producers

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ABSTRACT

Potato (*Solanum tuberosum* L.) hydroponic system has been introduced to provide an avenue to potentially double potato productivity and lower seed production costs significantly. However, improperly constituted nutrient solutions for hydroponic seed potato production have often led to low yields due to either toxicities or deficiencies. The aim of this study was to optimize nutrient solution concentrations for enhanced growth, yield and quality of seed potato cultivars production in a hydroponic system. Two experiments were conducted in a greenhouse at Egerton University, Njoro, Kenya. A randomized complete block design in a split plot arrangement was used. The main plot treatment comprised of 'ADC-Molo' nutrient stock solution concentrations (NSSC) (75% (N75), 100% (N100) and 125% (N125)) and the subplots comprised of rooted apical cuttings (ARC) of four potato varieties (*Shangi, Wanjiku, Nyota and Unica*). Data was collected from 5 tagged sample plants on growth, yield and quality parameters and subjected to Analysis of variance using SAS software version 9.4 and means separated using Tukey's Honest Significant Difference test at a probability level of $p \leq 0.05$ level of significance. Results showed that the growth rate was significantly affected by the application of NSSC. Increasing the nutrient concentrations positively influenced plant height, Normalized Difference Vegetation Index (NDVI), plant survival and the above ground biomass. The varieties were also influenced with the application of nutrient concentrations with Nyota reporting the highest plant height, NDVI values at 60 days after planting (DAP) and the highest plant survival (%) at 75 DAP. On the other hand, Unica reported the lowest growth rates. Increasing the NSSC significantly increased minitubers number (plant^{-1}) and yield per hectare (t ha^{-1}). The highest number of minitubers (9.33) and yield (9.97t ha^{-1}) were reported under the N125. Nyota (>7) and Wanjiku (>7) produced significantly higher number of minitubers per plant as compared to Shangi (>6) and Unica (>4). The highest yield per hectare was however reported in Unica (>7t ha^{-1}) and Shangi produced the lowest yields (<5t ha^{-1}). On the quality parameters, treatment N125 was significantly different from N100 and N75 and produced the highest starch content of 15.58ppm, specific gravity of 1.17 and the highest tuber dry matter content of 24.90%. Therefore, to achieve high rooted apical cuttings growth, yield and quality under a hydroponic system, this study recommends using 125% of the ADC Molo nutrient formulation to seed potato farmers. For developing highest minitubers numbers, Nyota and Wanjiku varieties are recommended.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND ACRONYMS

ADC	Agricultural Development Corporation
ARC	Rooted apical cuttings
CIP	International Potato Center
DAP	Days After Planting
DMC	Dry Matter Content
FAO	Food and Agriculture Organization of the United Nations
IFC	International Finance Corporation
KALRO	Kenya Agricultural and Livestock Research Organization
KEPHIS	Kenya Plant Health Inspectorate Service
KES	Kenya Shillings
KIA	Kenya Investment Authority
MoALF	Ministry of Agriculture, Livestock and Fisheries
NDVI	Normalized Difference Vegetation Index
NPCK	National Potato Council of Kenya
NS	Nutrient Solution
NSSC	Nutrient Stock Solution Concentrations
RCBD	Randomized Complete Block Design
SSSC	Standard Stock Solution Concentration
USD	United States Dollars

CHAPTER ONE
INTRODUCTION

1.1 Background information

Potato (*Solanum tuberosum* L.) belongs to the family *Solanaceae* and it is widely grown and consumed as a food crop across the world (Muthanna *et al*., 2017). The potato tuber contains 79% water, 18% starch, 2% protein, 1% vitamins and minerals such as calcium, magnesium and trace elements (Zewide *et al.*, 2016). It is the third most important food crop in the world after wheat and rice and has contributed to global food and nutritional security (Wambugu *et al*., 2022). It ranks first among root and tuber crops and it is projected that by 2050, a global population of 9.7 billion people will demand 70% more food than currently consumed quantities (FAO, 2018). Asia is the leading producer of potato producing 50.4% of the total potato production globally while Africa is ranked fourth producing 6.4% (Beata *et al*., 2020). Kenya is the fourth largest potato producer in Africa with a total production of 1.8 million tonnes cultivated on 217, 315 ha (FAOSTAT, 2018).

Potato is an important food crop in Kenya, being second to maize (*Zea mays*) and contributes 23.5% of the total value of horticultural produce (KIA, 2020). There has been a slight increase in potato production and consumption in recent years due to urbanization, population growth and crop diversification in areas with favourable climatic conditions (Waaswa *et al*., 2021). Potato continues to play an important role in food security and increases income of small holder farmers in Kenya (Harahagazwe *et al.*, 2018). More than 60 potato varieties are grown in Kenya, with the most popular being; *Shangi, Kenya Mpya, Tigoni, Nyota, Dutch Robijn, Unica* and *Kenya Karibu* (Sophie, 2018). Regardless of Kenya being the fourth potato producer in Africa, the average national farm yield is about 9-10 tonnes per ha which is quite low as compared to the global average potato productivity of 20-40 t ha^{-1} attainable yield (IFC, 2019; MoALF, 2016). The productivity gap is associated with shortage of quality seed, unbalanced mineral nutrition, pest and diseases and soil fertility constraints (Kaguongo & Maingi, 2014).

Inadequate certified potato seed of preferred varieties is a major potato constrain with approximately only 2% of the total potato area in Kenya being planted with certified seed potato obtained from the formal sector (KEPHIS, 2016). Recently, higher figures of 6-8% certified seed potato have been planted in Molo region of Nakuru county (Mutinda *et al*., 2020; Ong'ayo *et al.*, 2020). The great reliance on informal seed sources (i.e., obtained from previous seasons /

positive selection / clean seeds) by up to 98% seed potato demand has been the major cause of potato yields decline from 22 t ha^{-1} to 10 t ha^{-1} over the last decade (KEPHIS, 2016; Waaswa *et al*., 2021). Shortage of certified seed has led to high cost of seed potato that is estimated to account for 40%-60% of the total potato production cost (Tessema & Dagne, 2018). With the use of these poor quality seeds, pest and disease incidences have increased and low potato productivity is also on the increase (Hussain, 2016). For these reasons there is need to develop a production system that can increase the quantity and quality of certified seed potato.

Rapid multiplication techniques such as the use of rooted apical cutting (ARC) have shortened the multiplication time of certified seed potato (Harahagazwe *et al.*, 2018). They have increased large scale seed potato producers in Kenya from 12 producers in 2013 to 27 in 2019; while the number of potato varieties have increased from 13 varieties in 2013 to 60 in 2019 (NPCK, 2019). Rooted apical cuttings can be used as an efficient means of producing basic seed under strict management practices such as hydroponics, with each cuttings producing up to 15 tubers, depending on variety (Lemma *et al*., 2018; Parker, 2017). The productivity of these plantlets is however limited to nutritional factors in the hydroponic system. Therefore, determining the best nutrient solution concentration for producing seed potato will achieve higher production (Tufik *et al.*, 2019).

Hydroponics system has the potential to increase the production of certified seed potato that are high yielding and disease-free (Mbiri *et al.*, 2015). Hydroponically produced seed potato may yield up to 200% more than soil produced seed (Woznicki *et al*., 2021). The efficiency and superior productivity exhibited by hydroponics is dependent on the constant availability of nutrients (Corrêa *et al*., 2010). The use of improperly-formulated nutrient solutions in hydroponics often leads to low yielding and poor quality seed potato due to nutrient imbalances which impair plant growth and development (Lee *et al.*, 2017; Tufik *et al*., 2019). Each crop has an optimal nutritional requirement and each potato variety may require a specific nutrient solution in a hydroponic system (Degebasa *et al*., 2017). Similarly, mismatching the crop requirements and nutrients provision has led to reduced plant growth and development coupled with nutrient imbalances in the hydroponic solutions (Putra *et al.*, 2019).

Rooted apical cutting is a nursery grown seedling generated from tissue culture plantlets in which the mother plant is maintained in a juvenile stage throughout the production cycle (IFC, 2019). These plantlets have a high productivity potential which is attributed to the physiologically young tissue retained at the simple leaf stage which results in high productivity per ARC: 10-15 tubers per cuttings as compared to 6-8 obtained from seed potato tubers (Parker, 2017). They are the cheapest seed potato propagation method, have a faster regeneration potential and are true to type (Tsoka *et al.*, 2012). The production of the ARC has doubled the production of minitubers, reduced susceptibility to and proliferation of pest and diseases and is currently being use in many developing countries (IFC, 2019; Nikmatullah *et al*., 2021). However, the adoption of ARC is quite low in Kenya indicating that there is need to create awareness on the importance of using rooted apical cuttings (Harahagazwe *et al.*, 2018).

The starch content of a potato is an essential component of potato constituting about 20% dry matter (DM) of which 60- 80% is starch, with 70- 80% of this starch being amylopectin (Duan *et al*., 2019). Approximately 26 grams of carbohydrate content are contained in a medium-sized potato (Karim & Hossain, 2018). Potato starch is a good substitute for corn-starch as it can remain stable under high temperatures (Ebúrneo *et al*., 2018). It is however influenced by nutrition and variety with poor nutrition leading to low starch content and some varieties are reported to have high starch content as compared to others (Koch *et al*., 2020). Application of different rates of fertilizers influence potato starch with high nitrogen and phosphorus levels increasing the starch content but decrease mineral contents in potato (Ebúrneo *et al*., 2018; Kingori *et al*., 2015).

Nutrient optimization for potato varieties is the most critical factor in the production of high yielding and good quality seed under a hydroponic system (Degebasa *et al.*, 2017). Potato being a heavy feeder crop requires a variety of balanced elements for proper growth and development (Iraboneye *et al.*, 2020). Thus a balance of nutrient concentration in the tuber is essential to supply the appropriate amount of the required mineral ion based on crop demand, which should also accommodate all stages of growth and development. It is therefore necessary to specify nutrient application range in order to improve seed potato quality and quantity. Hence this research aims to optimize nutrient solution concentrations for enhanced yield and quality of seed potato cultivars production in a hydroponic system.

1.2 Statement of the problem

Despite the importance of potato in the Kenyan economy, its yield ha^{-1} has declined from 22.4 t ha^{-1} (2012) to 8.6 t ha^{-1} (2020) which is below the potential yield of about 20-40 t ha^{-1} (Waaswa *et al*., 2021). This decline is largely attributed to insufficient supply of certified seed which has led to farmers recycling previously used seeds leading to low potato yields. Recently, certified seed producers have embraced the use of hydroponic production technique which has been reported to have the potential to increase seed potato quality and quantity. A major challenge facing hydroponic production system is the lack/ unavailability of standardized nutrient solutions for growing different potato varieties. The use of the ADC-Molo nutrient formulation for different potato varieties has resulted to poor seed potato yield and quality since each potato variety may require a specific nutrient solution concentration. Moreover, the use of non-optimized nutritional variances often leads to nutrient toxicities or fixation, which negatively affects growth, yield and quality of seed potato. There is therefore the need to optimize nutrient solution concentrations for seed potato varieties production in hydroponic system in order to increase the seed potato quantities and quality.

1.3 Objectives

1.3.1 General objective

To contribute to potato productivity in Kenya by optimizing nutrient formulation for seed potato production using the hydroponic system

1.3.2. Specific objectives

i. To determine the effects of nutrient solution concentrations on the growth of rooted apical cuttings of seed potato varieties.
ii. To determine the effects of nutrient solution concentrations on the yield of rooted apical cuttings of seed potato varieties.
iii. To determine the effects of nutrient concentrations on the quality of minitubers produced from rooted apical cuttings of seed potato varieties.

1.4 Hypotheses

i. Nutrient concentrations have no significant effect on the growth of rooted apical cuttings of seed potato varieties.
ii. Nutrient concentrations have no significant effect on the yield of rooted apical cuttings of seed potato varieties.
iii. Nutrient concentrations have no significant effect on the quality of minitubers produced from rooted apical cuttings of seed potato varieties.

1.5 Justification of the study

The importance of the study arises from the rampant use of poor quality seed potato which has led to low potato productivity and poor potato quality in Kenya. Potato is considered the second most important food crop after maize in Kenya. It has a competitive advantage over maize in that; it has the ability to grow both in areas where maize does well and in high altitude areas where maize does not do well, and its production is currently 9-10 t ha^{-1} which is quite high as compared to maize production of 5.7 t ha^{-1} (KEPHIS, 2016). Also, potato is one of the most productive food crops, producing more dry matter (food) per hectare than cereals (Degebasa, 2020). In Kenya, it provides direct employment to about 800,000 farmers and indirectly supporting about 2.5 million people who are involved in the potato value chain (Kaguongo & Maingi, 2014). The availability of quality seed potato leads to higher production rate and minimizes the cost of production. It is predicted that with quality seed, Kenya can close the productivity gap to 20-40 t ha^{-1}. One way of solving this problem is by producing seed potato using the hydroponic system which ensures production of clean, pest and disease-free seed coupled with efficient water and nutrient utilization. Sufficient production of certified seed through the use of hydroponics can reduce the cost of seed improving the availability and use by small-holder farmers. The current study therefore aims at optimizing nutrient solution concentrations for enhanced yield and quality of seed potato cultivars. The findings of this study will contribute to the existing knowledge on seed potato production.

CHAPTER TWO
LITERATURE REVIEW

2.1. Global production of potato

Potato (*Solanum tuberosum* L.) is grown in all continents inhabited by humans apart from Antarctica. It is the world's most important root and tuber crop grown in more than 125 countries and consumed almost daily by more than a billion people globally (Pandey *et al*., 2020). In the year 2019, over 370 million tons of potatoes were produced globally which was an increase of 36 million tons from 2010 production level (FAO, 2019). China is the leading potato producer in the world, producing approximately 90,259,155 tonnes annually, followed by India and Ukraine (Ortiz & Campos, 2020). Sub-Saharan Africa produces more than 7 million tons of potato annually, accounting for 5% of the global production. In Africa, Egypt, Malawi, South Africa, Algeria, and Morocco produce more than two-thirds of the continent's total production (Ortiz & Campos, 2020). Global potato production and productivity faces relatively similar challenges such as prolonged drought, pest and diseases and soil infertility (Hussain, 2016). However, developed countries are more resilient to these shocks and have a relative advantage in mitigating these challenges over developing countries (Wijesinha-Bettoni & Mouillé, 2018).

2.2 Potato production in Kenya

Potato is a promising enterprise that can play a major role towards achieving the Big Four Agenda since it has the potential to address unemployment, food security and low income due to its high productivity and its numerous uses (MoALF, 2016). It serves as a staple food and cash crop to many rural and semi-urban households (KIA, 2020). Nearly 90% of potato farmers are small-scale, living in densely populated highland regions owning 0.25-5 hectares of land totalling to about 90,000ha (Janssens *et al*., 2013; Nyangeri, 2011). In 2015, potato consumption per capita in Kenya ranged from 30-40 kg per year and increased to 100kg by 2016 due to urbanization (MoALF, 2016).

The major potato growing counties in Kenya include: Narok, Bomet, Nyandarua, Elgeyo-Marakwet, Trans-Nzoia, Bungoma, Uasin-Gishu, Kiambu, Taita-Taveta, Nakuru, West Pokot, Nyeri and Meru. Upcoming counties include: Tharaka Nithi, Kajiado, Embu, Makueni, Samburu, Kwale, Nairobi and Machakos (NPCK, 2019). There are two potato production seasons per year which are based on the bimodal rainfall patterns in most growing regions (Muthoni *et al.*, 2017). The seasons are during the long rains that occur between March-July and short rains in October-

January (Janssens *et al.*, 2013). In Kenya, potato yield has been declining at the rate of 11% per year (FAO, 2010). Currently, the yields are between 7-10 t/ha and this has been attributed to high occurrence of pest and disease attack, adverse weather conditions, declining soil fertility, use of low yielding varieties and poor quality seed potato (Kaguongo *et al*., 2013). As a result of low yields, the profitability of potato crop has declined as well.

2. 3 Seed potato production in Kenya

Certified seed potato production in Kenya is faced with challenges such as lack of adequate land to practice crop rotation, increased prevalence of pest and diseases, poor crop nutrition and unfavourable weather conditions (MoALF, 2016). Inadequate seed potato varieties and shortage of certified seed potato has affected the expansion and profitability of potato industry in Kenya (MoALF, 2016). Currently, there are two seed production systems in Kenya: formal and informal seed production systems (Mbiyu *et al*., 2012). The formal sectors which produce certified seed potato include: government institutions; Kenya Agricultural and Livestock Research Organization (KALRO) Tigoni, Agricultural Development Corporation (ADC) and more recently Egerton University and Baraka Agricultural College. Private entities include Kisima Farm, Stokman Rozen Kenya Ltd and International research organizations such as International Potato Centre (CIP) (Mbiyu *et al*., 2012). However the formal sector cannot meet the demand for seed potato, leading to high seed cost which accounts for up to 42% of the total production costs (Kaguongo *et al.*, 2010). One acre of land requires 800-1000kgs of seed potato costing between 48,000-60,000 Kenya shillings (KES), in addition to transportation costs which further raise the cost of production (Kibe & Ngumba, 2020).

The informal sector has accelerated the adoption of conventional method of seed potato production which entails the use of soil as a media for seed multiplication (Mbiyu *et al.*, 2012). Though the conventional method is widely used in Kenya, it has a low multiplication rate in addition to encouraging build-up of tissue borne viruses, fungi and bacteria (Janssens *et al*., 2013; Tessema & Dagne, 2018). Increased infestation by insect pests, nematodes and seed-borne diseases such as bacterial wilt, late blight of potato and potato viruses have led to an overall decline in seed quality and yield leading to low productivity of 10t ha^{-1} (Kaguongo *et al.*, 2010). There is therefore need to adopt seed multiplication strategy that will ensure continuous supply and maintenance of pathogen-free seed production (Abebe *et al*., 2013). The production of high quality seed remains the key challenge in the development of the potato industry; and improving seed potato quality and availability will be one way of improving potato productivity.

2.4 Hydroponics in seed potato production

Rapid multiplication techniques (RMT) provide a distinct opportunity to produce seed potato at an enhanced rate in a controlled environment (Tessema & Dagne, 2018). These RMT techniques include micropropagation (micro-tubers and plantlets), cuttings (single-node and apical, tuber-sprout), aeroponic and hydroponics (Harahagazwe *et al*., 2018). Hydroponics is a technique of growing plants in nutrient solutions with or without the use of inert medium such as perlite and cocopeat to provide mechanical support (Sharma *et al*., 2019). In this system, plants can take all the required nutrients directly through their roots through fertigation. According to Tessema and Dagne (2018) 1 acre hydroponic greenhouse can produce same yield as 10 acres of field grown produce. Hydroponically produced seed potato may yield up to 200% more than soil produced seed (Woznicki *et al*., 2021).

Hydroponics technique has gained high adoption rate due to low initial and seasonal cost, it reduces the dependency on weather and also allows 90% water and nutrient utilization due to recirculation (Woznicki *et al.*, 2021). However, recirculation has created favourable conditions for the development and spread of diseases (Beata *et al*., 2020). Tessema and Dagne (2018) reported that the use of hydroponic system increased the overall seed potato production capacity from 43,000 to 650,000 minitubers and consequently improved the productivity and the seed quality. Beata *et al*. (2020) reported that the use of hydroponics in ARC production is economical since water and nutrient flow by gravity reduces the reliance on constant electricity supply. Additionally, hydroponic produces large seed tubers per plant compared to other RMTs (Beata *et al.*, 2020). The success of hydroponic system is however limited to optimal crop nutrition (Chang & Lee, 2016).

2.5 Utilization of cocopeat in hydroponic production.

Coconut coir dust commercially known as cocopeat is an affordable organic planting medium obtained after extraction of fibre from the coconut husk which has an easy absorbing and water saving attribute (Singh *et al*., 2016). About 70% of the total hydroponically produced seed potato in Kenya utilize cocopeat as a planting medium (Harahagazwe *et al*., 2018). Cocopeat is a suitable growing media with acceptable pH, potassium, EC, and other attributes (Farhan *et al*., 2018). However, untreated cocopeat contains large amounts of sodium (13.90cmol/kg), potassium (33.33cmol/kg), and chlorides and thus exhibits high salinity (EC>1) and pH of 6.5 (Gbollie *et al*., 2021). Sitawati *et al*. (2017) reported that soil + cocopeat had the highest number of tubers but the fresh weight and dry weight was low as compared to soil+ compost. Perlite + peat moss had the highest number of minitubers and highest weight as compared to perlite +soil (Kamrani *et al.*, 2019).

2.6. Rooted apical cuttings

Rooted apical cuttings (ARC) is a nursery grown seedling produced vegetatively through tissue culture technique as an alternative to minitubers (Parker, 2017). Due to shortage of seed potato, Kenya Plant Health Inspectorate Service (KEPHIS) who regulate seed certification, has endorsed the use of ARC and has integrated this technology into seed potato certification protocol (KEPHIS, 2018). Pre-basic seeds production using ARC has facilitated the production of economical, viable, high quality seeds in a short period of time and in an eco-friendly manner (Beata *et al*., 2020). The use of ARC has increased minitubers production from 30,000 to 1,000,000 minitubers from 2016-2019 in Kenya (IFC, 2019). Harahagazwe *et al.* (2018) reported that ARC produced in seven countries in Africa produced more than 7.5 million minitubers in a single season; representing the quantity of seed required to plant over 151ha per season.

According to Nikmatullah *et al*. (2021) ARC can be utilized as a seed multiplication technology to increase breeder seed and foundation potato seed. Proper use of ARC can reduce cost per hectare of marketable seed by approximately 300 USD, increasing affordability and accessibility of quality propagation material (IFC, 2019). However, the adoption of ARC is quite low in Kenya indicating that there is need to create awareness on the importance of using rooted apical cuttings (Harahagazwe *et al.*, 2018). To ensure the success of this technology, there is need to build market demand for ARC, which will rely on diversifying end-user needs (Parker, 2017).

2.7. Nutrient management in hydroponic seed potato production

Nutrition is an important factor in determining crop yield and quality (Asao, 2012). All the 17 essential plant nutrients are required for the growth and development of plants. In hydroponics, these essential elements are supplied as nutrient solutions using different formulations (Sakamoto & Takahiro, 2020). Management of nutrient solution composition, water quality and supply, pH and EC of the nutrients is essential for proper plant growth and development (Tessema & Dagne, 2018).

The optimum pH for seed potato under the hydroponic system is 5.5-6.5, a change in which leads to either alkalinity or acidity affecting nutrients uptake (Sharma *et al*., 2019). According to Corrêa *et al*. (2010) pH >6.0 led to reduction of micro-nutrient absorption and increased susceptibility to *Streptomyces scabies* in potato. Electrical conductivity of a potato hydroponic should be between EC of 0.8 to 1.4dSm^{-1} (Sakamoto & Takahiro, 2020). Trejo-téllez and Gómez-merino (2012) reported that high EC hinders nutrient uptake by increasing osmotic pressure while low EC severely affect plant health and yield. According to Calori *et al*. (2017), the use of 1.0 dSm^{-1} in seed potato production led to leaf chlorosis due to nitrogen deficiency while the use of 4.0 dSm^{-1} led to potassium deficiency. The use of sodium and chlorine nutrient formulations is highly discouraged since they increase the EC of the nutrient solution (Otazu, 2010).

2.8. Effect of varying nutrient formulations on the growth of seed potato

The balanced application of macronutrients is important in improving crop growth and development (Rietra *et al.,* 2017). Nitrogen, phosphorus, potassium, magnesium, manganese, calcium, zinc and iron are all reported to have influence of the rate of crop growth. Potato crop requires adequate nutrient supply for optimum growth and yield (Zewide *et al*., 2016).

Plant height increases with maturity and follows the sigmoid growth curve. Increasing the application of nutrient concentrations increase the growth of plants up to the optimum level beyond which increase in the concentrations does not have any effect in height (Iraboneye *et al*., 2020). Nitrogen is one of the most crucial macronutrients for plant growth and biomass development and increase in N concentrations has positive impact of plant height (Koch *et al*., 2020). Nitrogen increases the availability phosphorus where they both could synergistically increase plant height (Zewide *et al*., 2016). According to Mirdad (2010) increase in NPK fertilization increases plant height, foliage and fresh weight of the plant and leaves dry matter. Plant survival is also affected by nutrient solution concentrations (Tsoka *et al*., 2012). In a study done by Aarakit *et al*. (2021), there was significant difference in plant survival with the application of different rates of P in ARC production, with 1.5% P (90kg/ha) application having the lowest plant survival and 0.5% and 1% having no significant difference.

Normalised Difference Vegetable Index (NDVI) is measured using the GreenSeeker^{TM}Sensor (GS) which is used as an indicator of photosynthetic active biomass (Sultana *et al*., 2014). The NDVI is used for the quantification of vegetation by measuring the difference between the near infrared (NIR) (which vegetation strongly reflects) and red light (which vegetation absorb) (Sultana *et al*., 2014). The NDVI has been attributed to variables such as crop nutrient deficiency, grain yields, total biomass and canopy density (Gómez *et al*., 2019). According to Satognon *et al*. (2021) NDVI has been used to assess the amount of nitrogen in potato with increase in the nitrogen fertilizer rate increasing the percentage nitrogen content of the leaf hence a higher plant biomass. Gómez *et al*. (2019) reported that NDVI values differed among potato cultivars and growth stages with a significant increase in NDVI at 125 DAP (tuber filling) and significant difference was also reported between fertilizer doses and cultivars.

Plant biomass production increases with the application of nutrient concentrations (Lee *et al*., 2021). Adequate application of phosphorus and nitrogen influence total leaf area that increases light interception by the crops and this contributes directly to biomass accumulation (Gumede & Kempen, 2017). According to Zewide *et al*. (2016) adequate application of P_2O_5 significantly increased the above ground biomass by 8.78% and underground biomass by 61.4%. The accumulation of biomass varies amongst the varieties that are grown for example *Jalene* variety that was grown in this experiment showed the highest accumulation of biomass with application of nitrogen and phosphorus (Misgina, 2016).

2.9. Effect of varying nutrient formulations on the yield of seed potato

According to Tessema *et al*. (2017) different nutrient concentrations in a hydroponic system affected plant nutrient uptake and crop yield. The potato plant requires optimum nutrients to maximize growth to attain the optimum yield. Fertilizer application corresponds to increased plant growth and yield and care should be taken when choosing the concentrations of nutrients depending with the type of crop (Iraboneye *et al*., 2020). Potato yields can be increased through timely application of phosphorus because it promotes early tuber development, increases tuber number and tuber size (Koch *et al*., 2020).

The use of 50% Factor nutrient formulation gave the highest number of stems, leaves and minitubers in all potato varieties (Calori *et al*., 2017). Conversely, no adverse effects on growth, fruit yield and fruit quality was observed in tomato after a 50% reduction in macro nutrients (Trejo-téllez & Gómez-merino, 2012). Increasing nutrient strength solution by 200% increased the N levels but reduced K availability; this was due to osmotic stress and ion toxicity. Reducing the macro nutrients by half after flowering led to large seed potato size and highest weight was observed (2090g) as compared to the standard (350g) using the Otazu formulation in aeroponic system (Tessema *et al*., 2017). Varying phosphorus level by 50% and 75% had significant effects with 0% (21ppm) reporting less number of tubers and yields while highest tuber number and highest yields was reported at 75% increase in P (75ppm) (Abbasian *et al*., 2018). Increasing nitrogen and potassium content ultimately results to better root growth and increased mineral absorption that leads to increased tuber number per plant and this in turn increase total yield (El-Hadidi *et al*., 2017). Increasing potassium increased potato yields and tuber number per plant this is because it is involved in enzymes activation significant to utilization of energy, starch synthesis, metabolism of nitrogen and respiration (El-Hadidi *et al*., 2017).

2.10 Effect of varying nutrient levels on seed potato quality

Quality seed of an improved potato variety is key to increasing the productivity of a potato crop. The genetic potential and other traits of a potato are determined or manifested using good quality seed potato (Tessema *et al*., 2017). Starch content and dry matter are two overriding factors governing the quality of potato varieties.

Potato starch plays an important role in the potato quality since it affects potato cooking quality (Hosseini *et al*., 2017). Zhang *et al*. (2018) reported that increase in K fertilization rate increased amylose, improved resistance to heat, shear stress and decreased the retro-gradation of starch. Fernandes *et al*. (2015) reported that there was no significant difference between starch content in potato cultivars with no application of P fertilizers, however, increase in P application increased starch contents. This was similar to the results obtained by Hosseini *et al*. (2017) where increasing N and K rates from 0 kg ha^{-1} to 6 kg ha^{-1} increased starch content. In contrast, excess application of N may decrease starch concentration hence reducing dry matter content (DMC) (Koch *et al.*, 2020). According to Abebe *et al*. (2012) different potato cultivars have different starch and DMC with new improved varieties recording low DMC and high starch content.

The dry matter content of tubers is the most important character determining the quality and yield of fried and dehydrated products (Marwaha *et al.*, 2010). Inadequate fertilization affects DM of tubers with N and P being the most important nutrients in determining dry matter (Terraza *et al.*, 2018). Excessive application of P fertilizers was reported to reduce the DM content and specific gravity in the potato tubers (Fernandes *et al.*, 2015). Long maturing varieties have a longer time to accumulate carbohydrates hence they have a higher dry matter and starch content as compared to short maturing varieties (Hasnat *et al*., 2015). According to Akoto *et al*. (2020) increasing phosphorus content increases tuber DM since it has various effects on tuber quality, since it functions in cell division and synthesis and storage of starch in tubers hence, it can increase the size and percentage of dry matter.

Specific gravity is considered one of the most practical indices for potato quality as it is positively correlated with starch content and dry matter (Mohammed, 2016). It is highly influenced by the amount of fertilizer and variety (Hasnat *et al*., 2015). According to Akoto *et al*. (2020) increasing fertilizer application increased specific gravity; however, over fertilization can lower the specific gravity of potato tubers. High specific gravity is important for processing of dehydrated and fried products as it enhances high product recovery rate, lower oil absorption, less energy consumption during processing, better flavor and texture and generally high fried products (Gikundi *et al*., 2021). Increase in nutrient application is reported to increase the specific gravity of Unica and Shangi; however, there were no significant differences between the varieties (Akoto *et al*., 2020).

2.11. Performance of different potato varieties in Kenya

In Kenya, more than 60 potato varieties are grown, but relatively few are widely distributed (Kaguongo *et al*., 2013). The dominance of certain varieties shifts with time due to popularity and also due to preference from region to region. Currently, *Shangi* is the most popular potato variety in Kenya due to its availability and short maturity period (NPCK, 2019). International Potato Center (CIP) has however introduced new improved climate- resilient potato varieties such as *Nyota, Wanjiku, Chulu, Lenana* and *Unica* (VanderZaag *et al*., 2021). Different varieties have different performance (yield variables, number of tubers, tuber weight) and this is attributed to genetic differences (Mbiyu *et al*., 2018). In a survey done on ARC performance in Nakuru by VanderZaag *et al*. (2021) *Wanjiku* reported highest number of minitubers 18.2 (>20mm) followed by *Nyota* (14.5 plants) and *Shangi* (12.8). However, *Shangi* reported the highest multiplication rate followed by *Wanjiku, Unica* then *Nyota.* Aarakit *et al.* (2021) reported highest number of marketable yield in *Shangi* (10.66 tubers per hill) followed by *Wanjiku* (9.87) after uniform application of phosphorus rates. Also, Akoto *et al*. (2020) reported that *Shangi* had highest seed tuber yields (33.7 t ha^{-1}) as compared to *Unica* (33.3 t ha^{-1}) at 60kg ha^{-1} of phosphorus. Conversely, Gikundi *et al*. (2021) reported that there was no significant difference in the tuber weight, length, width and thickness of ware potato of *Unica* and *Shangi* varieties.

CHAPTER THREE
MATERIALS AND METHODS

3.1. Experimental site

Two greenhouse trials were conducted at Egerton University Agronomy, Field Seven, Njoro campus, Kenya. The site lies between 0^{o}22'11.0"South, 35^{o}55'58.0" East and at an altitude of 2670 meters above sea level. The site is in agro-ecological zone III (medium potential) with an average annual rainfall of 800-1500 mm. The rainfall pattern is bimodal; with the short rains falling between October and December, and the long rains between March and June. The maximum temperature is 22.4^{o}C and the minimum temperature is 7.8^{o}C. Potato, maize and wheat are the most common crops grown in this region depending on the farm scale. The soils in this region are well-drained, dark reddish clays, slightly acidic and contain medium levels of organic carbon and low levels of phosphorus classified as *Mollic Andosols* (Jaetzold, 2012).

3.2. Description of the potato varieties

Rooted apical cuttings were sourced from ADC-Molo. *Wanjiku* variety is a medium tall variety with strong semi- erect stems and dark green medium- sized leaves with pinkish flowers. It takes 90-120 days to maturity yielding >40 t ha^{-1} (NPCK, 2019). *Shangi* variety is about 1m high with broad leaves which are light green in colour without anthocyanin pigmentation on the midrib. It has an upright growth and its flowers are abundant and it takes 75-90 days to maturity yielding 30-40 t ha^{-1} (NPCK, 2019). *Nyota* is a medium tall potato plant with strong semi erect stems and dark green medium size leaves with pink flowers. It takes 90-120 days to maturity yielding >40 t ha^{-1}(NPCK, 2019). *Unica* variety is a medium tall variety with strong semi- erect stems and dark green medium- sized leaves. It flowers profusely and the flowers are pink. It takes 80-90 days to maturity yielding >45t ha^{-1} (NPCK, 2019).

3.3. Cocopeat media analysis and preparation

Cocopeat was prepared by following the methods described by Gbollie *et al.* (2021). Cocopeat was briefly soaked for 36 hours using Calcium Nitrate (100g $CaNO_3$ per 1.5kg of cocopeat) to extract K and Na. It was then rinsed with tap water and hydrogen peroxide was added according to Larry *et al*. (2006) to kill pests (0.5 mL into 1L of tap water). The cocopeat was rewashed using tap water and left to stand till dry. Samples of cocopeat were analysed for EC, pH, Ca, N, C, Mg, Na, P and K at KALRO Kabete. The pH was determined according to Okalebo *et al*. (2002), where deionized water was added to the cocopeat (20 ± 1g of media). The solution was stirred for 10 minutes and left to stand for 30 minutes after which it was stirred for 2 minutes. The pH was then measured using a pH meter (pHep®4 pH-HI98127 made by HANNA Company). The electrical conductivity was determined using the same solution using an EC meter (HI98304 DiST 4 made by HANNA Company).

Nitrogen was analysed using Kjeldahl method of digestion as described by Okalebo *et al.* (2002). The samples were digested by placing 0.3g of dried cocopeat into the digestion tubes and 2.5ml of the digestion mixture was then added. The digestion mixtures were prepared by adding 0.42g selenium powder and 14g lithium sulphate in 350ml 30% Hydrogen peroxide. About 420ml of concentrated H_2SO_4 was then added to the mixture and cooled in an ice bath. The mixture was digested for one hour at 110^oC in the digestion chamber. The temperature was then raised to 330^oC until a colourless solution was obtained after which the mixture was allowed to cool. About 25ml of distilled water was mixed to dissolve any sediment and finally the solution was topped up to 50ml by distilled water. About 10ml of the aliquot of the sample was placed at the reaction chamber where 1% sodium hydroxide was added. The ammonia released was transferred into a receiver vessel where 5ml of 1% of boric acid containing 4 drops of the mixed indicators was added forming solvated ammonium ions. Distillation was done until a green colour forms. Titration was then done using 0.25mol/l hydrochloric acid and an indicator until a slightly violet colour was obtained.

Carbon was determined using the Walkly-black method. The procedure was done according to Okalebo *et al*. (2002). Here, the oxidizable carbon in the cocopeat was oxidized by 0.167M potassium dichromate solution in concentrated sulfuric acid. Carbon was then estimated by measuring the remaining unreduced dichromate by back-titrating with ferrous sulphate using diphenylamine as an indicator. Phosphorus was determined following Bray 2 procedures as outlined by Okalebo *et al*. (2002). Phosphorus was extracted using a digestion mixture of hydrogen peroxide + concentrated sulfuric acid + selenium powder + salicylic acid at temperatures of 110^oC to 330^oC. After samples extraction, the concentration of phosphorus in sample solution was determined calometrically.

Potassium, calcium, magnesium and sodium were determined using the same procedure as explained by Okalebo *et al*. (2002). About 5g of the cocopeat was weighed and 100ml of 1M (NH_4OAc) solution was added after which the mixture was then shaken for 30 minutes then filtered. The mixture was then diluted ten times and 5ml of the mixture was pipetted into a 50ml volumetric flask. One ml of 26.5% lanthanum chloride solution was added to the contents. The mixture was then sprayed into the flame photometer to determine K, Ca, Mg and Na at a wavelength (λ) of 422.7 nm, 766.5nm, 285.2 nm and 589nm, respectively.

The concentrations of K, Ca, Mg and Na were calculated as:

$$\textbf{K, Ca, Mg and Na} = \frac{(a-b) \text{ x } v \text{ x } f \text{ x } 1000}{1000 \text{ x } w} \quad \text{.......................... (Equation 1)}$$

Where; a= concentration of K, Ca, Mg and Na in the sample extract, b = concentration of analyst in the black extract, v= volume of the extract solution, w= weight of the sample and f= dilution factor.

3.4. Water analysis

To check the suitability of water for irrigation, an aliquot of irrigation water was taken for analysis at KALRO, Kabete. The analysis was done based on the procedures explained in section 3.3 above. The pH and electrical conductivity (EC) were measured using pH (pHep®4 pH-HI98127) and EC (Hanna-pHep®4 pH-HI98127) meters made by HANNA Company. Sodium, potassium, calcium and magnesium analysis were determined according to Okalebo *et al.* (2002); where Na, K, Ca and Mg concentrations was measured using a flame photometer at 589 nm, 766.5 nm, 422.7 and 285.2 nm wavelengths, respectively. The chloride concentration of the water sample was determined by titrating an aliquot with silver nitrate and potassium dichromate while carbonates was analysed as bicarbonates by titrating the sample with hydrochloric acid and phenolphthalein (Cox *et al.*, 1967).

3.5. Preparation of the planting materials

Rooted apical cuttings were hardened in the greenhouse for 7 days before transplanting into the planting troughs (Tsoka *et al*., 2012).

3.6. Experimental design and treatment combination

The experiment was laid out in a split plot design in Randomized Complete Block Design (RCBD) arrangement with three replications. The nutrient solutions were the main plot and the varieties were the sub plots. The ADC Molo nutrient formulations were administered in three different concentrations (1.0, 0.75 and 1.25 strength solution) (Table 1) and the treatment combinations were as described in Table 2.

ADC Molo nutrient solution: Stock solution B: Ca $(NO_3)_2$ (29.5 g), KNO_3 (11.5 g), KH_2PO_4 (34.0g) and Stock solution A: $MgSO_4$ (61.0g), Microsol-B (3.0g) and Iron (Fe-EDTA) (4.5g).

Table 1: Nutrient concentrations compositions (250 litre dilution)

	$Ca(NO_3)_2$	KNO_3	$MgSO_4$	KH_2PO_4	Microsol-B*	Iron (Fe-EDTA)
0.75% **(N75)**	22.125 g	8.625 g	45.750 g	25.500g	2.250 g	3.375g
100% **(N100):** Control	29.500 g	11.500 g	61.000g	34.000g	3.000g	4.500g
125% **(N125)**	36.875 g	14.375 g	76.250g	42.500g	3.750g	5.625g

[Microsol-B* is a commercial foliar micronutrient powder formulated as Cu (0.1 g), Zn (0.3g), B (0.7g) Mo (0.1 g) and Mn (1.5g)]

Table 2: Treatment combinations of NSSC concentrations and ARC potato varieties

	Varieties			
NSSC	**Shangi**	**Nyota**	**Wanjiku**	**Unica**
N75	N75 V_S	N75V_N	N75V_W	N75V_U
N100	N100 V_S	N100V_N	N100V_W	N100V_U
N125	N125 V_S	N125 V_N	N125 V_W	N125 V_U

NSSC-Nutrient stock solution concentrations, N75 (75%), N100 (100%) and N125 (125%); V_S-Shangi, V_N-Nyota, V_W- Wanjiku and V_U-Unica

The experimental site (Greenhouse) measured 750cm by 800cm. Each experimental plot (troughs) measured 30cm by 700cm and was placed in a slanted position on the ground to allow drainage. Two tanks were used per nutrient solution concentration with one being an inlet of 1500 litres and the other being the outlet of 250 litres. The inlet tanks were raised at an elevation of 1.5m and the outlet tank were placed at the end of the troughs to collect the excess nutrient solutions. About 120 kg of cocopeat were placed in each planting troughs considering that one plant requires 2 kg of air dried cocopeat. Rooted apical cuttings of the four potato varieties and each level of nutrient solution concentration were assigned to every experimental plot (Figure 1). A plant population of 80 plantlets per plot was attained with interplant spacing of 15cm and an inter-row spacing of 15cm. A divider was placed in the troughs to separate the potato varieties. The nutrient solutions were prepared with tap water and EC of the nutrient solution was measured using an EC meter (pHep®4 pH-HI98127 made by HANNA company) and the pH was measured using pH meter (pHep®4 pH-HI98127 made by HANNA company). The pH and EC were maintained at 5.5-6.5 and 1mS cm^{-1}, respectively using sodium hydroxide and phosphoric acid in all the nutrient stock solution concentrations (Putra *et al*., 2019).

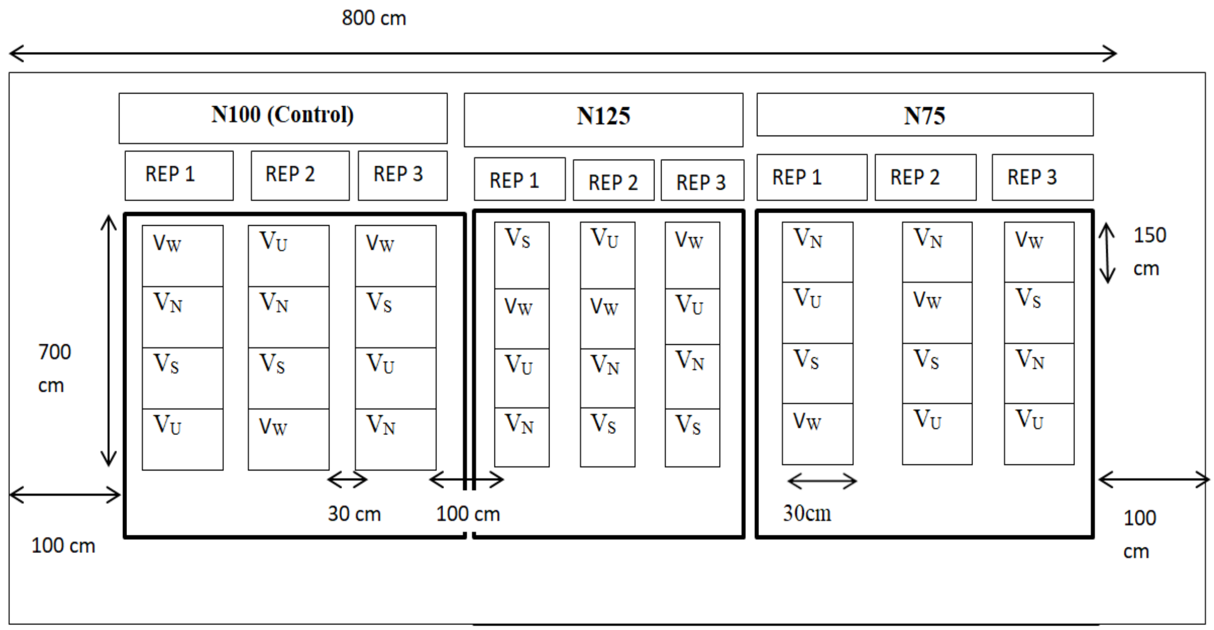

Figure 1: Experimental layout

Where;

V_S - *Shangi* N75- 75% nutrient concentration

V_W - *Wanjiku* N100- 100% nutrient concentration

V_N- *Nyota* N125- 125% nutrient concentration

V_U- *Unica*

All plots were irrigated at equal time intervals depending on environmental conditions using drip lines. Lateral drip lines that supply 1.6 L h^{-1} per dripper were placed in each row. The drippers were spaced at 20 cm apart. To control potato diseases and pests, appropriate fungicides and pesticides were used, respectively. Weeding was manually done once they appeared while earthing up was carried out a month after planting. Dehaulming was done two weeks before harvesting for tuber skin hardening and tuber bulking before harvesting.

3.7. Data collection

Data on plant growth, yield and quality of minitubers produced was collected from 5 plants that were randomly selected.

3.7.1 Objective 1: To determine the effects of nutrient concentrations on the growth of rooted apical cuttings seed potato varieties

Plant height- plant height was taken to be the distance from the base of the plant to the highest point of the plant (Aarakit *et al*., 2021). It was measured using a ruler (cm) from the surface of the media till the highest point of the plant at 15, 30, 45 and 60 Days after Planting (DAP).

Plant survival- These were all the plants that remained green after being planted into the experiment trough (Tsoka *et al*., 2012). The numbers of surviving plants were manually counted at 14 DAP and 75 DAP and the percentage plant survival was calculated using the following formula:

Plant survival (%) = $\frac{\text{surviving plants after 14 DAP}}{\text{number of plants planted}} \quad X\ 100$ (USEPA, 2018)…. (Equation 2)

Plant above ground biomass- This was determined as described by Iraboneye *et al*. (2020) where the top biomass (stem, leaves and flowers) of the individual plants per plot were taken during dehaulming and were weighed using an electric weighing balance (1708-374 Precisa 310M made by Precisa Gravimetrics, Switzerland).

Above ground dry matter- the top biomass of the plants was weighed and dried for 72 hours at 60^{O}c and weighed again. To obtain dry matter percentage, the following equation was used:

Dry matter (%) = $\frac{\text{weight of sample after drying (g)}}{\text{initial weight of the sample}} \quad X\ 100$ (Agle & Woodbury, 1968)..(Equation 3)

Normalised Difference Vegetable Index (NDVI) - this was taken every two weeks till 75 DAP using the Green-Seeker sensor (HCS-100 GreenSeeker, Trimble, Carlifonia, USA) which used a self-illuminating light source in the near-infrared and red wavelengths, (650±10nm) and (770±15nm) respectively. Readings were obtained about 60cm over the top of the potato plant (Zaeen *et al.*, 2020).

3.7.2. Objective 2: To determine the effects of nutrient solution concentrations on the yield of rooted apical cuttings seed potato varieties

Numbers of tubers – all tubers per plant (tagged) were counted during harvesting. The number of tubers was obtained by averaging tubers obtained per plant per treatment.

Weight of tubers –Tuber weight (g) of individual tagged plants was measured using an electronic weighing balance after harvest according to the method described by Gikundi *et al*. (2021). The average weights for each plot were calculated to obtain mean weight.

Total yield- Total yield was determined using the formula:

yield (t ha^{-1}) = $\frac{\text{Yield (kg) X 1000m2}}{\text{number of plants harvested X planting distance}}$ (Gbollie *et al*., 2022)……(Equation 4)

Minitubers sizes- tuber sizes were graded as described by Gbollie *et al*.(2022). The tubers were weighed and categorized into four different sizes <8.00 g, 8.01-15.99 g, 16-18 g, and >18.00 g represented as C1, C2, C3 and C4, respectively.

3.7.3 Objective 3: To determine the effects of nutrient concentrations on the quality of minitubers produced from rooted apical cuttings of various seed potato varieties

Prior to evaluation, the tubers were cleaned using a dry towel to get rid of any cocopeat and any other inert matter on the tuber. Under yield attributes, three main parameters; minitubers dry matter, specific gravity and starch content were measured.

Minitubers dry matter- five randomly selected tubers from each plot were weighed sliced and mixed thoroughly then oven dried for 72 hours at $60^{O}C$ to obtain dry matter percentage.

Dry matter (%) = $\frac{\text{weight of sample after drying (g)}}{\text{initial weight of the sample}}$ X 100 (Agle & Woodbury, 1968)….(Equation 5)

Specific gravity- specific gravity was determined using the weight in air and weight in water method where five tubers were selected from each plot and washed with water then weighed first in air and then in water. The specific gravity of the tubers was calculated using the following formula (Gikundi *et al*., 2021).

Specific gravity (gcm^{-3}) = $\frac{\text{weight in air}}{\text{weight in air} - \text{weight in water}}$ ……………. (Equation 6)

Starch content- Starch content of the tubers was determined according to method 996.11 of the Association of Official Analytical Chemists (AOAC, 1995).

About 5kgs of seed potato from each treatment was washed and grinded through a 0.5-mm screen and 25 mg of the sample was placed in a test tube. About 1 ml of ethanol solution (80% v/v) and 2 ml of distilled water was added to the test tube. About 10 ml of hot ethanol was then added into the sample which was then mixed thoroughly by vortexing. The samples were then centrifuged at 2000g for ten minutes at room temperature. Next, the supernatant was decanted into a boiling tube and 7.5ml of per-chloric acid was added to the sediments and left for one hour at 17.5ml of distilled water was added to the filtrate. About 1ml of the extracted filtrate was pipetted and mixed with 1ml of distilled water. About 0.5ml of phenol was added and vortexing was done thoroughly. This was followed by an addition of 2.5ml of concentrated sulphuric acid and vortexing was repeated. The samples were then left to cool at room temperature for about ten minutes and vortexing was done again. For blanks, 0.1 ml of water was used instead of 0.1 mL of diluted solution, and other added reagents were added the same time. Samples were read for absorbance at 510nm.

Starch (%wet basis) = $100 * \frac{(A-1)*DF2*V2*0.9}{B*W*10\wedge6}$……………………………………..(Equation 7)

Where:

A=Absorbance of sample

I=Intercept of standard curve

D.F2= Dilution factor based on aliquot of sample extract taken for assay

V2= Total extract volume (mL)

B= Slope of the standard curve (Ml/µg)

W= Sample weight (mg)

3.8. Data analysis

Data collected were first subjected to Shapiro-Wilk test for normality test at $p \leq 0.05$. For any abnormally distributed data, data transformation was done based on the best suitable method using SAS statistical software version 9.4. General Linear Models (GLM) procedure of SAS was used for ANOVA. Means separation was done using Tukey's Honest Significant Difference test at a probability level of $p \leq 0.05$ level of significance. Regression analyses were done using Microsoft Excel. Linear ($y=a+bx^2$) and quadratic ($y=a+bx+bx^2$) regressions were developed to explain the relationships of the dependent variable (y, i.e., yield, above ground biomass (AGB), NDVI, minitubers DM, size, weight and number) to independent variables (x, i.e., NSSC, NDVI, height, maturity, AGB). Correlation analysis was performed to examine the relationship between plant height, number of leaves, NDVI, plant survival, number of tubers, dry matter of the tubers and top biomass, top biomass fresh weight, weight of tubers and tuber class, specific density, dry matter and starch content (Gomez & Gomez, 1984).

$\boldsymbol{r} = \frac{n(\sum xy)-(\sum x)(\sum y)}{\sqrt{[n\sum_x 2-(\sum_x)2}\,[n\sum_y 2-(\sum_y)2}}$ ……………… correlation coefficient……………….. (Equation 8)

Where:

r= Correlation coefficient,

Σ= Sum,

x= Values of x-variables in the sample,

y= Values of y-variables in the sample,

The statistical model that was used for the experiment was split plot in RCBD

$y_{ijk} = \mu + \beta_j + N_i + (V\beta)_{ij} + N_K + (VN)_{Ik} + \varepsilon_{ijk}$……………………………………………………………(Equation 9)

Where;

y_{ijk} =	Overall observation
μ =	Overall mean
B_j=	Effects of j[th] block
N_i=	Effects of i[th] nutrient solutions (whole plot)
$(V\beta)_{ij}$ =	Random error corresponding to nutrient solutions and block
V_K =	Effect of the k[th] varieties (subplot)
$(NV)_{ik}$ =	Interaction between nutrient solution and varieties
ε_{ijk} =	Random error

CHAPTER FOUR

RESULTS

4.1. Effects of nutrient stock solution concentrations on the growth of apical rooted cuttings varieties

Growth parameters, i.e., plant height and Normalised Difference Vegetation Index (NDVI) were taken periodically at 15 days intervals. Plant survival (%) was taken at 14 and 75 days after planting (DAP) while above ground biomass weight fresh weight and dry matter was determined after dehaulming. The treatments used in the experiment were four potato rooted apical cutting (ARC) varieties namely; Shangi (V_S), Nyota (V_N), Wanjiku (V_W) and Unica (V_U) which were grown (in sub-plots) and three (3) nutrient stock solution concentrations (NSSC) (allocated in main-plots) (Fig. 1). The control NSSCs' treatment N100 was the conventionally used ADC Molo standard stock solution concentration (SSSC) as given in Table 1. For treatment N75 and N125, the nutrients were applied at 75% and 125% of the control treatment (N100), respectively.

4.1.1 Effect of nutrient stock solution concentrations on heights of potato rooted apical cutting varieties

Effect of nutrient stock solution concentrations on the height of ARCs

Results in Figure 2 and 3 below shows that the height of rooted apical cuttings significantly ($P \leq 0.05$) increased with maturity under varying NSSCs in both experiments. The application of nutrient stock solutions had significant effect in the height of the ARCs. At 15 DAP, N125 (8.12cm and 8.37cm in experiment one and two respectively) and N100 (6.96cm and 7.89cm in experiment one and two respectively) were significantly taller than N75 (5.28cm and 5.27cm in experiment one and two respectively). At 30 DAP, all nutrient solutions differed significantly ($p \leq 0.05$) with N125 producing the tallest plant (13.08cm) followed by N100 (9.69cm) and N75 produced the shortest plants (7.92cm) in experiment one while in experiment two, N125 (13.62cm) produced significantly taller plants as compared to N100 (9.53cm) and N75 (8.32cm). At 45 DAP, N125 gave the tallest plants (23.17cm ad 23.75cm in experiment one and two respectively) which was significantly different from N100 (16.22cm and 16.39cm in experiment one and two respectively) and N75 (14.96cm and 14.83cm in experiment one and two respectively). At 60 DAP, all nutrient solutions differed significantly with N125 producing the tallest plants (29.91cm) followed by N100 (20.63cm) and the shortest plants were produced by N75 (18.82cm) in experiment one while in experiment two, N125 (31.29cm) produced significantly taller plants as compared to N100 (22.41cm) and N75 (19.15cm).

Growth of ARCs under varying NSSC was analysed using regression analysis and by fitting linear and quadratic regression curves as depicted in Figs 2 and 3 below for experiment one and two, respectively. The response of height to all NSSCs treatments followed a sigmoid curve. These responses could best be explained by fitting quadratic mathematical functions ($y= a+bx+cx^2$). The best regression was curvilinear with a very high goodness of fit, R^2 = 0.99 in both experiments (Figs 2 and 3).

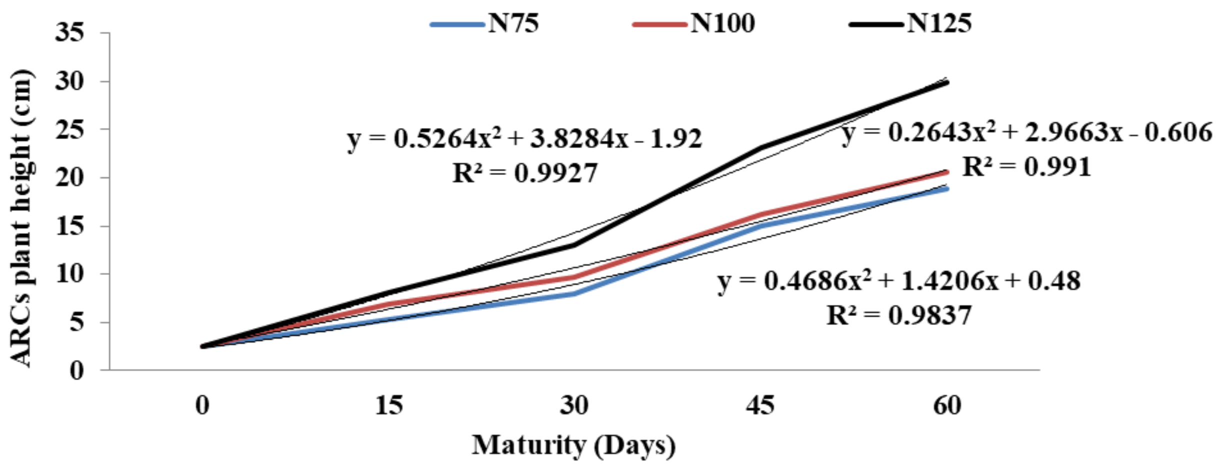

Figure 2: Main effects of nutrient stock solution concentrations on combined heights of potato rooted apical cuttings in experiment one

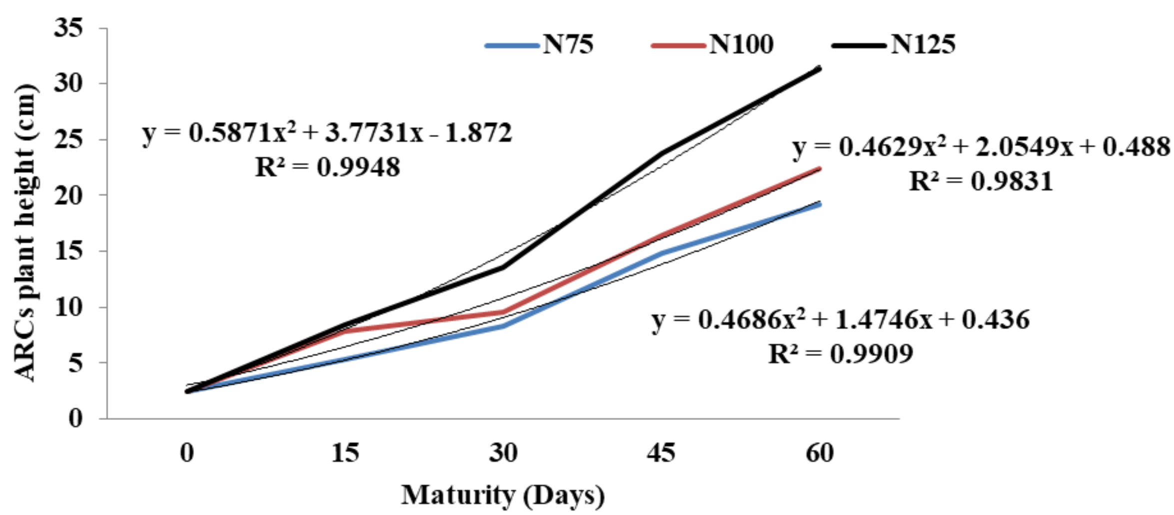

Figure 3: Main effects of nutrient stock solution concentrations on combined heights of potato rooted apical cuttings in experiment two

Effect of potato rooted apical cuttings varieties on height

Height of the potato varieties increased with maturity and the growth trends followed a sigmoid curve. The height of all potato varieties were significantly different ($P \leq 0.05$) throughout the growing stages (15th, 30th, 45th, and 60th days after planting) in both experiments (Fig 4 and 5). During early growth stage (15th DAP), Nyota (7.46cm) and Wanjiku (7.04cm) were significantly taller than Shangi (6.72cm) and Unica (5.92cm). By the 30th day, Nyota was significantly taller than the other varieties. By the 45th and 60th DAP, Nyota and Wanjiku were significantly taller than Shangi and Unica in experiment one. Also, in experiment two, Nyota (26.9cm) and Wanjiku (26.02cm) were observed to be taller ($p \leq 0.05$) than Shangi (22.8cm) and Unica (22.77cm) by the 60th DAP. Experiment two had relatively taller plants (22.02cm-26.90cm) than experiment one (21.47cm-25.08cm) crops. Growth during the initial 15 days was slow followed by an increased growth rate up to the 30th day and thereafter a decline up to the 60th day in both experiments as given in Figs 4 and 5 below.

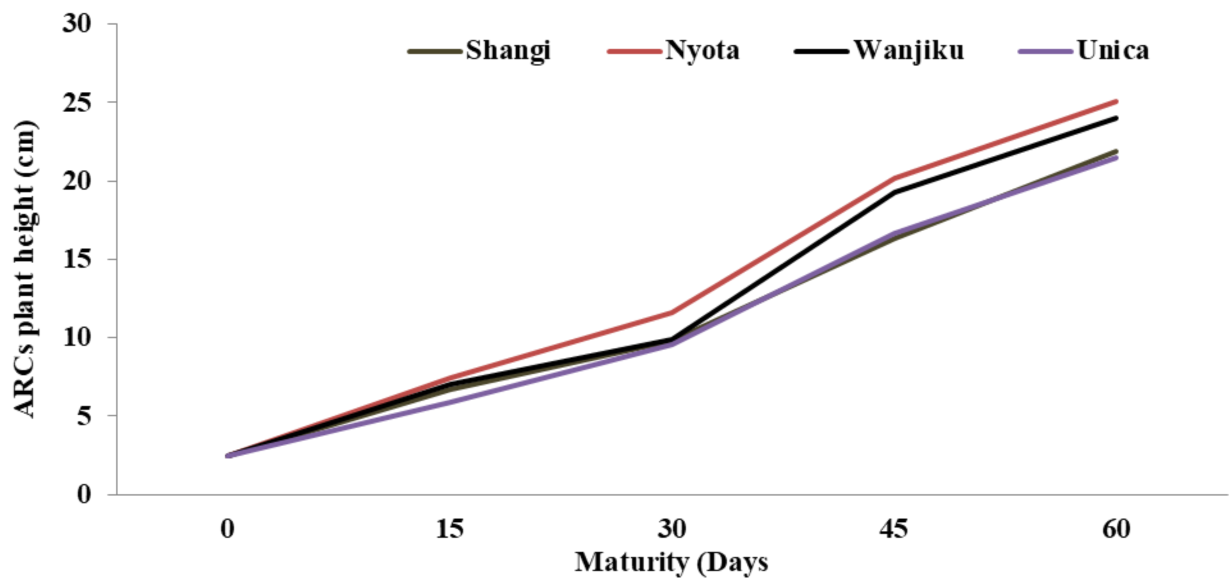

Figure 4: Effect of potato rooted apical cuttings varieties on height in experiment one

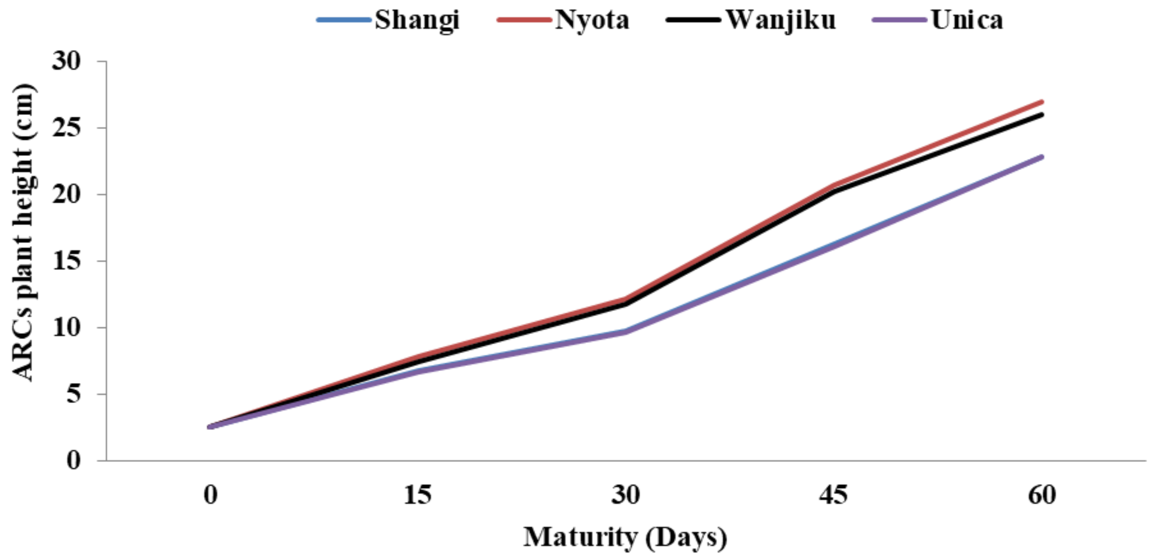

Figure 5: Effect of potato rooted apical cuttings varieties on height in experiment two

Effect of the interaction of the nutrient stock solution concentrations and ARC varieties on the height

There was no significant interaction ($p \leq 0.05$) with the application of nutrient stock solution concentrations (NSSCs') and potato varieties in both experiments except on the 30th DAP in experiment one (Table 3). The shortest ARCs were observed for all varieties under the N75 stock solution. Under N75, at 15 DAP Nyota had a plant height of 5.73cm followed by Wanjiku (5.61cm), Shangi (5.37cm) and Unica (4.41cm) in experiment one while in experiment two, Nyota had 5.80cm followed by Wanjiku (5.59cm), Shangi (4.96cm) and Unica (4.74cm). At 30 DAP, all varieties did not differ significantly in experiment one with Nyota reporting 8.95cm followed by Wanjiku (8.03cm), Shangi (7.38cm) and Unica (7.31cm). In experiment two, no significant interaction was observed. Nyota had 9.42cm followed by Wanjiku (9.25cm), Unica (7.40cm) and Shangi (7.23cm). At 45 DAP, Nyota had 17.25cm followed by Wanjiku (16.30cm), Shangi (12.68cm) and Unica (13.60cm) in experiment one while in experiment two, Nyota had 16.84cm which was followed by Wanjiku (16.74cm), Shangi (12.88cm) and Unica (12.86cm).

At 60 DAP, Nyota had 20.02cm and 20.99 cm in experiment one and two, respectively which was followed by Wanjiku (19.75cm and 20.52cm in experiment one and two, respectively), Shangi (17.97cm and 17.49cm in experiment one and two, respectively) and Unica (17.52cm and 17.61cm, in experiment one and two respectively) (Table 3).

Under N100, at 15 DAP, Nyota had a plant height 7.67cm followed by Wanjiku (7.65cm), Unica (6.30cm) and Shangi (6.21cm) in experiment one while in experiment two, Nyota had 8.49cm followed by Wanjiku (8.32cm), Shangi (7.39cm) and Unica (7.38cm). At 30 DAP, significant interaction was evident with Nyota having a plant height of 11.33cm which was significantly different from Unica (7.61cm) but not significantly ($p<0.05$) different from Wanjiku (9.93cm) and Shangi (9.89cm) in experiment one while in experiment two, there was no significant interaction between the NSSC and the varieties ($p<0.05$). Nyota had 10.95cm followed by Wanjiku (10.56cm), Shangi (8.35cm) and Unica (8.25cm). At 45 DAP; Nyota had a plant height of 18.04cm and 18.77cm in experiment one and two, respectively. This was followed by Wanjiku (17.03cm and 18.77cm in experiment one and two, respectively), Unica (15.26cm and 13.89cm in experiment one and two, respectively) and Shangi (14.54cm and 14.12cm in experiment one and two, respectively) (Table 3). At 60 DAP, Nyota had (23.39cm) followed by Wanjiku (21.38cm), Shangi (19.66cm) and Unica (18.07cm) in experiment one while in experiment two, Nyota had 24.75cm followed by Wanjiku (23.71cm), Shangi (20.77cm) and Unica (20.40cm).

Under N125, at 15 DAP, Nyota had a plant height of 9.00cm followed by Shangi (8.56cm), Wanjiku (7.85cm) and Unica (7.06cm) in experiment one while in experiment two, Nyota had 9.13cm followed by Wanjiku (8.01cm), Shangi (8.01cm) and Unica (7.88cm). At 30 DAP, the varieties did not differ significantly ($p\leq0.05$). Nyota had a plant height of 14.63cm followed by Wanjiku (13.74cm), Shangi (12.16cm) and Unica (13.78cm) in experiment one while in experiment two, Nyota had 15.99cm followed by Wanjiku (15.48cm), Shangi (13.69cm) and Unica (13.35cm) in experiment two. At 45 DAP, Nyota had 31.84cm, followed by Wanjiku (30.94cm), Unica (28.81cm) and Shangi (28.03cm) in experiment one while in experiment two, Nyota had 26.59cm, followed by Wanjiku (25.05cm), Shangi 21.80cm and Unica (21.56cm). At 60 DAP; Nyota had 31.84cm followed by Wanjiku (31.84cm), Unica (288.81cm) and Shangi (28.03cm) and Unica. In experiment two, Nyota had a plant height of 34.96cm followed by Wanjiku (33.84cm), Unica (30.21cm) and Shangi (30.13cm).

Table 3: Interaction effects of nutrient stock solution concentration and potato varieties on height in experiment one and two

		Maturity (days)							
Nutrient solution	**ARC varieties**	**Experiment one (Plant height)**				**Experiment two (Plant height)**			
		15	**30**	**45**	**60**	**15**	**30**	**45**	**60**
N75	$V_{1(Shangi)}$	5.37	7.38^{e}	12.68	17.97	4.96	7.23	12.88	17.49
	$V_{2(Nyota)}$	5.73	8.95^{de}	17.25	20.02	5.80	9.42	16.84	20.99
	$V_{3(Wanjiku)}$	5.61	8.03^{e}	16.30	19.75	5.59	9.25	16.74	20.52
	$V_{4(Unica)}$	4.41	7.31^{e}	13.60	17.52	4.74	7.40	12.86	17.61
N100	$V_{1(Shangi)}$	6.21	9.89^{cde}	14.54	19.66	7.39	8.35	14.12	20.77
	$V_{2(Nyota)}$	7.67	11.33^{bcd}	18.04	23.39	8.49	10.95	18.77	24.75
	$V_{3(Wanjiku)}$	7.65	9.93^{cde}	17.03	21.38	8.32	10.56	18.77	23.71
	$V_{4(Unica)}$	6.30	7.61^{e}	15.26	18.07	7.38	8.25	13.89	20.40
N125	$V_{1(Shangi)}$	8.56	12.16^{abc}	21.8	28.03	8.01	13.69	21.80	30.13
	$V_{2(Nyota)}$	9.00	14.63^{a}	25.29	31.84	9.13	15.99	26.59	34.96
	$V_{3(Wanjiku)}$	7.85	13.74^{ab}	24.52	30.94	8.45	15.48	25.05	33.84
	$V_{4(Unica)}$	7.06	13.78^{ab}	21.07	28.81	7.88	13.35	21.56	30.21
P value		1.13	0.02	0.35	0.395	0.9971	0.9994	0.938	0.9748
Mean		6.785	10.228	18.116	23.116	7.178	10.824	18.322	24.614
CV		11.550	9.380	7.842	5.140	11.425	13.252	7.777	5.556

The means followed by the same letter(s) in the same column and row are not significantly different using Tukey HSD test at a 5% significance level

4.1.2 Effect of nutrient stock solution concentrations on the NDVI of potato rooted apical cutting varieties

Effect of nutrient stock solution concentrations on the NDVI of ARCs

Results in Fig. 6 and 7 shows that the growth of the potato plants as given by the normalized difference vegetation index (NDVI) increased significantly ($p \leq 0.05$) with days, under varying nutrient solutions concentrations (NSSCs) in both experiments. The few exceptions however, were on the 15th and 75th day in experiment one and 30th day in experiment two where variations in NDVI were not significant. The highest seed potato NDVIs' ($P \leq 0.05$) were observed in ARCs grown under N125 (0.60 to 0.62 in experiment one and two, respectively) and N100 (0.50 to 0.46 in experiment one and two, respectively) by the 60th DAP. As the crop develops, NDVI increases up to the 60th day. Beyond the 60th day, there was a decline in the NDVI with increasing age of the crop up to the 75th day. Low application of fertilizers (i.e., N75) resulted in a poorer growth and health of the crop as indicated by the lower NDVI results ranging from 0.4 to 0.42 in both seasons. Growth of ARCs under varying NSSC was analysed using regression analysis and by fitting linear and quadratic regression curves as depicted in Figs 6 and 7, below. The goodness of fit was high and it ranged from R^2=0.90-0.99 for the curvilinear functions developed in both experiments. The relationships were explained by the quadratic mathematical functions given in Figs. 6 and 7, for experiments one and two, respectively.

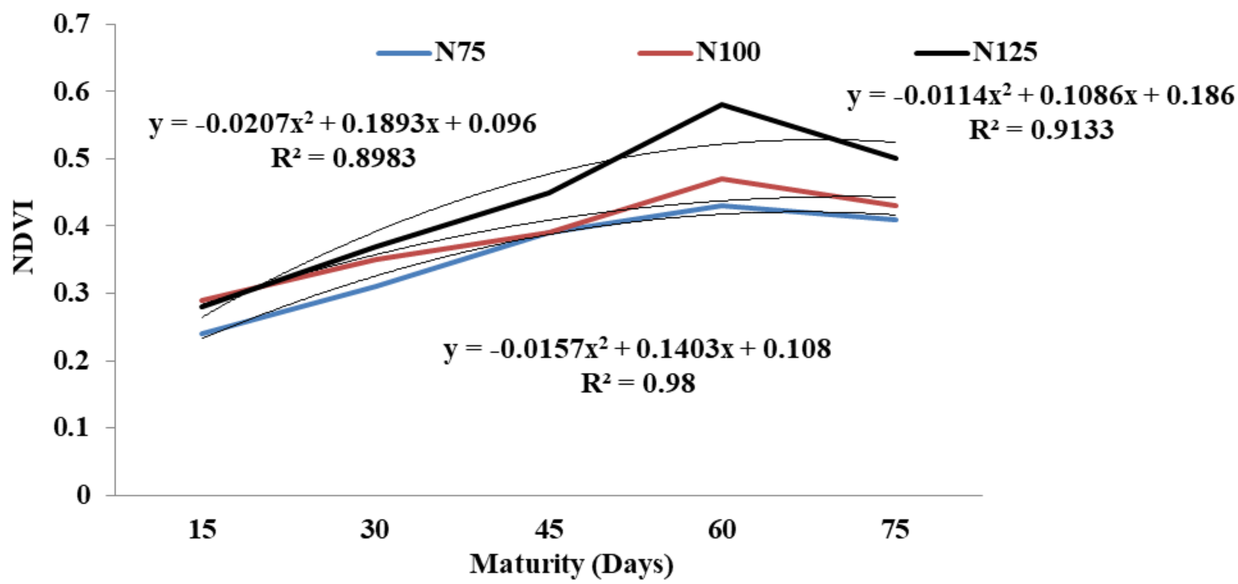

Figure 6: Main effects of nutrient stock solution concentrations on potato rooted apical cuttings NDVI in experiment one

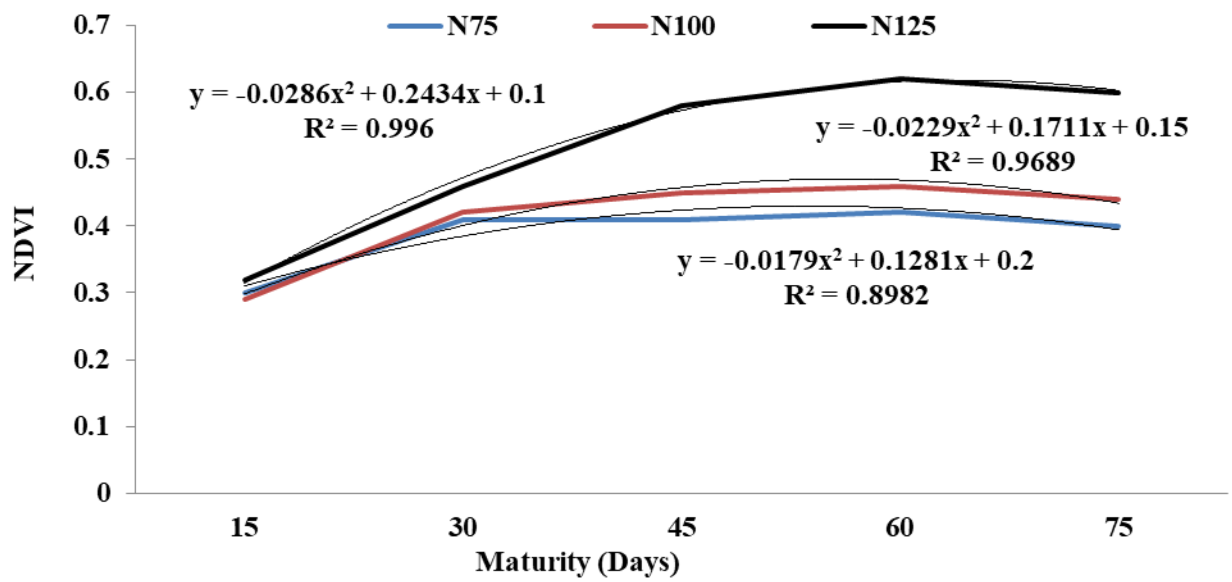

Figure 7: Main effects of nutrient stock solution concentrations on potato rooted apical cuttings NDVI in experiment two

Effect of potato rooted apical cuttings varieties on NDVI

The treatment means of NDVI values of potato across the varieties varied significantly ($p \leq 0.05$) throughout the growing period in both experiments (Figs 8 and 9). At 15 DAP, Nyota (0.28) was significantly different ($p \leq 0.05$) from Shangi (0.26) and Unica (0.25) while Wanjiku (0.28) did not differ significantly with the NDVI values of Nyota and Shangi in experiment one. In experiment two, Nyota (0.32) was significantly different from Shangi (0.3) and Unica (0.3) while Wanjiku (0.31) was not significantly different from the NDVI values of all varieties. At 30 DAP, the NDVI values of Nyota (0.36), Wanjiku (0.36) and Shangi (0.33) differed significantly ($p \leq 0.05$) from Unica (0.31) in experiment one while in experiment two, Nyota (0.47) differed significantly from Shangi (0.40) and Unica (0.47). Wanjiku (0.43) did not differ significantly from all the varieties (Figs 8 and 9).

At 45 DAP, the NDVI values of Nyota (0.43), Wanjiku (0.48) and Shangi (0.47) differed significantly ($p \leq 0.05$) from Unica (0.38) in experiment one while in experiment two, Nyota (0.53) was significantly different from Shangi (0.47) and Unica (0.47) while Wanjiku (0.49) did not have significantly different ($p \leq 0.05$) NDVI values form all the varieties. At 60 DAP, the NDVI values of Nyota (0.5) was significantly different from Unica (0.44) while Shangi (0.47) and Wanjiku (0.5) did not differ significantly ($p \leq 0.05$) with all the varieties in experiment one. In experiment two, Nyota (0.52) was significantly different from Shangi (0.47) and Unica (0.47) while Wanjiku (0.50) did not differ significantly in the NDVI values of all varieties. At 75 DAP; all the varieties recorded the same NDVI values in both experiments (Figs 8 and 9).

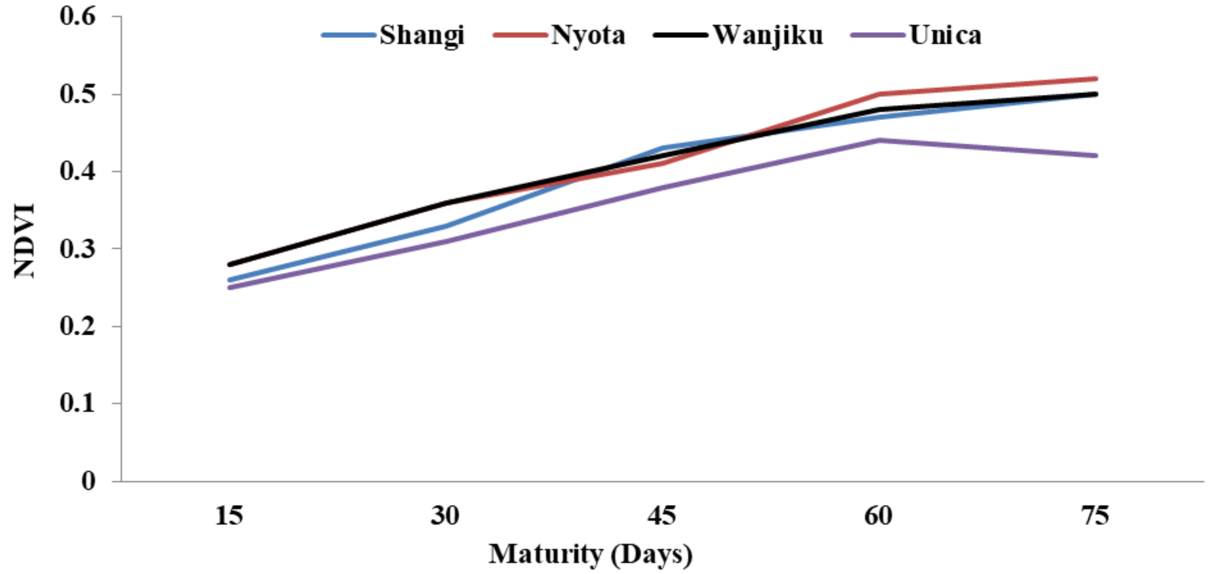

Figure 8: Effect of potato rooted apical cuttings varieties on NDV1 in experiment one

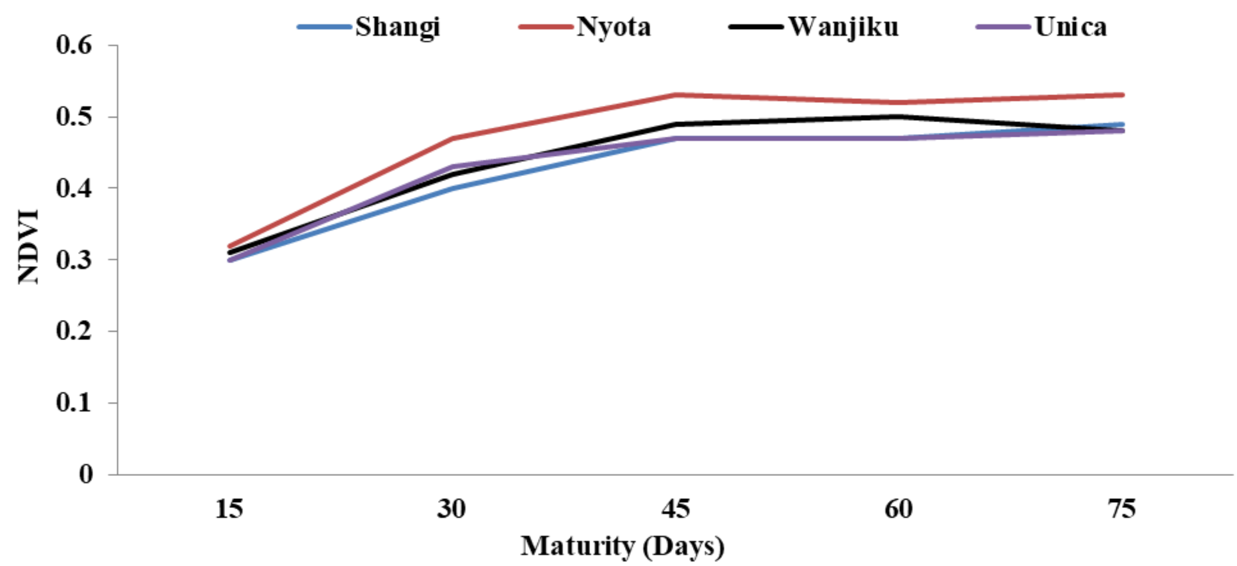

Figure 9: Effect of potato rooted apical cuttings varieties on NDV1 in experiment two

Effect of the interaction of the nutrient stock solution concentrations and ARC varieties on the NDVI

The interaction effects between the nutrient concentrations and ARC varieties were significantly different ($p \leq 0.05$) on the 15th DAP in experiment one but not significant in experiment two (Table 4). Under N125, at 15 DAP, the varieties did not differ significantly

($p \leq 0.05$) in experiment one. Nyota and Wanjiku reported the same NDVI values of 0.28 followed by Unica (0.29) and Shangi 0.27 in experiment one. In experiment two, Wanjiku had 0.33 followed by Nyota (0.32), Shangi (0.31) and Unica (0.30). At 30 DAP, Shangi had 0.38 followed by Wanjiku had 0.37, Nyota and Unica which had the same NDVI value of 0.36 in experiment one while in experiment two, Nyota had 0.49 followed by Wanjiku and Unica which had the same NDVI values of 0.46 and Shangi (0.41). At 45 DAP, Wanjiku had 0.46 followed by Nyota and Shangi had same NDVI values of 0.45 and Unica 0.36 in experiment one while in experiment two, Nyota and Wanjiku had the same NDVI values of 0.61 followed by Unica 0.55 and Shangi 0.54. At 60 DAP, Nyota had NDVI values of 0.65 which was followed by Wanjiku (0.57), Unica and Shangi which had the same NDVI values of (0.55) in experiment one while in experiment two, Wanjiku had NDVI values of 0.67 followed by Nyota (0.63), Unica and Shangi which had the same NDVI values of 0.58. At 75 DAP, Nyota had 0.72 and 0.67 in experiment one and two, respectively. This was followed by Wanjiku (0.63 and 0.64 in experiment one and two, respectively), Shangi (0.62 and 0.66 in experiment one and two, respectively) and Unica (0.44 and 0.61 in experiment one and two, respectively).

Under N100, at 15 DAP, Wanjiku (0.32) was significantly different from Unica (0.25) while Nyota (0.31) and Shangi (0.27) was not significantly different from all varieties in experiment one. In experiment two, Nyota had 0.31 followed by Shangi and Unica (0.29) and Wanjiku (0.28). At 30 DAP, Nyota had 0.37 followed by Wanjiku (0.36), Shangi (0.35) and Unica (0.31) in experiment one while in experiment two, Nyota had 0.47 followed by Wanjiku (0.41), Unica (0.40) and Shangi 0.40. At 45 DAP, Shangi had 0.41 followed by Nyota (0.40), Wanjiku (0.39) and Unica (0.37) in experiment one while in experiment two, Nyota had 0.50 followed by Shangi (0.45), Wanjiku (0.44) and Unica (0.43). At 60 DAP, Nyota had NDVI values of 0.46 which was followed by Wanjiku and Shangi which had the same values (0.44) and Unica (0.40) in experiment one while in experiment two, Nyota had NDVI values of 0.52 followed by Wanjiku and Shangi which had the same values (0.45) and Unica (0.43). At 75 DAP, Shangi had 0.51 followed by Nyota (0.49), Wanjiku (0.47) and Unica (0.43) in experiment one while in experiment two, Nyota had 0.50 followed by Unica (0.45), Shangi (0.42) and Wanjiku (0.39) (Table 4).

Under N75, the interaction effects were only significant at 15 DAP in experiment one (Table 4). Nyota and Wanjiku had the same NDVI values of 0.25 which was followed by Shangi

(0.23) and Unica (0.23) in experiment one while in experiment two, Nyota had NDVI values of 0.32 which was followed by Wanjiku (0.31) and Unica and Shangi which had the same values (0.29). At 30 DAP, Wanjiku had 0.35 followed by Nyota (0.34), Shangi (0.28) and Unica (0.27) in experiment one while in experiment two, Nyota had 0.44 followed by Unica (0.43), Shangi (0.40) and Wanjiku (0.38). At 45 DAP, Shangi had 0.43 followed by Wanjiku (0.40), Nyota (0.37) and Unica (0.36) in experiment one while in experiment two, Nyota had 0.48 followed by Unica (0.43), Shangi (0.42) and Wanjiku (0.41). At 60 DAP, Wanjiku had 0.44 followed by Shangi (0.41), Nyota (0.39) and Unica (0.38) in experiment one while in experiment two, Nyota had 0.40 followed by Unica (0.39), Wanjiku (0.38) and Shangi (0.37). At 75 DAP, Wanjiku had 0.46 followed by Shangi (0.44), Nyota (0.42) and Unica (0.38) in experiment one while in experiment two, Nyota had 0.42 followed by Wanjiku (0.41), Shangi (0.39) and Unica (0.38).

Table 4: Interaction effects of nutrient stock solution concentration and potato varieties on the NDVI in experiment one and two

Nutrient solutions	Potato varieties	Experiment one (NDVI)					Experiment two (NDVI)				
		15	30	45	60	75	15	30	45	60	75
N75	$V_{1(Shangi)}$	0.23[c]	0.28	0.43	0.41	0.44	0.29	0.40	0.42	0.37	0.39
	$V_{2(Nyota)}$	0.25[bc]	0.34	0.37	0.39	0.42	0.32	0.44	0.48	0.40	0.42
	$V_{3(Wanjiku)}$	0.25[bc]	0.35	0.40	0.44	0.46	0.31	0.38	0.41	0.38	0.41
	$V_{4(Unica)}$	0.22[c]	0.27	0.36	0.38	0.38	0.29	0.43	0.43	0.39	0.38
N100	$V_{1(Shangi)}$	0.27[abc]	0.35	0.41	0.44	0.51	0.29	0.38	0.45	0.45	0.42
	$V_{2(Nyota)}$	0.31[ab]	0.37	0.40	0.46	0.49	0.31	0.47	0.50	0.52	0.50
	$V_{3(Wanjiku)}$	0.32[a]	0.36	0.39	0.44	0.47	0.28	0.41	0.44	0.45	0.39
	$V_{4(Unica)}$	0.25[bc]	0.31	0.37	0.40	0.43	0.29	0.40	0.43	0.43	0.45
N125	$V_{1(Shangi)}$	0.27[abc]	0.38	0.45	0.55	0.62	0.31	0.41	0.54	0.58	0.66
	$V_{2(Nyota)}$	0.28[abc]	0.36	0.45	0.65	0.72	0.32	0.49	0.61	0.63	0.67
	$V_{3(Wanjiku)}$	0.28[abc]	0.37	0.46	0.57	0.63	0.33	0.46	0.61	0.67	0.64
	$V_{4(Unica)}$	0.29[abc]	0.36	0.43	0.55	0.44	0.30	0.46	0.55	0.58	0.61
P value		0.0231	0.134	0.9601	0.3229	0.73	0.2333	0.256	0.2565	0.0589	0.6717
Mean		0.268	0.340	0.407	0.474	0.500	0.304	0.429	0.488	0.489	0.497
CV		6.485	8.816	7.83	10.04	23.21	4.380	6.587	6.770	6.552	10.987

alpha = 0.05. Same letters in the same column indicate no significant difference, while different letters indicate a significant difference at a significant level of 0.05.

Regression analyses for the response of potato varieties and nutrient stock solution concentrations to NDVI

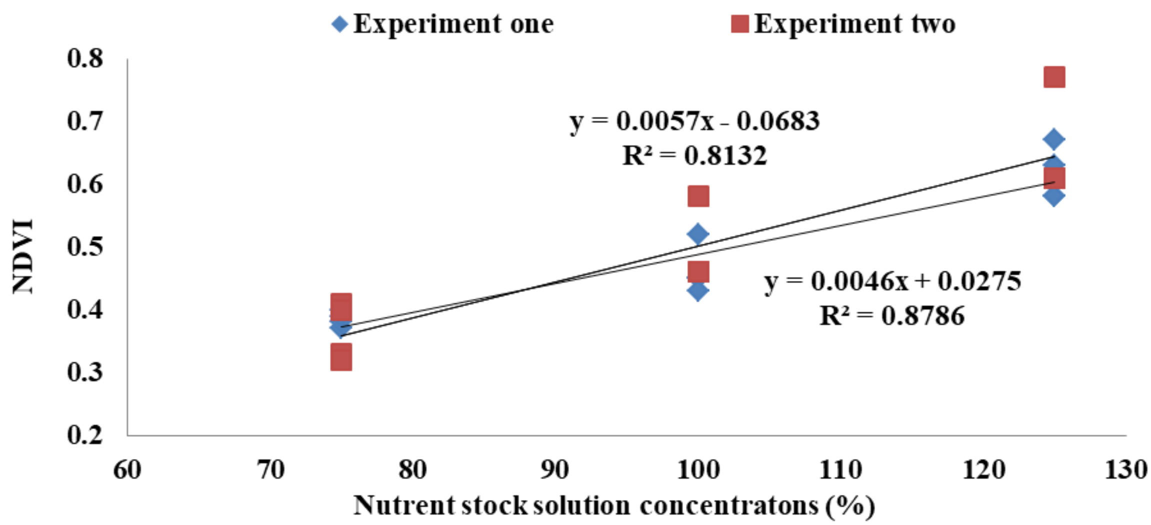

Figure 10: Relationship of NDVI at 60 DAP to nutrient stock solution concentrations in experiment one and two

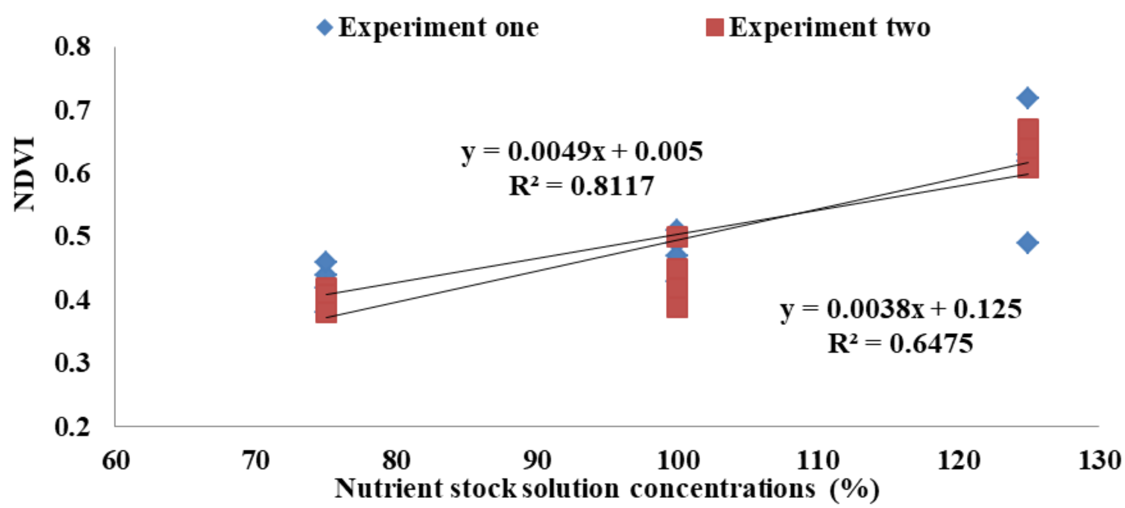

Figure 11: Relationship of NDVI at 75 DAP to nutrient stock solution concentrations in experiment one and two

At 60 DAP, the NDVI was increasing with increase in NSSC as given by the linear equation y=0.0275+0.0046x in experiment one and y=-0.0683+0.0057 in experiment two (Fig.11). The regression coefficients were higher at more than 0.65 in experiment one and 0.81 in experiment two (Figure 10). This means that for every increase in NSSC, the NDVI increased by a coefficient of 0.0046 and 0.0057 unit NDVI for experiment one and two, respectively for all varieties. Similarly, at 75 DAP, the NDVI increased with increase in NSSC as given by the linear equation y=0.125+0.0038x in experiment one and y=0.005+0.0049x in experiment two.

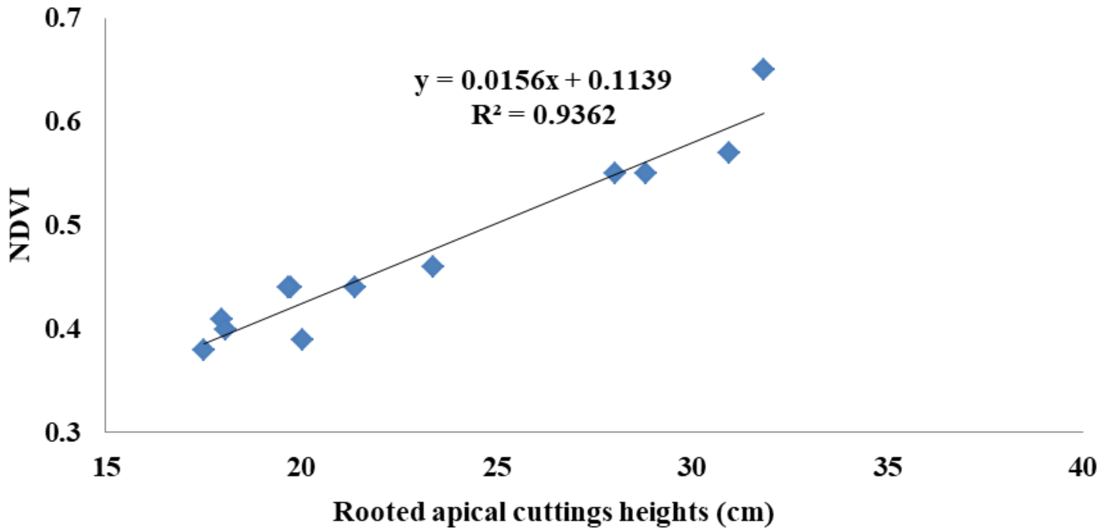

Figure 12: Relationship of ARC heights with NDVI at 60 DAP in experiment one

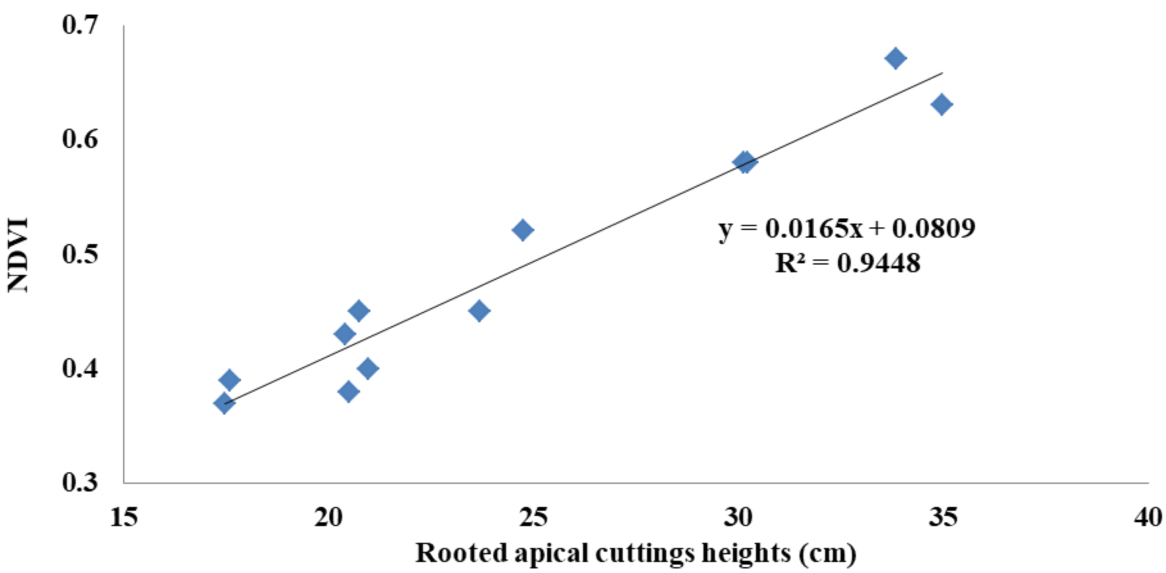

Figure 13: Relationship of ARC heights with NDVI at 60 DAP in experiment two

ARCs heights taken at 60 DAP were regressed against NDVI measurements (Figs. 12 and 13). The relationship of heights with NDVI of the rooted apical cuttings was explained by fitting linear functions which had high goodness of fit of more than 0.9362 and 0.9448 in experiment one and two, respectively. It is therefore possible to predict the ARCs NDVI using plant height data collected at 60 DAP using these mathematical functions.

4.1.3 Effect of nutrient stock solution concentrations on the survival of potato rooted apical cutting varieties

Effect of nutrient stock solution concentrations on the survival of ARCs

Results in Figure 14 below shows that the survival of potato ARCs did not differ significantly ($P \leq 0.05$) with the application of NSSC in both experiments at 15 days after planting (DAP) in both experiments. Treatment N125 had a survival rate of 93.98%, N100 had 87.04% and N75 had 82.26% in experiment one while in experiment two, N125 had a survival rate of 93.74%, N100 had 92.13% and N75 had 87.96%. At 75 DAP, however, the plant survival was significantly ($P \leq 0.05$) affected by the application of NSSC. In experiment one, N125 had a significantly higher ARC survival (84.26%) followed by N100 (54.18%) and N75 (47.22%) which were not significantly different. In experiment two, N125 (82.15%) and N100 (53.65%) differed significantly from N75 (47.15%).

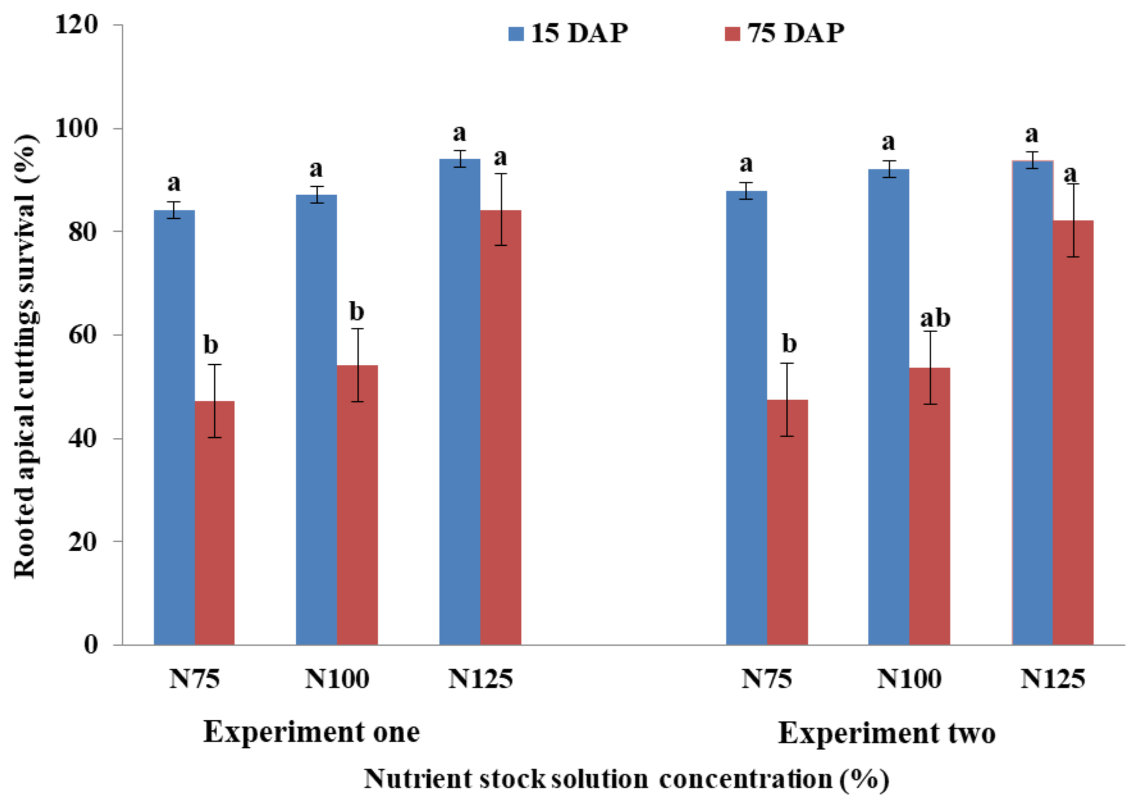

Figure 14: Main effects of nutrient stock solution concentration on survival of potato ARCs in experiment one and two

Effect of potato rooted apical cuttings varieties on the plant survival

Plant survival of the potato varieties were not significantly different (P≤0.05) at 15th DAP and 75th DAP in both experiments (Figure 15). On the 15th DAP, Nyota had a survival rate of 88.89% followed by Wanjiku (88.27%), Unica (88.27%) and Shangi (88.27%) in experiment one while in experiment two, Wanjiku had 94.44%, followed by Nyota (93.83%), Unica (90.12%) and Shangi (86.71%). At 75th DAP, Unica and Nyota had 62.35% followed by Shangi 61.73% and Wanjiku 61.11% in experiment one while in experiment two, Nyota had 64.23% followed by Unica (64.80%), Shangi (56.75%) and Wanjiku (56.75%) (Figure15)

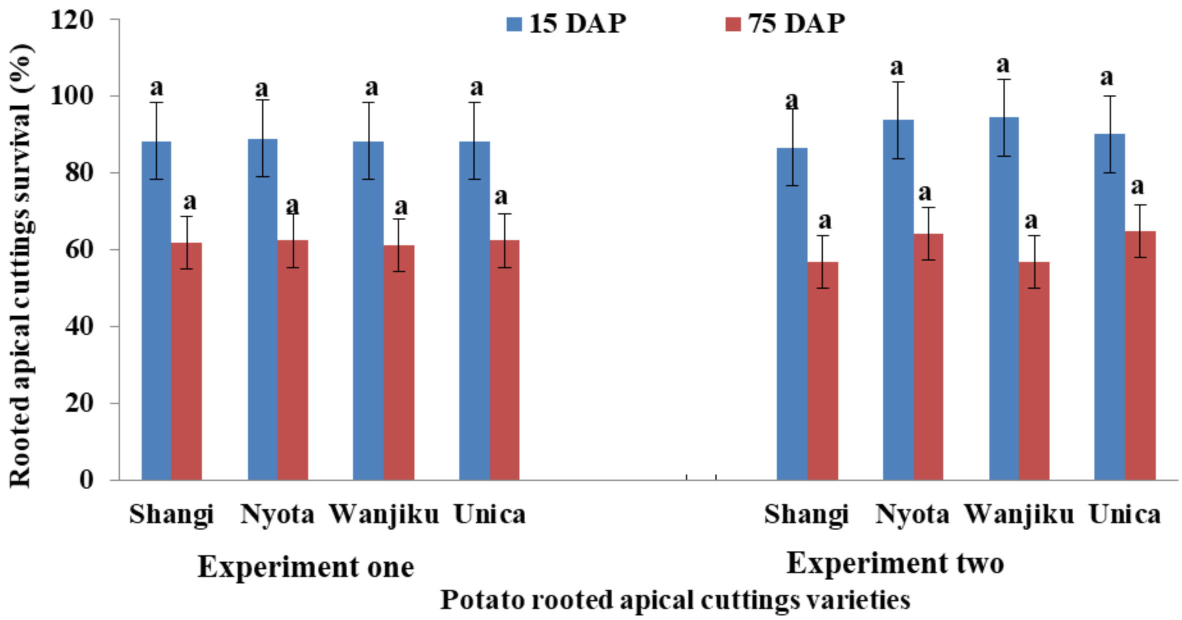

Figure 15: Effect of potato ARC varieties on percentage survival in experiment one and two

Effect of the interaction of the nutrient stock solution concentrations and ARC varieties on the plant survival

In both experiments, there was no significant interaction (P≤0.05) both at day 15 and during day 75 (Figs. 16 and 17). At 15th DAP, the interaction between N75 and varieties showed that Wanjiku had 87.04% survival rates followed by Shangi (85.18%), Unica (83.33%) and Nyota (81.48%) in experiment one while in experiment two, Wanjiku had 94.44% followed by Nyota (90.74%), Unica (88.89%) and Shangi (77.78%). At 75th DAP, Wanjiku and Nyota both had survival rates of 48.15% followed by Unica and Shangi which both had survival rates of 46.30% in experiment one while in experiment two, Nyota had 63.63% followed by Shangi

(48.00%), Unica (43.22%) and Wanjiku (35.19%). At 15th DAP, the treatment combination of N100*varieties showed that Nyota had a survival rate of 88.89% followed by Shangi and Unica which had the same survival rate (87.04%) and Wanjiku (85.18%) in experiment one while in experiment two, Unica had 64.18% survival rate followed by Wanjiku (57.07%), Nyota (50.74%) and Shangi (42.59%). At 75th DAP, Nyota had a survival rate of 55.55% and all the other varieties had 53.71% in experiment one while in experiment two, Unica had a survival rate of 64.18% followed by Wanjiku (57.07%), Nyota (50.74%) and Shangi (42.59%). At 15th DAP, treatment combination of N125*varieties showed that Nyota had a survival rate of 96.30% followed by Unica (94.44%) and Shangi and Wanjiku which had the same survival rates (92.59%) in experiment one while in experiment two, Unica had 87.00% survival rate followed by Shangi (85.30%), Nyota (78.33%) and Wanjiku (78.00%). At 75th DAP, Unica had 87.00% survival rate followed by Shangi (85.30%), Nyota (78.33%) and Wanjiku (78.00%) as shown in Figs 16 and 17.

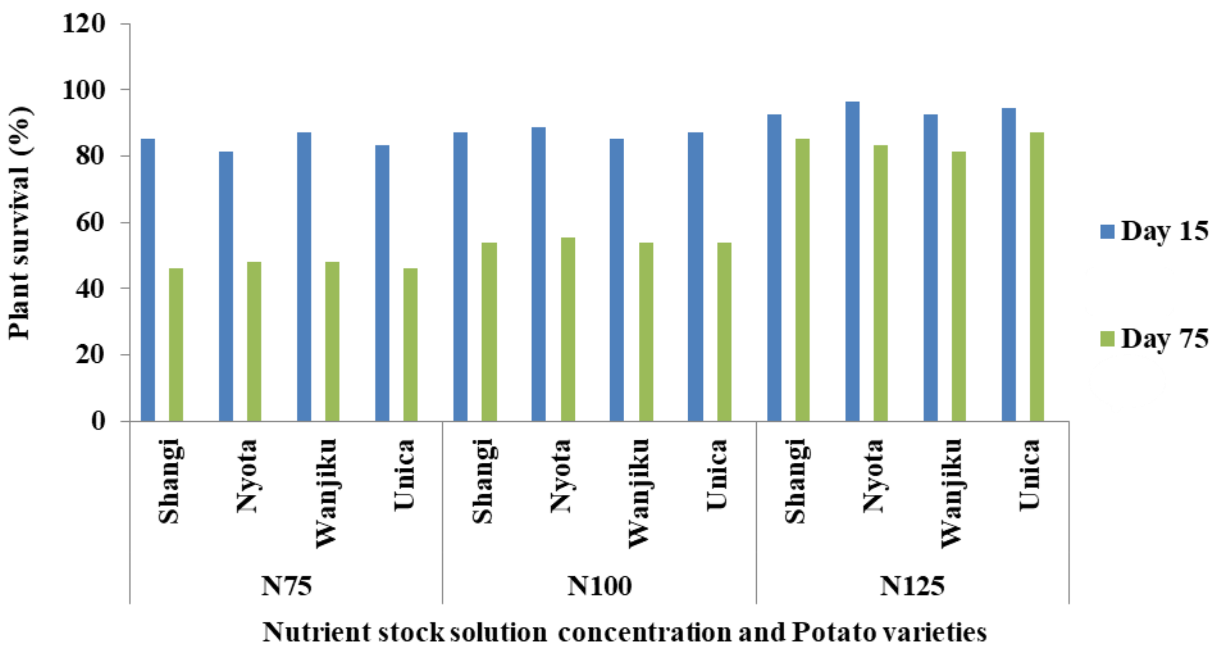

Figure 16: Interaction effects of nutrient stock solution concentration and potato varieties on plant survival in experiment one

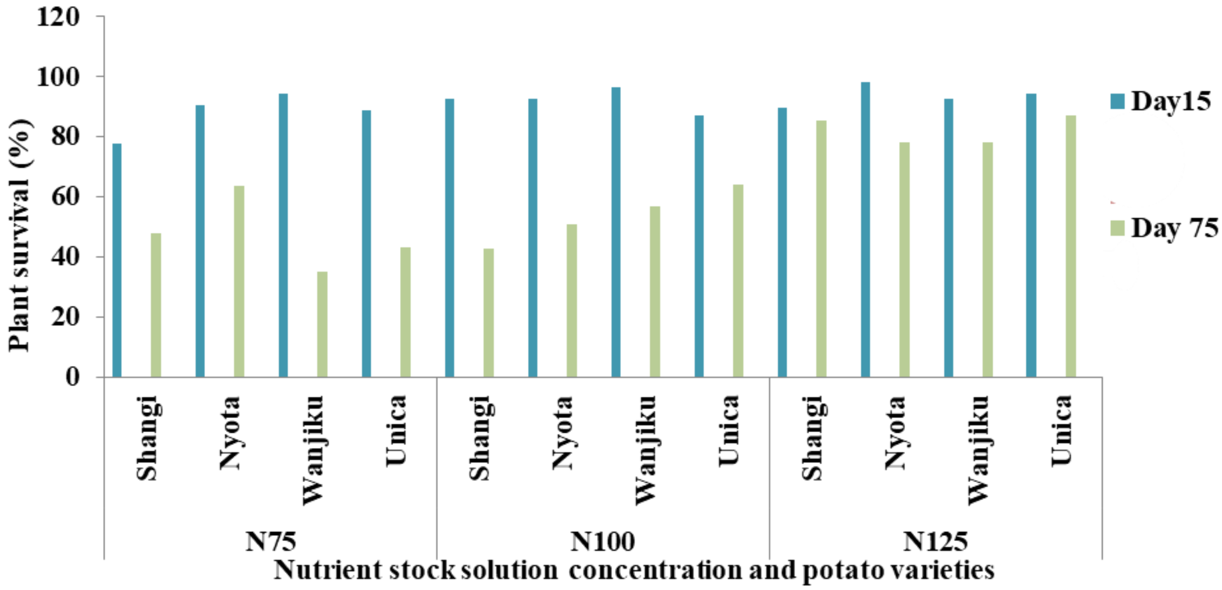

Figure 17: Interaction effects of nutrient stock solution concentration and potato varieties on plant survival in experiment two

4.1.4 Effect of nutrient stock solution concentrations on the above ground biomass fresh weight of potato rooted apical cutting varieties

Effect of nutrient stock solution concentrations on the above ground biomass fresh weight of ARCs

Results in Fig.18 below shows that the above ground biomass (AGB) fresh weight significantly increased ($p \leq 0.05$) with the application of nutrient stock solution concentrations (NSSC). Treatment N125 (58.66g and 79.04g in experiment one and two, respectively) differed significantly from N100 (50.00g and 47.20g in experiment one and two, respectively) and N75 (36.41g and 43.31g in experiment one and two, respectively) which were not significantly different in experiment one and two respectively.

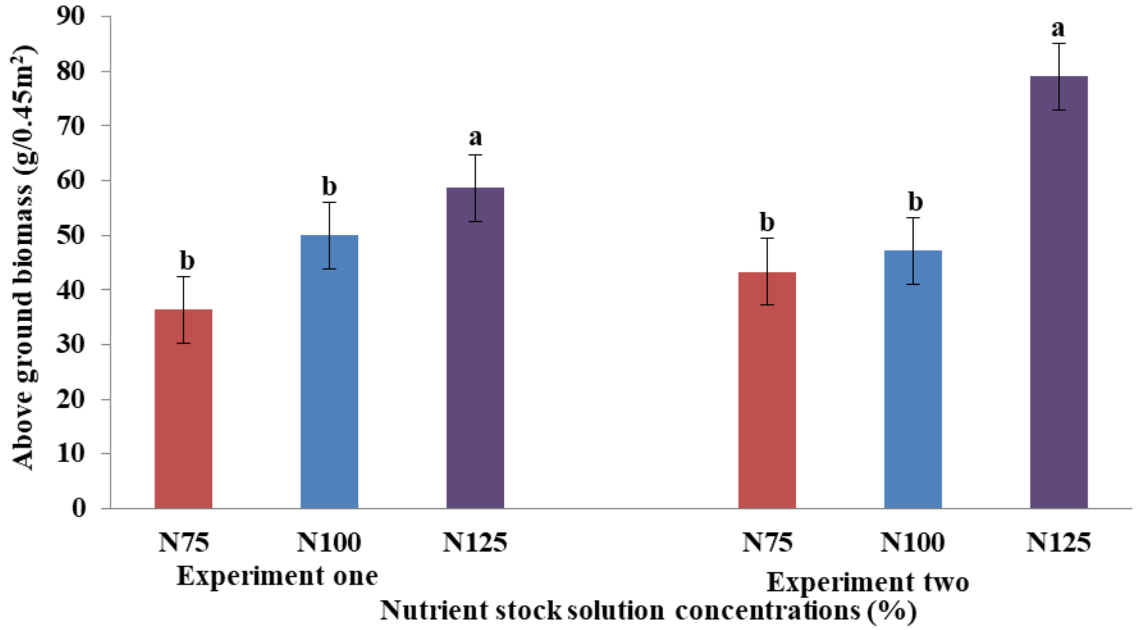

Figure 18: Main effects of nutrient stock solution concentration on above ground biomass fresh weight of potato ARCs in experiment one and two

Effect of the nutrient stock solution concentrations on the above ground biomass fresh weight of ARC varieties

The above ground biomass fresh weight of all potato varieties were significantly different at 75th DAP (Figure 19). Nyota had the highest biomass fresh weight of 48.01g and 64.87g in experiment one and two respectively and differed significantly ($P \leq 0.05$) from all varieties. Wanjiku had 44.39g and 55.91g in experiment one and two, respectively followed by Shangi (44.19g and 53.13g in experiment one and two, respectively) and Unica (43.83g and 52.25g in experiment one and two, respectively) in experiment one and two respectively.

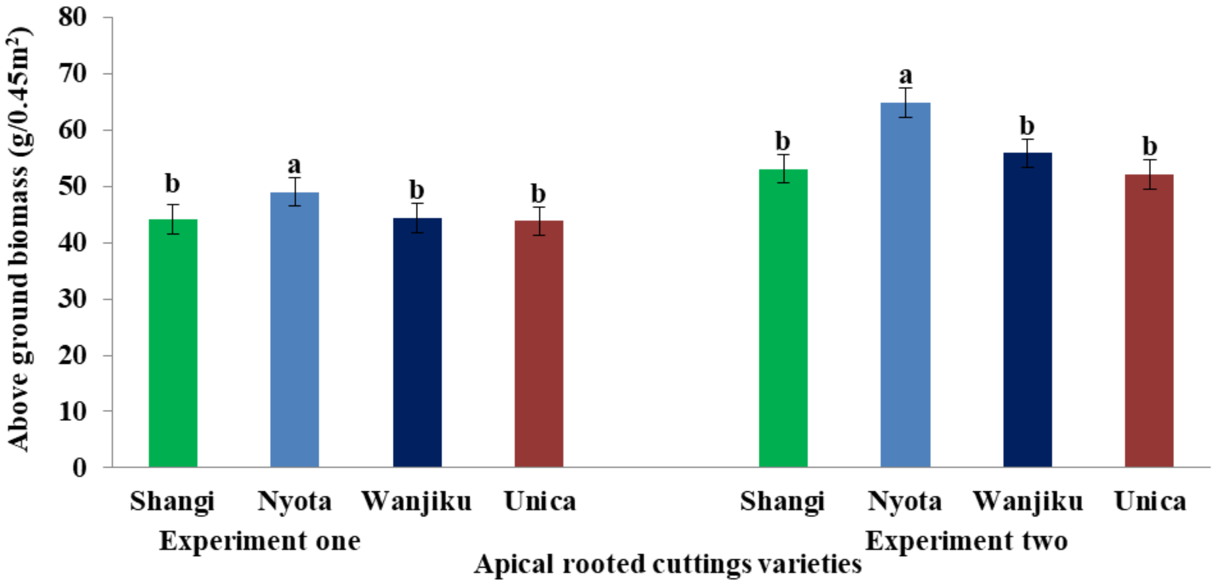

Figure 19: Effect of potato rooted apical cuttings varieties on above ground biomass fresh weight in experiment one and two

Effect of the interaction of the nutrient stock solution concentrations and ARC varieties on the above ground biomass fresh weight

There was no significant ($p \leq 0.05$) interaction with the application of nutrient concentrations (NSSCs') and potato varieties on the above ground biomass fresh weight in both experiments (Fig. 20). Under N125, Nyota gave (63.12g and 88.65g in experiment one and two, respectively) followed by Wanjiku (57.55g and 78.58g in experiment one and two, respectively), Shangi (57.20g and 73.82g in experiment one and two, respectively) and Unica (56.76g and 75.20g in experiment one and two, respectively). Under N100, Nyota had 44.83g followed by Unica (39.87g), Wanjiku (39.77g) and Shangi (39.52g) in experiment one while in experiment two, Nyota had 58.24g followed by Wanjiku (46.16g), Unica (49.75g) and Shangi (43.64g). Under treatment N75, Nyota weighed 39.07g and 47.72g followed by Wanjiku (35.85g and 42.99g in experiment one and two respectively), Shangi (35.84g and 41.94g in experiment one and two, respectively) and Unica (34.86g and 40.61g in experiment one and two, respectively).

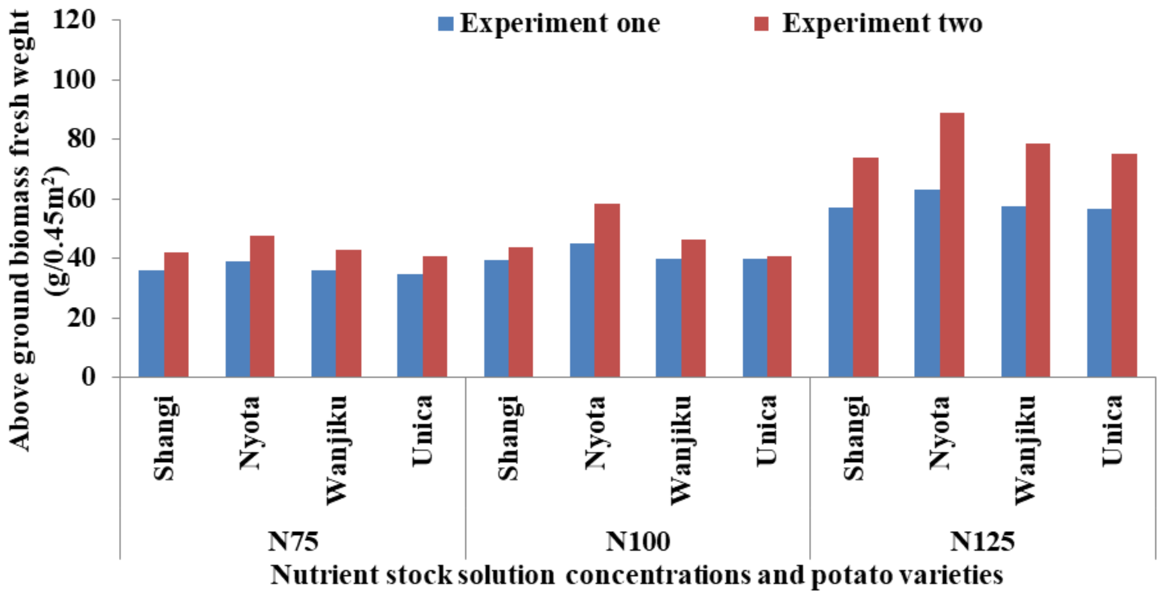

Figure 20: Interaction effects of nutrient stock solution concentration and varieties on the above ground biomass fresh weight of potato varieties in experiment one and two

Regression analyses for the response of potato varieties and nutrient stock solution concentrations to above ground biomass fresh weight

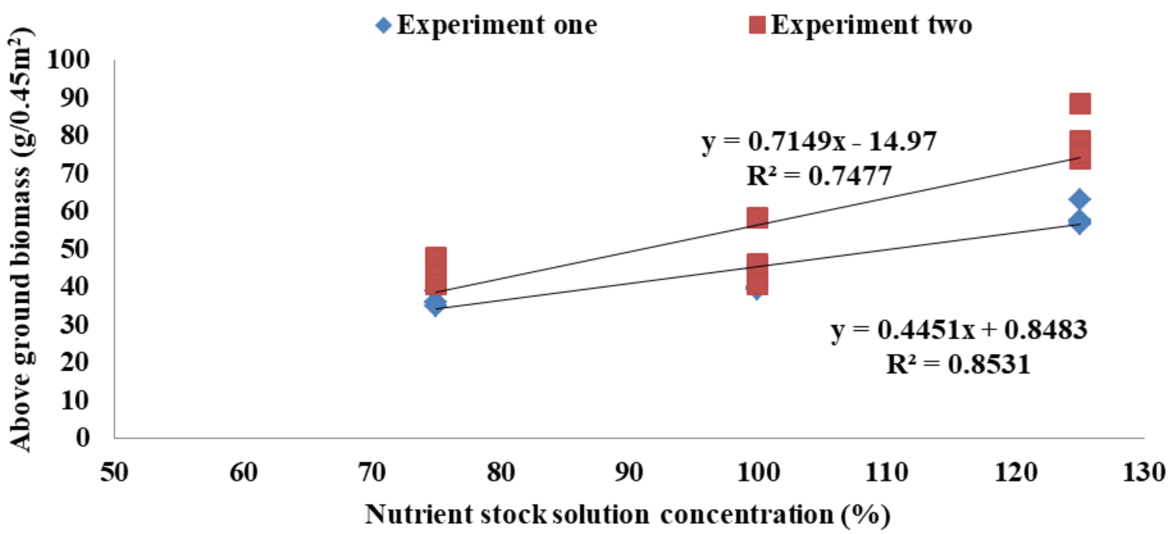

Figure 21: Relationship of the above ground biomass fresh weight to nutrient stock solution fresh weight concentrations in experiment one and two

Increase in NSSC resulted in increase in above ground biomass fresh weight by the 75th DAP (dehaulming time) as given by the linear equation y=0.8483 +0.4451x in experiment one and y=-14.97 +0.7149 in experiment two (Fig. 21). Extrapolation of the linear response curve revealed that increasing the NSSC to 200% increased the above ground biomass fresh weight to 70g for all varieties.

Regression analyses for the relationship of ARCs height with above ground biomass fresh weight

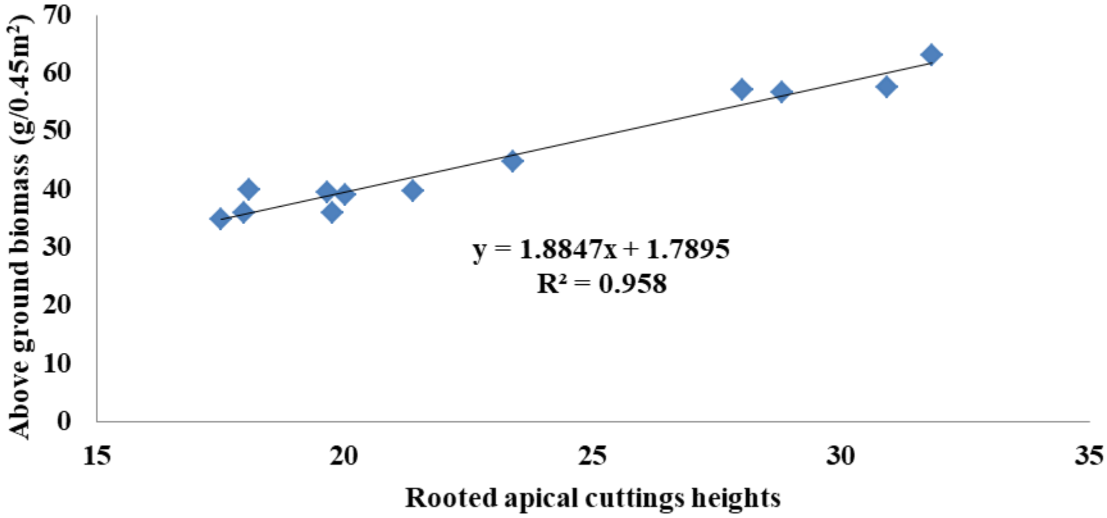

Figure 22: Relationship of plant height at 60th DAP with above ground biomass fresh weight in experiment one

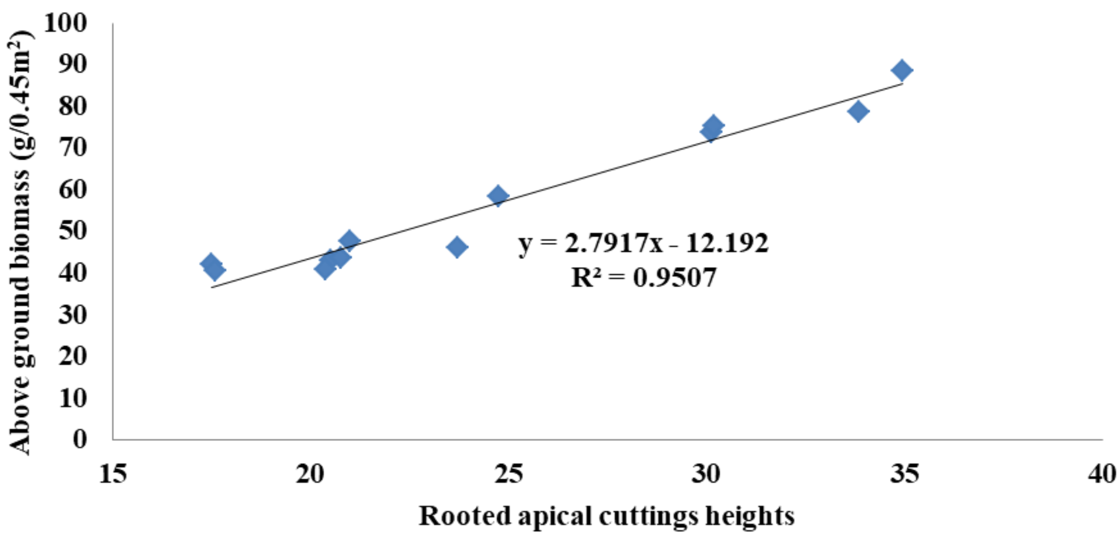

Figure 23: Relationship of plant height at 60th DAP with above ground biomass fresh weight in experiment two

The above ground biomass fresh weight was increasing with increase in NSSC as given by the linear equation y=1.7895+1.8847x in experiment one and y=-12.192+2.7917x in experiment two (Figs. 22 and 23). The regression coefficients were higher at more than 0.95 in both experiments. This means that for every unit increase in NSSC, the above ground biomass fresh weight increased by a coefficient of 1.8847 and 12.7917 in experiment one and two, respectively.

Regression analyses for the relationship of ARCs NDVI with above ground biomass fresh weight

The relationship of NDVI taken at 60 DAP could be explained by fitting linear functions whose mathematical functions had a regression coefficient of R^2 =0.9386 for experiment 1 and 0.8596 for experiment two (Figs. 24 and 25).

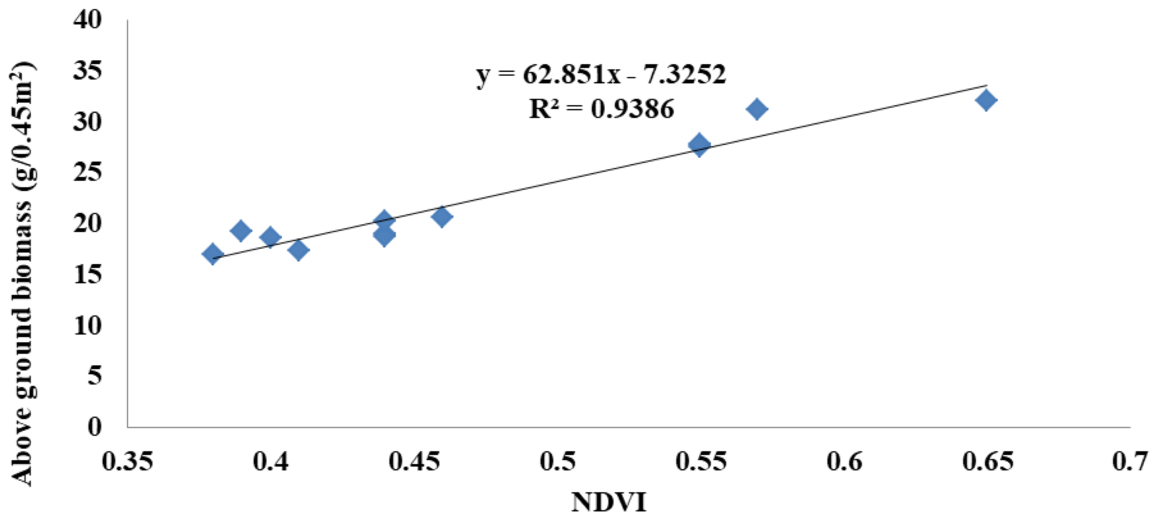

Figure 24: Relationship of NDVI at 60 DAP with above ground biomass fresh weight in experiment one

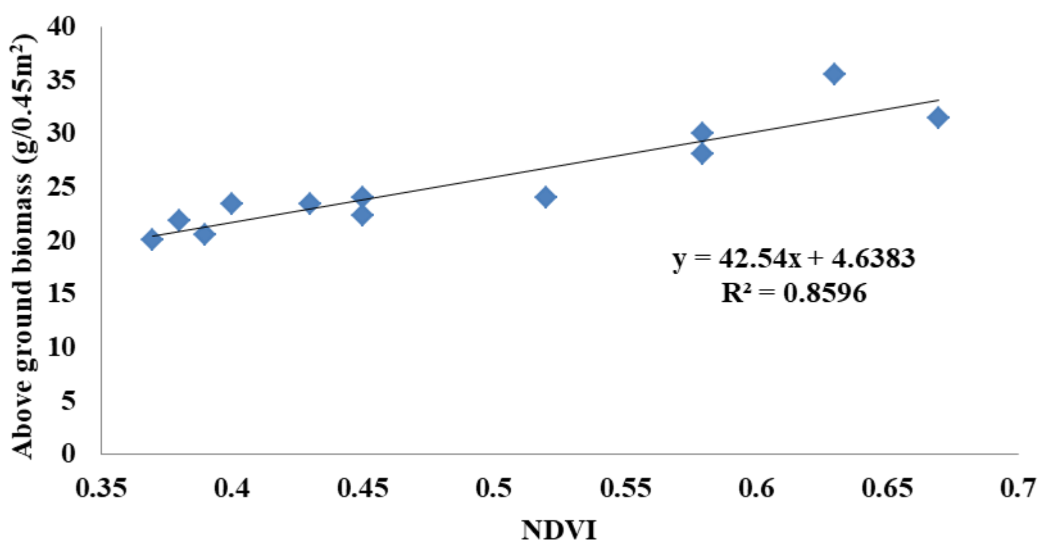

Figure 25: Relationship of NDVI at 60 DAP with above ground biomass fresh weight in experiment two

4.1.5 Effect of nutrient stock solution concentrations on the above ground dry matter of potato rooted apical cutting varieties

Effect of nutrient stock solution concentrations on the above ground dry matter of ARCs

Results in Figure 26 below shows that the above ground dry matter (DM) of ARCs significantly ($P \leq 0.05$) increased with the application of increasing NSSCs in both experiments. Treatment N125 (29.65% and 31.26% in experiment one and two, respectively) was significantly different from N100 (19.53% and 23.43% in experiment one and two, respectively) and N75 (18.11% and 21.44% in experiment one and two, respectively).

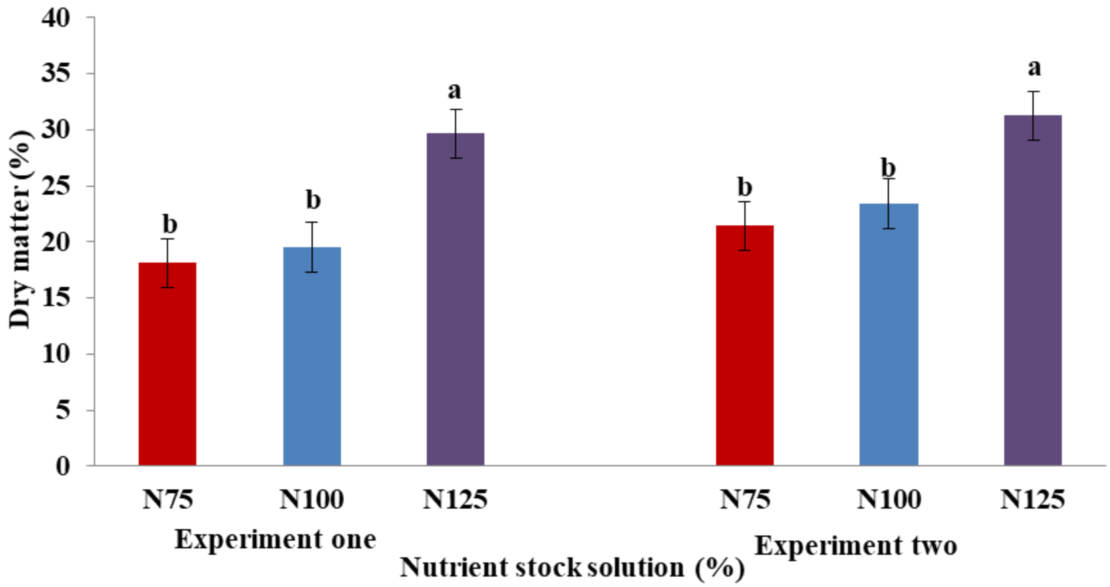

Figure 26: Main effects of nutrient stock solution concentration on the above ground dry matter of potato ARC in experiment one and two

Effect of potato rooted apical cuttings varieties on the above ground dry matter of ARC varieties

The effect of potato varieties on the above ground biomass dry matter was significant ($p \leq 0.05$) in both experiments (Figure 27). In experiment one, Nyota (23.98%) had significantly higher DM than Unica (21.12%) while Wanjiku (23.43%) and Shangi (21.20%) were not significantly different from Nyota and Unica. In experiment two, Nyota (27.60%) had significantly higher DM than Shangi (24.14%) and Unica (24.00%). Wanjiku (25.77%) did not differ significantly ($p \leq 0.05$) with all the varieties (Figure 27).

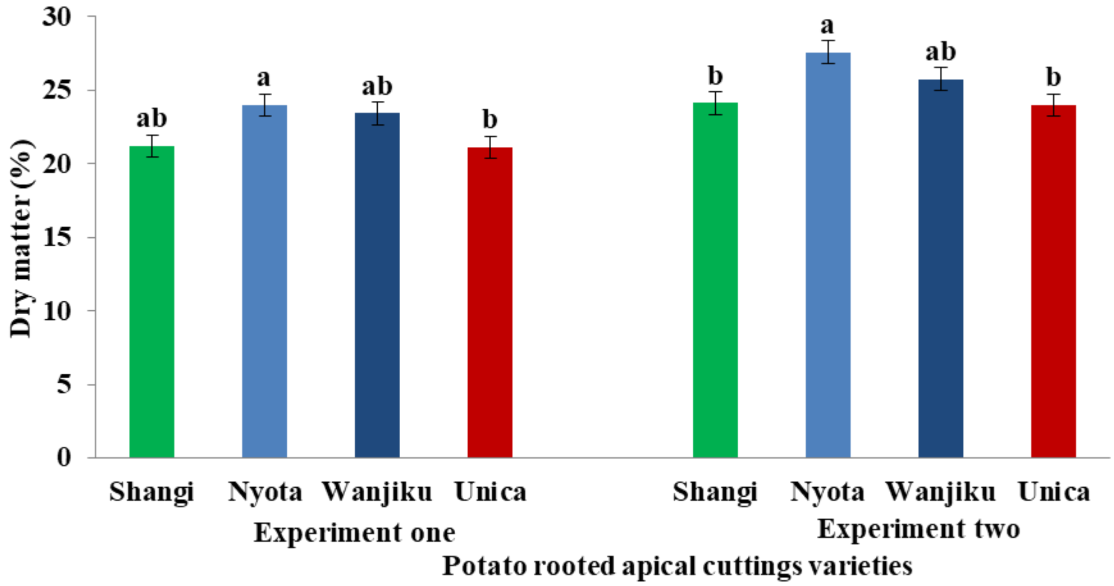

Figure 27: Effect of potato rooted apical cuttings varieties on above ground dry matter of in experiment one and two

Effect of the interaction of the nutrient stock solution concentrations and ARC varieties on the above ground dry matter

Nutrient concentrations and potato varieties interactions did not affect the above ground biomass dry matter significantly ($p \leq 0.05$) in both experiments (Fig. 28). Under N125, Nyota had a DM of 32.09% followed by Wanjiku (31.13%), Shangi (27.56%) and Unica (27.82%) in experiment one while in experiment two, Nyota had 35.46% followed by Wanjiku (31.47%), Shangi (and 30.06%) and Unica (28.06%). Under N100, Nyota had a DM of 20.58% followed by Wanjiku (20.20%), Shangi (18.75%) and Unica (18.60%) in experiment one while in experiment two; Nyota had a DM of 23.97% followed by Wanjiku (24.03%), Shangi (22.36%) and Unica (23.35%). Under N75, Nyota had a biomass DM of 19.27% followed by Wanjiku (18.96%), Shangi (17.30%) and Unica (16.90%) in experiment one while in experiment two, Nyota had a biomass DM of 23.36% followed by Wanjiku (21.81%), Shangi (20.01%) and Unica (20.58%) as shown in Figure 28.

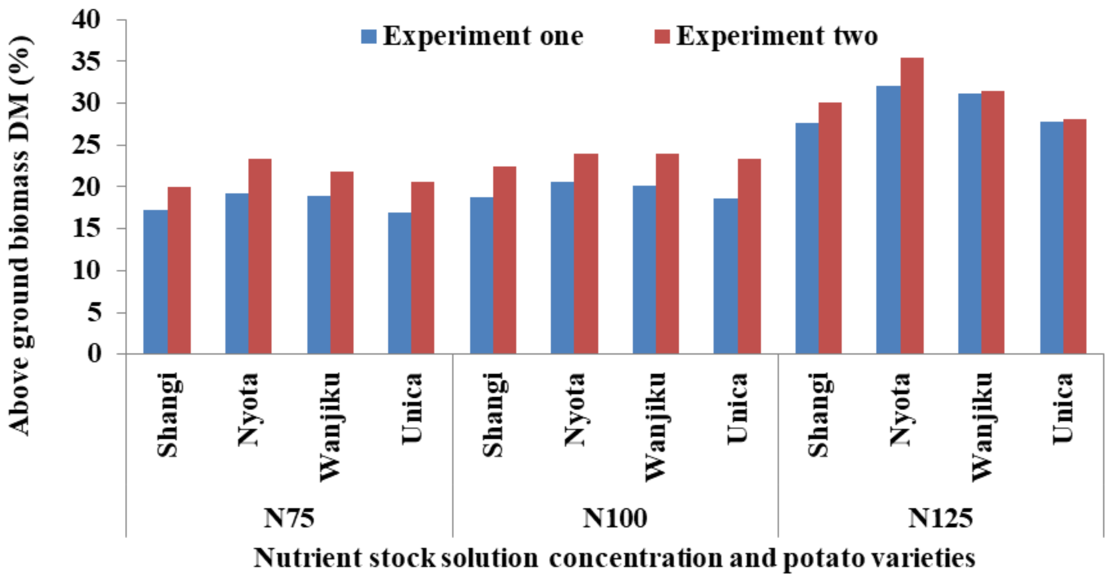

Figure 28: Interaction effects of nutrient stock solution concentrations and ARC varieties on the above ground biomass dry matter

4.2. Effects of nutrient concentrations on the yield of rooted apical cuttings seed potato varieties

Yield parameters, i.e., minitubers numbers, weight, yield and size were determined during harvesting for four (4) potato apical rooted cutting (ARC) varieties namely; Shangi, Nyota, Wanjiku and Unica. These were grown (in sub-plots) under three (3) nutrient stock solution concentrations (NSSC) (allocated in main-plots) (Fig. 1).

4.2.1. Effect of nutrient solution concentrations on the minitubers number per plant of potato varieties

Effect of nutrient stock solution concentrations on the minitubers number per plant of ARCs

All treatments differed significantly ($p \leq 0.05$) in the number of minitubers per plant with the application of different NSSC. The number of minitubers increased with the application of nutrient stock solutions. In experiment one, N125 produced 8.67 followed by N100 (6.33) and N75 (3.58) while in experiment two, N125 had 9.33 followed by N100 (6.50) and N75 (4.00) (Figure 29).

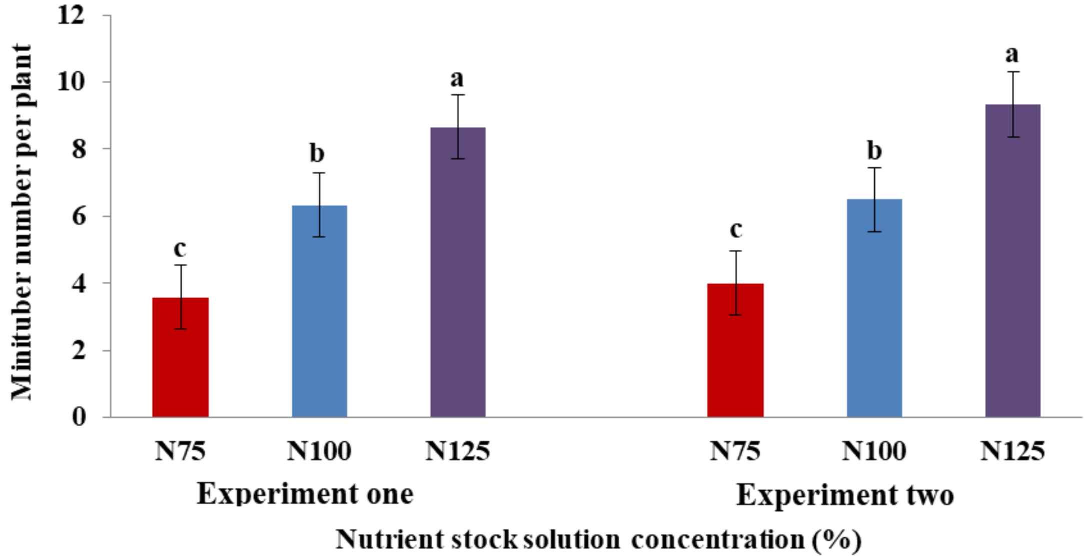

Figure 29: Main effects of nutrient stock solution concentrations on the number of minitubers per plant in experiment one and two

Effect of potato rooted apical cuttings varieties on the minitubers number per plant

The potato rooted apical cuttings varieties differed significantly in the number of minitubers per plant at $p \leq 0.05$. Nyota (7.11) and Wanjiku (6.89) produced significantly ($p \leq 0.05$) higher minitubers per plant followed by Shangi (5.89) and Unica which produced the least number of minitubers (4.89) in experiment one. Similar results were obtained in experiment two where Nyota (7.67) and Wanjiku (7.33) produced significantly higher number of minitubers per plant followed by Shangi (6.11) and Unica (5.33) (Figure 30).

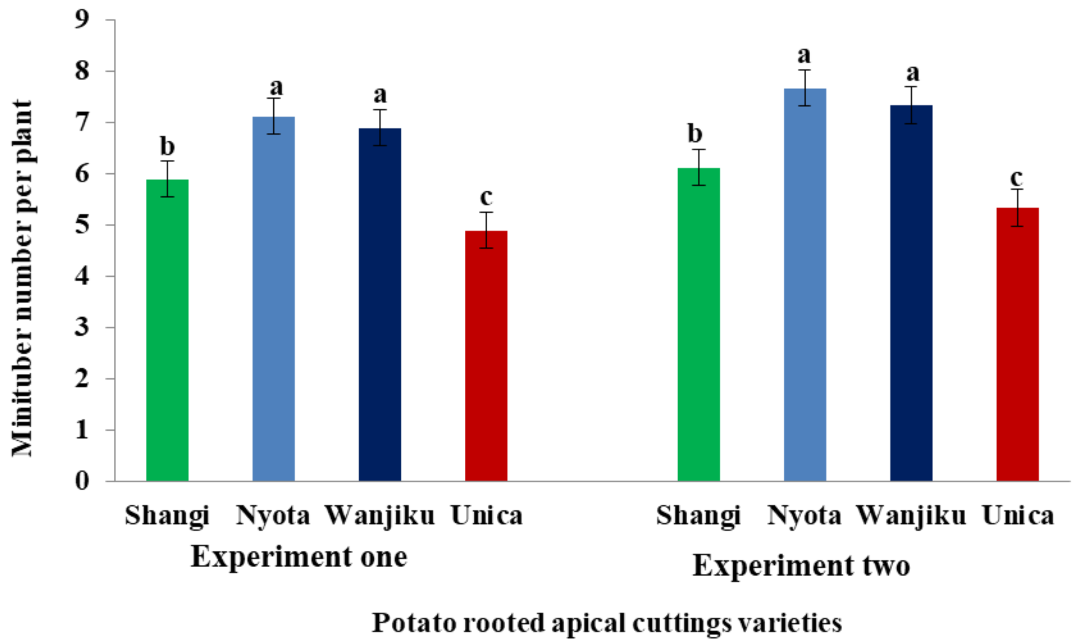

Figure 30: Effect of potato rooted apical cuttings varieties on number of minitubers per plant in experiment one and two

Effect of the interaction of the nutrient stock solution concentrations and ARC varieties on the number of minitubers per plant

There were significant ($p \leq 0.05$) interaction effects between the nutrient stock solution concentrations and the varieties (Table 5). The treatment combination of N125 and varieties had the highest significant interactions. Treatment combination of N125 and Nyota (10.00), Wanjiku (10.00) and Shangi (8.33) gave the highest tuber numbers while N125* Unica gave the least number of minitubers (6.3) in experiment one. In experiment two, Nyota (11.33) and Wanjiku (10.67) had significantly higher minitubers followed by Shangi (8.67) which was significantly ($p \leq 0.05$) different from all varieties. Unica produced the least minitubers numbers (6.67). The interaction between N100 and varieties was significant ($p \leq 0.05$) with Nyota (7.33), Wanjiku (7.00) and Shangi (4.67) being significantly different from Unica (4.67) in experiment one while in experiment two, Wanjiku (7.33) and Nyota (7.33) gave the highest minitubers number followed by Shangi (6.33) and Unica (5.00). The interaction of N75 and varieties produced equal minitubers numbers in experiment one and two (Table 5).

Table 5: Interaction effects of nutrient stock solution concentration and potato varieties on minitubers numbers per plant in experiment one and two

Nutrient solutions	Potato varieties	Experiment one	Experiment two
N75	$V_{1(Shangi)}$	3.00^{d}	3.33^{f}
	$V_{2(Nyota)}$	4.00^{d}	4.33^{ef}
	$V_{3(Wanjiku)}$	3.67^{d}	4.00^{ef}
	$V_{4(Unica)}$	3.67^{d}	4.33^{ef}
N100	$V_{1(Shangi)}$	4.67^{cd}	6.33^{cd}
	$V_{2(Nyota)}$	7.33^{b}	7.33^{bc}
	$V_{3(Wanjiku)}$	7.00^{b}	7.33^{bc}
	$V_{4(Unica)}$	4.67^{bc}	5.00^{de}
N125	$V_{1(Shangi)}$	8.33^{ab}	8.67^{b}
	$V_{2(Nyota)}$	10.00^{a}	11.33^{a}
	$V_{3(Wanjiku)}$	10.00^{a}	10.67^{a}
	$V_{4(Unica)}$	6.3^{bc}	6.67^{c}
P value		<.0001	<.0001
Mean		6.19	6.66
CV		11.2	8.733

The means followed by the same letter(s) in the same column are not significantly different using Tukey HSD test at a 5% significance level.

Regression analyses for the response of potato ARCs to nutrient stock solution concentrations to number of minitubers

Tuber number was increasing with increase in NSSC as given by the linear equation y= -4.065 + 0.1068x in experiment one and y=-4.0917+0.1015x in experiment two (Fig 31). The regression coefficients were higher at more than 0.76 in both experiments. This means that for every unit increase in NSSC, the tuber number increased by a coefficient of 0.1015 to 0.1068 unit tuber for experiment two and one, respectively for all varieties.

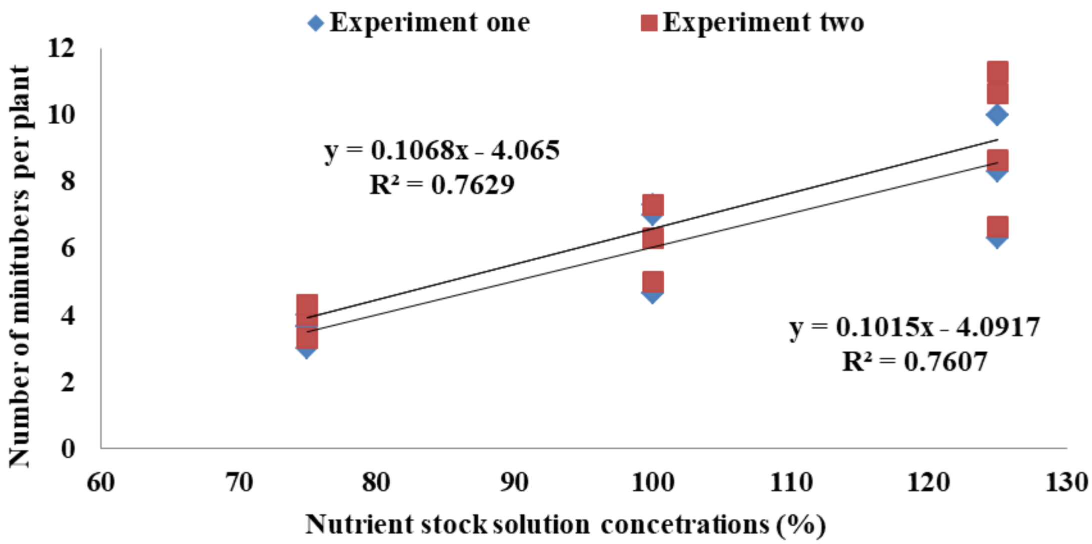

Figure 31: Relationship of the number of minitubers per plant to nutrient stock solution concentrations in experiment one and two

Regression analyses for the response of individual potato varieties to nutrient stock solution concentrations to number of minitubers

The number of minitubers per plant increased with increase in NSSC for all varieties studied (Fig. 32). The highest rate of increase in minitubers numbers was Nyota at 0.12x and 0.14x in experiment one and two, respectively followed by Wanjiku 0.1266x and 0.1334x, Shangi 0.1066x and 0.1068x and Unica 0.9812x and 0.0468x.

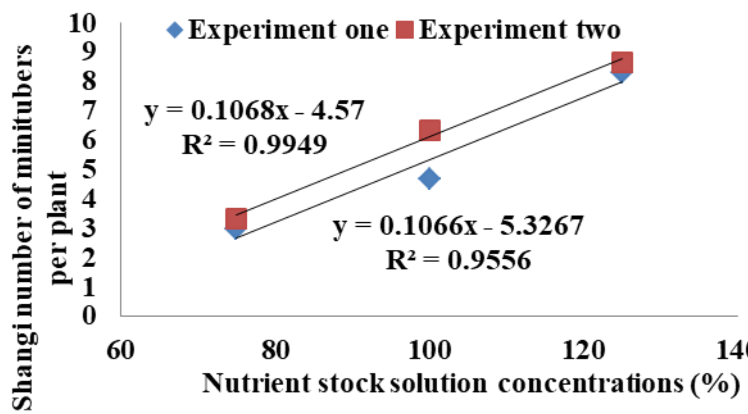

Fig. 32a: Relationship of Shangi number of minitubers per plant with NSSC

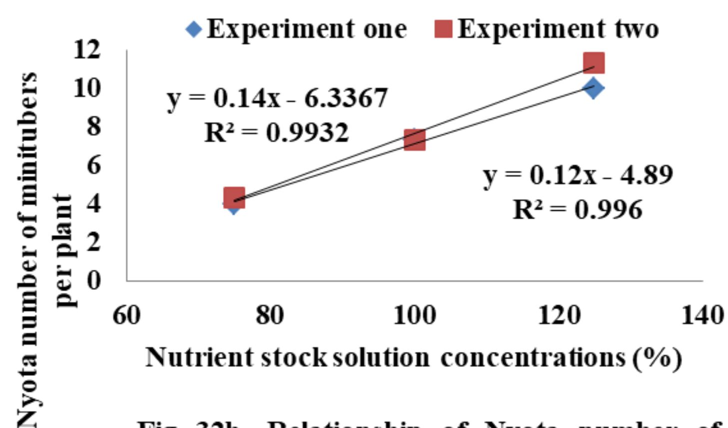

Fig 32b. Relationship of Nyota number of minitubers per plant with NSSC

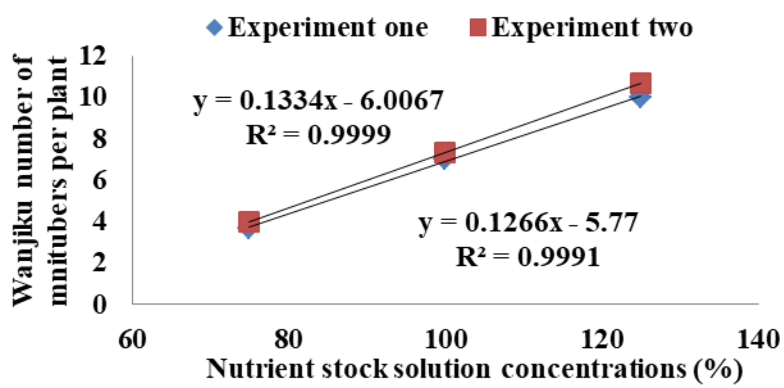

Fig 32c. Relationship of Wanjiku number of minitubers with NSSC

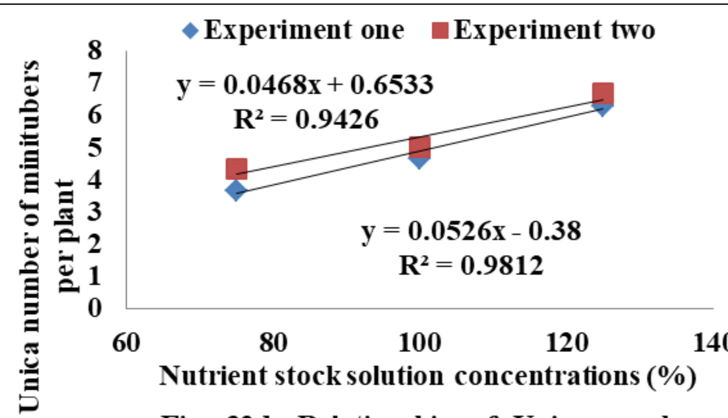

Fig. 32d: Relationship of Unica number of minitubers per plant with NSSC

Figure 32: Relationship of number of minitubers per plant and nutrient stock solution concentrations of potato varieties in experiment one and two

4.2.2. Effect of nutrient solution concentrations on the minitubers weight per plant of ARC varieties

Effect of nutrient stock solution concentrations on the combined means of minitubers weight per plant of ARCs

Results in Figure 33 below shows the combined mean minitubers weight per plant of all varieties. Minitubers weight per plant was influenced significantly ($p \leq 0.05$) by increased application of NSSC in both experiments. Treatment N125 had the highest minitubers weight per plant (22.44g and 29.44g in experiment one and two, respectively) followed by N100 (11.76g and 12.90g in experiment one and two, respectively) and N75 (4.26g and 5.01g in experiment one and two, respectively).

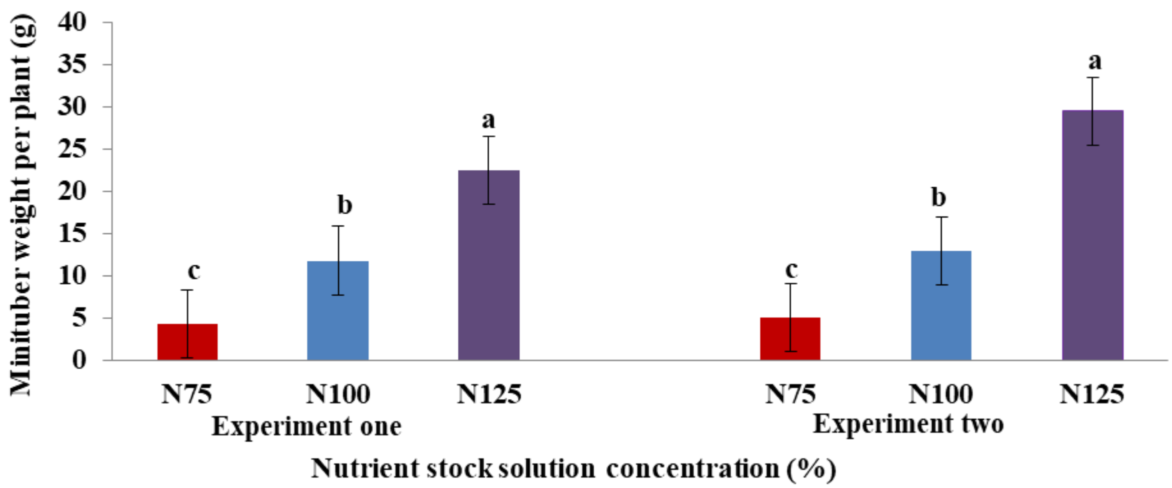

Figure 33: Main effects of nutrient stock solution concentrations on the weight of tubers per plant in experiment one and two

Effect of potato rooted apical cuttings varieties on weight of tubers per plant

The seed potato varieties differed significantly ($p \leq 0.05$) in the weight of tubers per plant in both experiments as shown in Figure 34 below. Unica produced the heaviest tubers per plant (17.86g and 20.68g in experiment one and two, respectively) followed by Nyota (13.05g and 16.36g in experiment one and two, respectively) and Wanjiku (12.42g and 15.41g in experiment one and two, respectively) and Shangi produced the lightest tubers (7.95g and 10.68g in experiment one and two respectively).

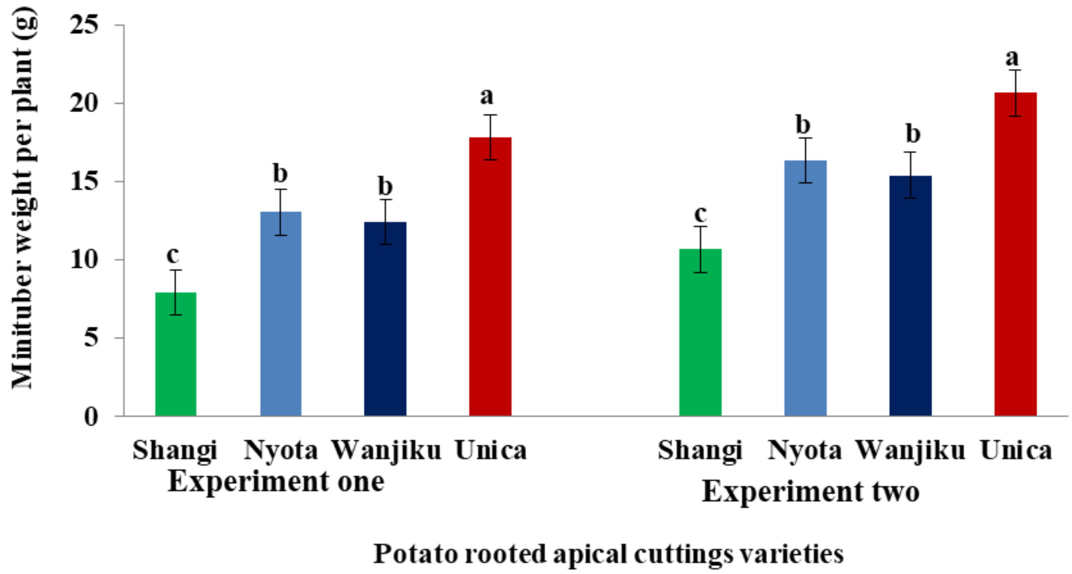

Figure 34: Effect of potato rooted apical cuttings varieties on weight of tubers per plant in experiment one and two

Effect of the interaction of the nutrient stock solution concentrations and ARC varieties on the minitubers weight per plant of ARCs

The interaction effect between the nutrient stock solution concentrations and the potato varieties on minitubers weight per plant was significant ($p \leq 0.05$) in both experiments (Table 6). Under N125, Unica (31.06g) differed significantly from Wanjiku (20.54g), Nyota (21.65g) and Shangi (16.52g) in experiment one while in experiment two, Unica (36.85g) was significantly different from Shangi (22.27g) and not significantly different from Nyota (30.22g) and Wanjiku (28.41g). Under N100, Unica (16.73g) differed significantly ($p \leq 0.05$) to Shangi (5.16g) but was not significantly different from Nyota (12.94g) and Wanjiku (12.19g) in experiment one. Similar results were obtained in experiment two where Unica (18.11g) was significantly ($p \leq 0.05$) different from Shangi (7.41g) but did not differ from Nyota (13.68g) and Wanjiku (12.40g). Under N75, all varieties did not differ significantly ($p \leq 0.05$) with weights ranging from 5.80g to 2.17g in experiment one and 7.08g to 2.37g in experiment two.

Table 6: Interaction effects of nutrient stock solution concentration and potato varieties on minitubers weight per plant in experiment one and two

Nutrient solutions	Potato varieties	Experiment one (weight plant^{-1})	Experiment two (weight plant^{-1})
N75	$V_{1(Shangi)}$	2.17^{g}	2.37^{f}
	$V_{2(Nyota)}$	4.57^{fg}	5.19^{ef}
	$V_{3(Wanjiku)}$	4.52^{fg}	5.42^{ef}
	$V_{4(Unica)}$	5.80^{efg}	7.08^{ef}
N100	$V_{1(Shangi)}$	5.16^{efg}	7.41^{ef}
	$V_{2(Nyota)}$	12.94^{cde}	13.68^{cde}
	$V_{3(Wanjiku)}$	12.19^{efd}	12.40^{de}
	$V_{4(Unica)}$	16.73^{bcd}	18.11^{cd}
N125	$V_{1(Shangi)}$	16.52^{bcd}	22.27^{bc}
	$V_{2(Nyota)}$	21.65^{b}	30.22^{ab}
	$V_{3(Wanjiku)}$	20.54^{bc}	28.41^{ab}
	$V_{4(Unica)}$	31.06^{a}	36.85^{a}
P value		0.0487	<.0001
Mean		12.82	15.78
CV		22.89	20.78

The means followed by the same letter(s) in the same column are not significantly different using Tukey HSD test at a 5% significance level.

Regression analyses for the response of potato varieties to nutrient stock solution concentrations to minitubers weight per plant

Relationships of seed potato varieties to varied NSSC were developed using regression analyses as given in Figs. 35 to 36. Increasing NSSC percentage resulted in increasing in minitubers weight as given by the linear regressions in Fig. 35 below. For every unit change in NSSC, minitubers weight increased by a coefficient of 0.3636 and 0.4885 above -23.53 and -33.06 grams in experiment one and two respectively. It is therefore possible to predict minitubers weight using the linear functions with a confidence of 77.02% and 83.98% in experiment one and two, respectively.

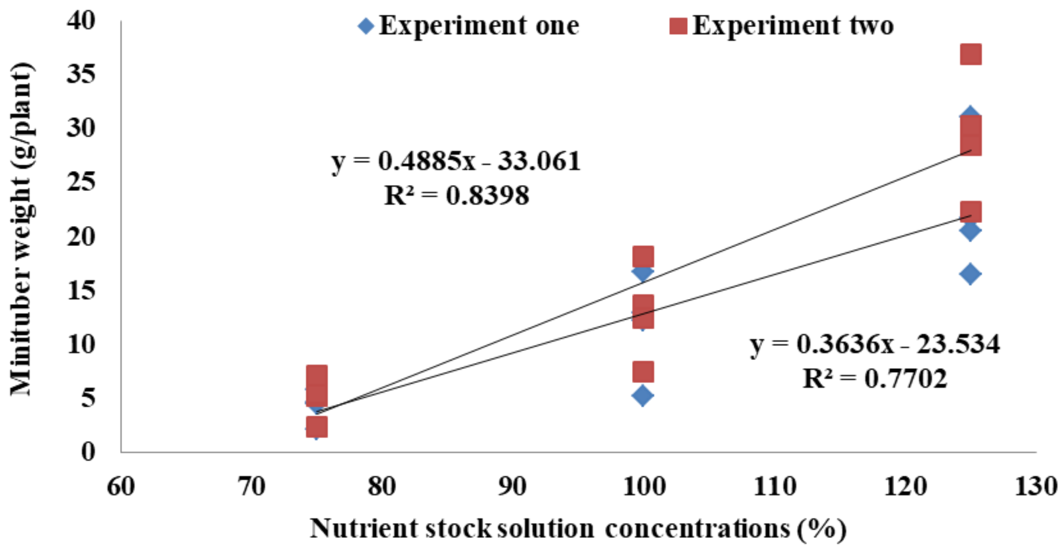

Figure 35: Relationship of the minitubers weight per plant to nutrient stock solution concentrations in experiment one and two

Results in Figures 36a to 36d below shows the mean minitubers weight per plant for each ARC variety in response to increased NSSC. Unica had a high gain in weight coefficient of 0.5052 and 0.5954 for every unit change in NSSC percentage in experiment one and two respectively. This was followed by Nyota with weight coefficient of 0.3416 and 0.5006 in experiment one and two, respectively; Wanjiku 0.2948 and 0.4266; and Shangi 0.287 and 0.398 respectively. This means that Unica increased in minitubers weight faster than Nyota, Wanjiku and Shangi in that order in response to increase in NSSC.

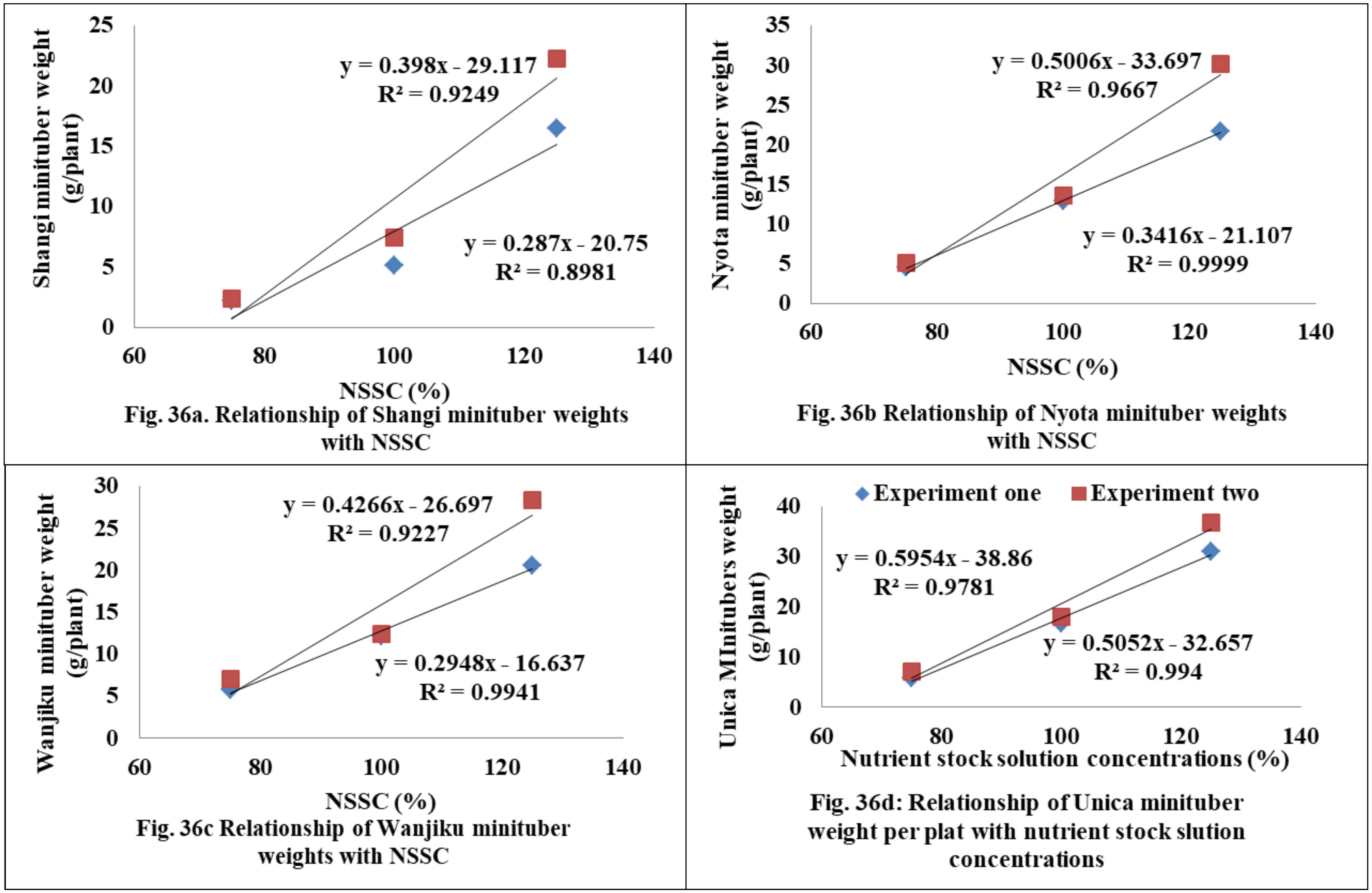

Fig. 36a. Relationship of Shangi minituber weights with NSSC

Fig. 36b Relationship of Nyota minituber weights with NSSC

Fig. 36c Relationship of Wanjiku minituber weights with NSSC

Fig. 36d: Relationship of Unica minituber weight per plat with nutrient stock slution concentrations

Figure 36: Relationship of minitubers weight per plant and nutrient stock solution concentrations of potato varieties in experiment one and two

4.2.3. Effect of nutrient solution concentrations on the yield per hectare of ARC varieties

Effect of nutrient stock solution concentrations on the yield per hectare of ARCs

All NSSC differed significantly ($p \leq 0.05$) from each other with the application of nutrient stock solution on yield per plant. Treatment N125 gave the highest yield (9.97t ha^{-1}) followed by N100 (5.22t ha^{-1}) and N75 (1.90t ha^{-1}) in experiment one. Similar results were obtained in experiment two where N125 gave significantly ($p \leq 0.05$) higher yields per plant (13.08t ha^{-1}) followed by N100 (5.74t ha^{-1}) and N75 (2.23t ha^{-1}) (Figure 37).

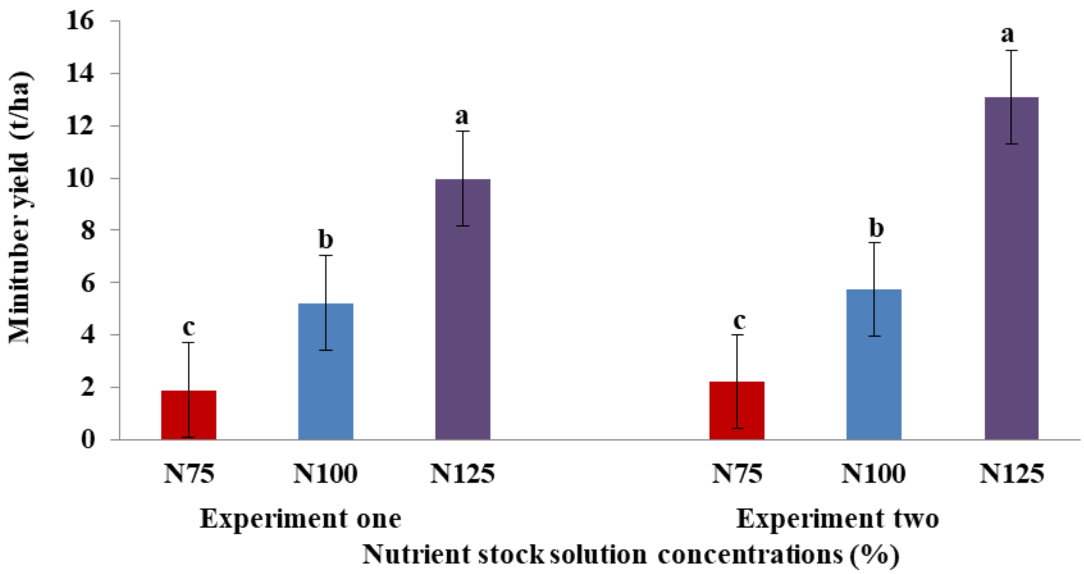

Figure 37: Main effects of nutrient stock solution concentrations on yield per hectare in experiment one and two

Effect of potato rooted apical cuttings varieties on yield per hectare

The varieties differed significantly ($p \leq 0.05$) in yield per hectare with Unica having the highest yield (7.94t ha^{-1} and 9.19t ha^{-1} in experiment one and two, respectively). There was no significant difference in the yield between Nyota (5.80t ha^{-1} and 7.27t ha^{-1} in experiment one and two, respectively), Wanjiku (5.52t ha^{-1} and 6.85t ha^{-1} in experiment one and two, respectively) and Shangi (3.53t $ha^{-1}$and 4.75t ha^{-1} in experiment one and two, respectively (Figure 38).

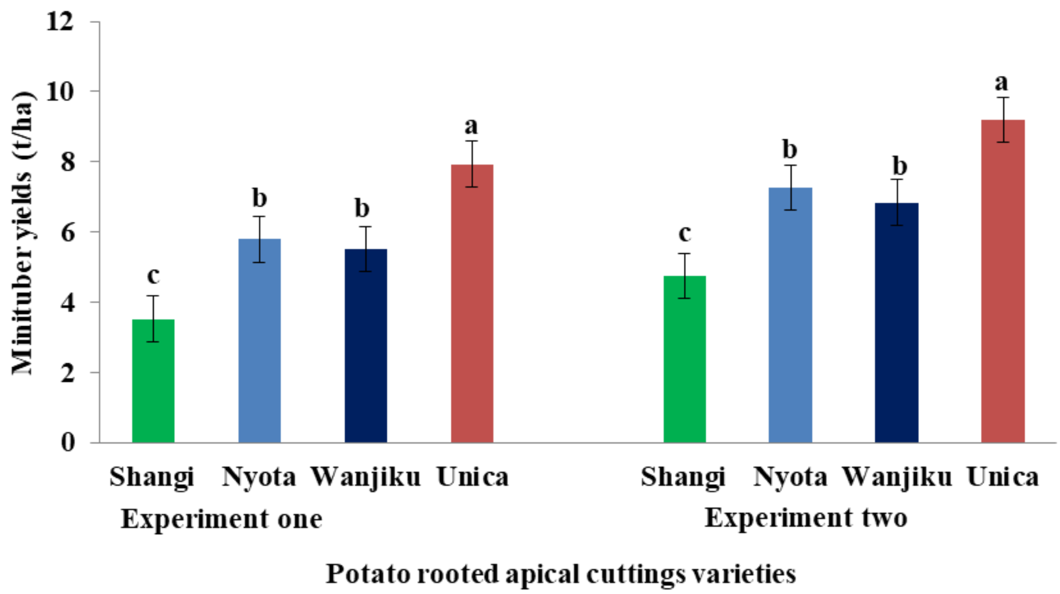

Figure 38: Effect of potato rooted apical cuttings varieties yield per hectare in experiment one and two

Effect of the interaction of the nutrient stock solution concentrations and ARC varieties on the yield per hectare of ARCs

The interaction effect between the nutrient stock solutions and the potato varieties affected tuber yield t ha^{-1} significantly ($p \leq 0.05$) in both experiments (Table 7). The interaction effect on rooted apical cuttings yield was highest in treatments N125 and potato varieties. Growing Unica under N125 produced the highest yield (13.80t ha^{-1}) which was significantly different ($p \leq 0.05$) from Nyota (9.62t ha^{-1}), Wanjiku (9.13t ha^{-1}) and Shangi (7.34t ha^{-1}) in experiment one. Similar results were obtained in experiment two, where Unica (16.38t ha^{-1}) produced significantly higher yields than Nyota (13.43t ha^{-1}), Wanjiku (12.63t ha^{-1}) and Shangi (9.90t ha^{-1}). There was significant difference ($p \leq 0.05$) in N100*varieties interactions. In experiment one, Unica (7.44t ha^{-1}) differed significantly with Shangi (2.29t ha^{-1}), Nyota (5.75t ha^{-1}) and Wanjiku (5.42t ha^{-1}). Similar results were obtained in experiment two where Unica (8.05t ha^{-1}) was significantly different from Nyota (6.08t ha^{-1}), Wanjiku (5.51t ha^{-1}) and Shangi (3.29t ha^{-1}). The lowest yields were observed under the treatment combination of N75 and varieties. All varieties did not differ significantly ($p \leq 0.05$) with the application of N75 NSSC in both experiments. Yields ranged from 0.96t ha^{-1} to 2.58t ha^{-1}in experiment one and 1.06t $ha^{-1}$to 3.14t ha^{-1}in experiment two.

Table 7: Interaction effects of nutrient stock solution concentration and potato varieties on minitubers yield (t/ha) in experiment one and two

Nutrient solutions	Potato varieties	Experiment one (Yield t/ha)	Experiment two (Yield t/ha)
N75	$V_{1(Shangi)}$	0.96^{g}	1.06^{f}
	$V_{2(Nyota)}$	2.03^{fg}	2.31^{ef}
	$V_{3(Wanjiku)}$	2.01^{fg}	2.41^{ef}
	$V_{4(Unica)}$	2.58^{efg}	3.14^{ef}
N100	$V_{1(Shangi)}$	2.29^{efg}	3.29^{ef}
	$V_{2(Nyota)}$	5.75^{cde}	6.08^{cde}
	$V_{3(Wanjiku)}$	5.42^{def}	5.51^{de}
	$V_{4(Unica)}$	7.44^{bcd}	8.05^{cde}
N125	$V_{1(Shangi)}$	7.34^{bcd}	9.90^{bc}
	$V_{2(Nyota)}$	9.62^{b}	13.43^{ab}
	$V_{3(Wanjiku)}$	9.13^{bc}	12.63^{ab}
	$V_{4(Unica)}$	13.80^{a}	16.38^{a}
P value		0.0485	<.0001
Mean		5.70	7.01
CV		21.88	20.78

The means followed by the same letter(s) in the same column are not significantly different using Tukey HSD test at a 5% significance level.

Regression analyses for the relationship of ARCs NDVI with yield (t/ha)

The relationship of NDVI taken at 60 DAP could be explained by fitting linear functions whose mathematical functions had a regression coefficient of R^2 =0.5663 for experiment 1 and 0.7887 for experiment two (Figs. 39 and 40). The relationship of individual varieties and NDVI are explained in Fig. 41a-41h. All the 2nd degree (quadratic) regression functions developed revealed a high goodness of fit greater than 0.97 except for Shangi and Nyota (>0.71) in experiment two. At highest NSSC application rates, the growth and health of the crops were significantly ($p \leq 0.05$) better than for crops grown under N75. Highest values for NDVI were observes to peak about the 60 DAP for crops grown under N100 and N75. However, for potato ARC varieties grown under N125, NDVI peaked earlier than 60th DAP, implying that higher doses of NSSC application (i.e., 125% through fertigation), enhances the growth and health (NDVI) of ARC potato varieties (Nyota, Wanjiku and Shangi, respectively). Unica however appeared to respond slowly even under higher N125 application with a NDVI of less than 0.6.

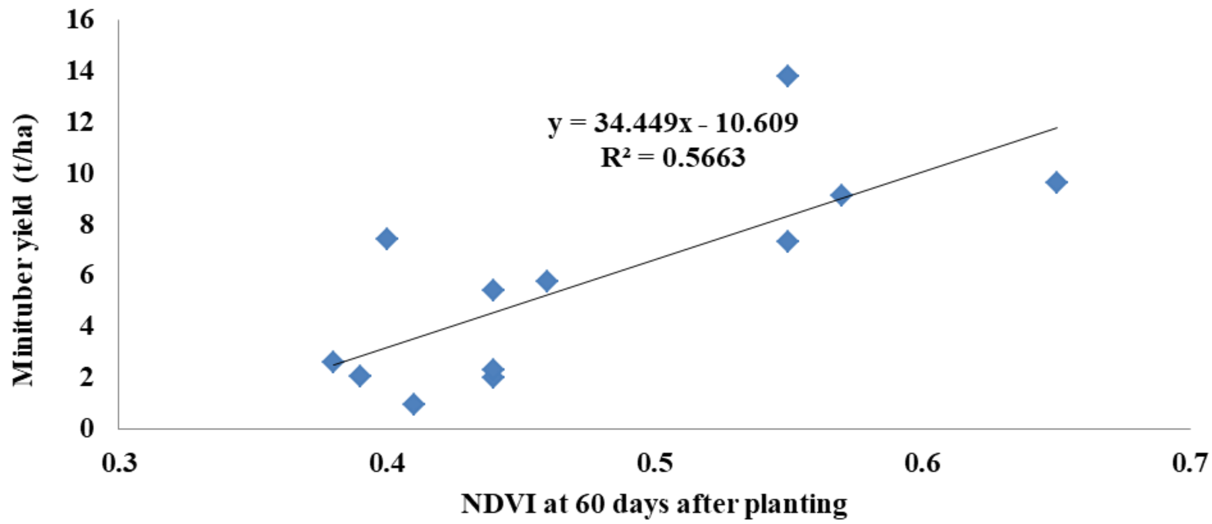

Figure 39: Relationship of NDVI at 60 days after planting with minitubers yield in experiment one

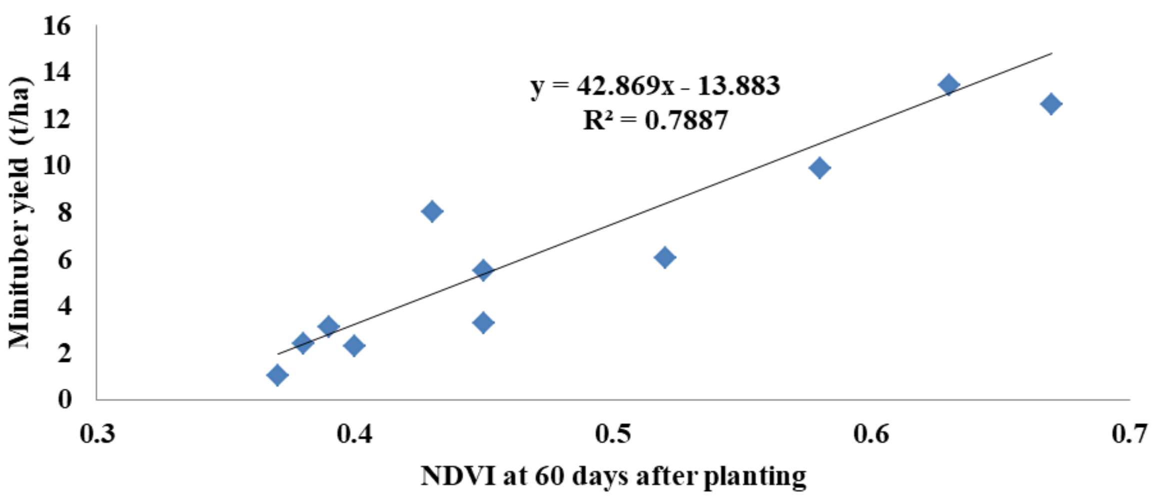

Figure 40: Relationship of NDVI at 60 days after planting with minitubers yield in experiment two

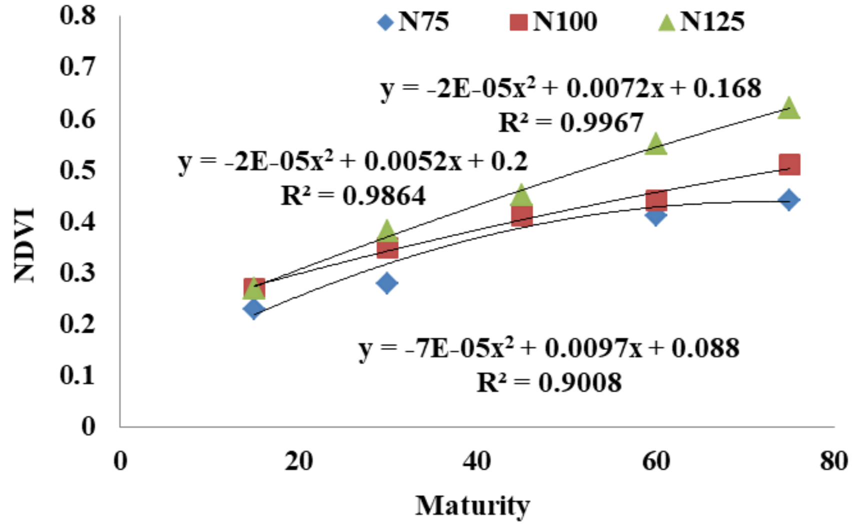

Fig. 41a: Relationship of shangi ARC maturity with NDVI in experiment 1

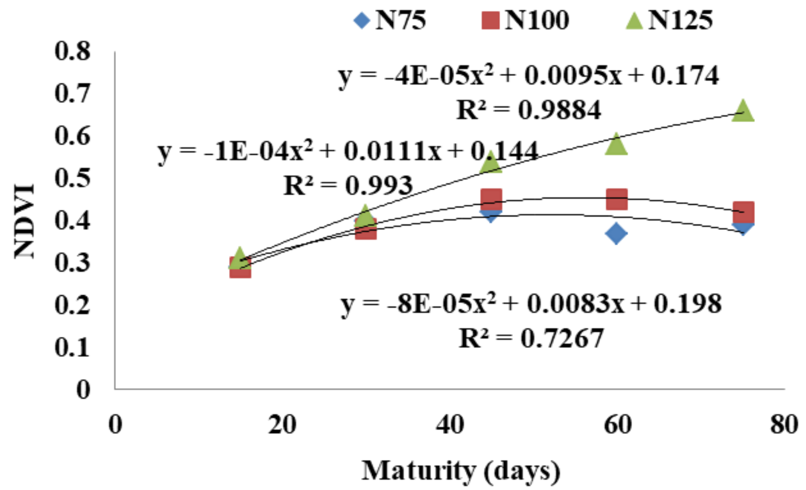

Fig 41b: Relationship of shangi ARC maturity with growth (NDVI) in experiment 2

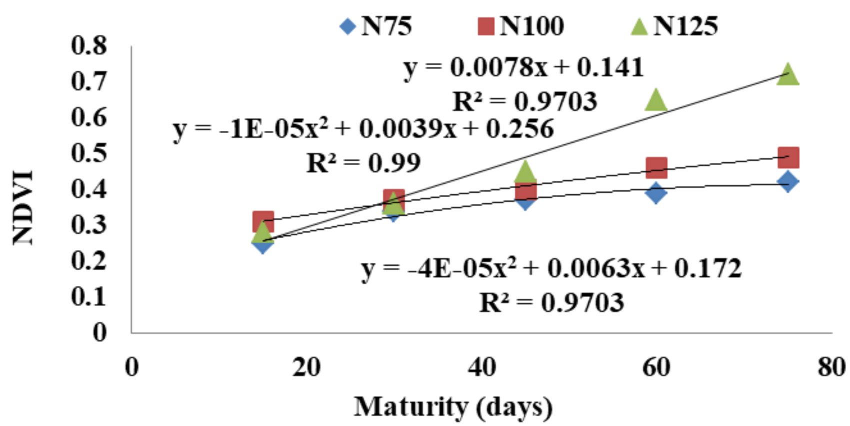

Fig. 41c: Relationship of Nyota ARC maturity with growth (NDVI) in experiment 1

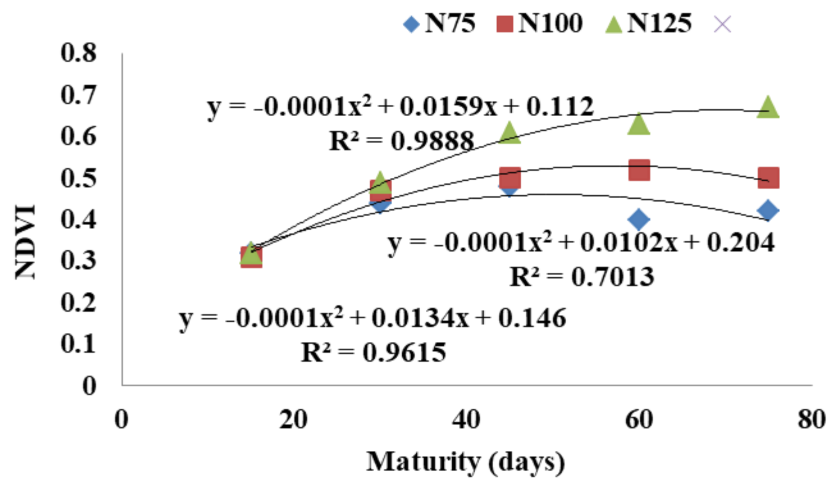

Fig. 41d: Relationship of Nyota ARC maturity with NDVI in experiment 2

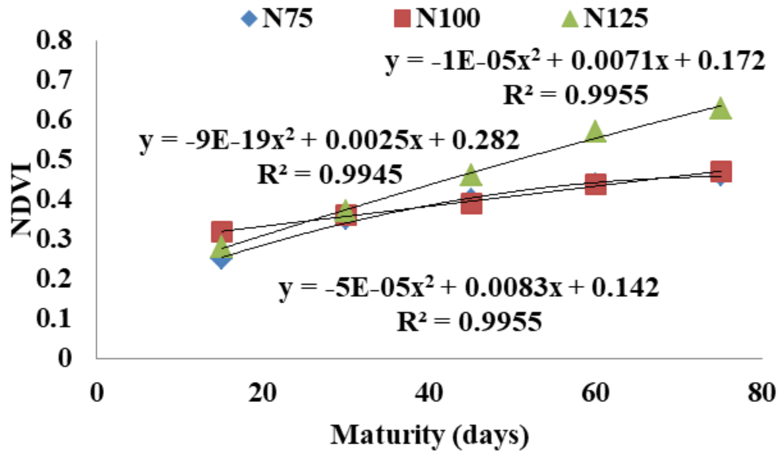

Fig 41e: Relationship of Wanjiku ARC maturity with NDVI in experiment 1

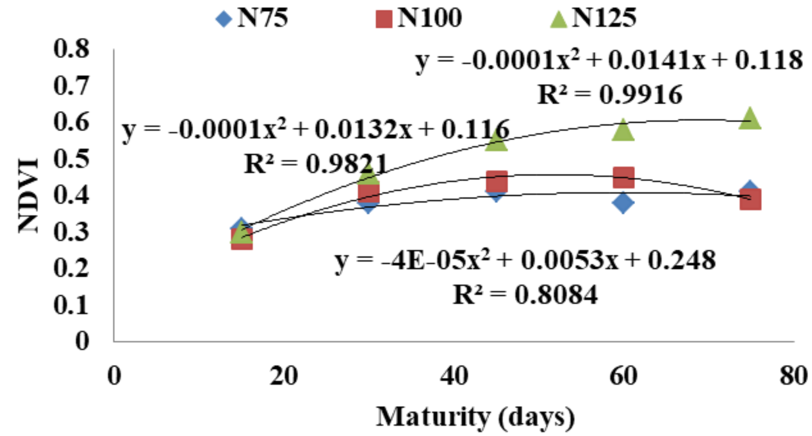

Fig 41f: Relationship of Wanjiku ARC maturity with NDVI in experiment 2

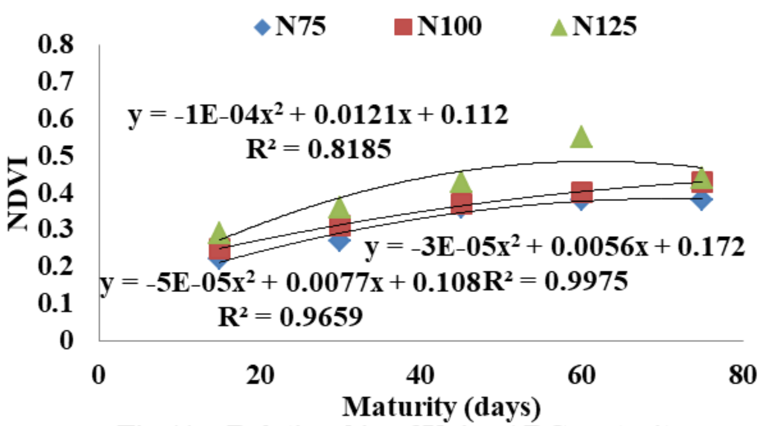

Fig 41g: Relationship of Unica ARC maturity with NDVI in experiment 1

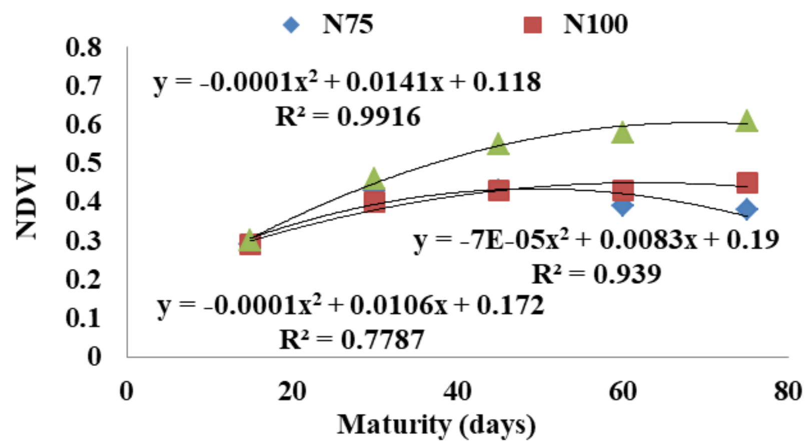

Fig 41h: Relationship of Unica ARC maturity with NDVI in experiment 2

Figure 41: Relationship of potato varieties yields with NDVI in experiment one and two

4.2.4: Effect of nutrient solution concentrations on the minitubers classes per plant in potato ARC varieties

Effect of nutrient stock solution concentrations on the minitubers classes per plant of ARCs

The nutrient stock solutions had significant effect ($p<0.05$) on the minitubers classes (Figs 42 and 43). There was significant difference on the application of NSSC on the Class one (C1) (<8g) minitubers). Treatment N100 and N75 were significantly ($p\leq0.05$) different from N125 in both experiments in C1. Treatment N125 produced less C1 tubers per plant (2 tubers) as compared to N100 (3 tubers) and N75 (3 tubers) in experiment one. Similar results were obtained in experiment two where N75 (3 tubers) and N100 (2 tubers) produced significantly higher number of minitubers than N125 (1 tuber). Under class 2 (8.01g-15.99g) minitubers), N125 (3 tubers) and N100 (2 tubers) produced significantly ($p<0.05$) higher C2 minitubers numbers as compared to N75 (1 tuber) in experiment one while in experiment two, N125 and N100 produced 2 tubers and N75 produced 1 tuber. In class 3 (16.00g-18.00g) minitubers), N125 produced significantly ($p<0.05$) higher number of minitubers (2 tubers) as compared to N100 and N75 which produced 1 tuber in experiment one In experiment two, all nutrient solution concentrations differed significantly ($p\leq0.05$) with N125 producing the highest number of C3 minitubers (3 tubers) followed by N100 (2 tubers) and N75 did not produce any minitubers under class 3. Under class 4 (>18.00g minitubers), N125 produced the highest minitubers number (3 tubers) which was significantly ($p<0.05$) different from N100 (1) and N75 which did not give any C4 minitubers in experiment one. Similar results were obtained in experiment two where N125 differed significantly from N100 and N75 which did not give any C4 minitubers.

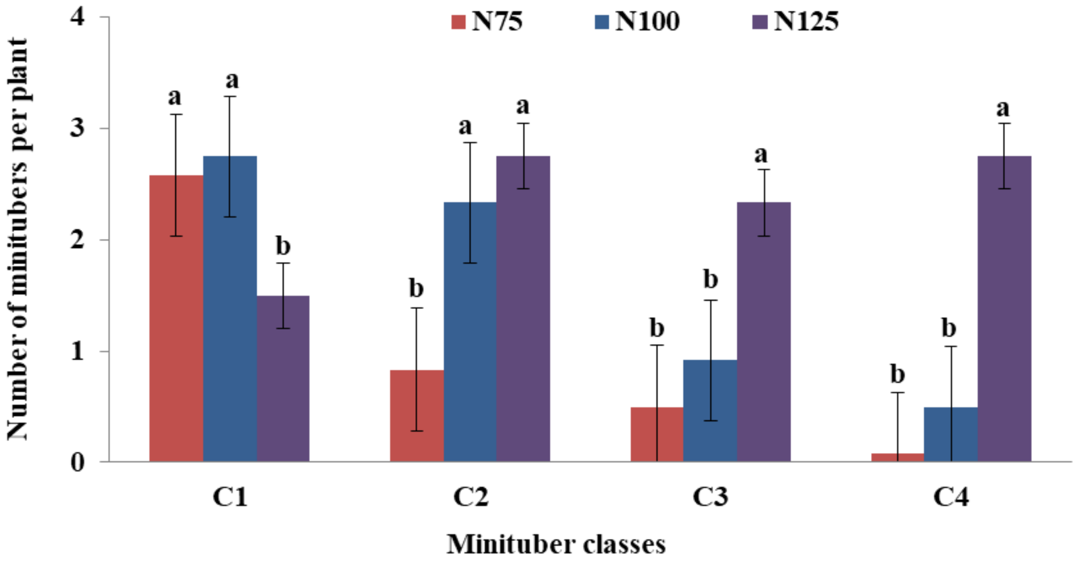

Figure 42: Main effects of nutrient stock solution concentrations on minitubers classes in experiment one

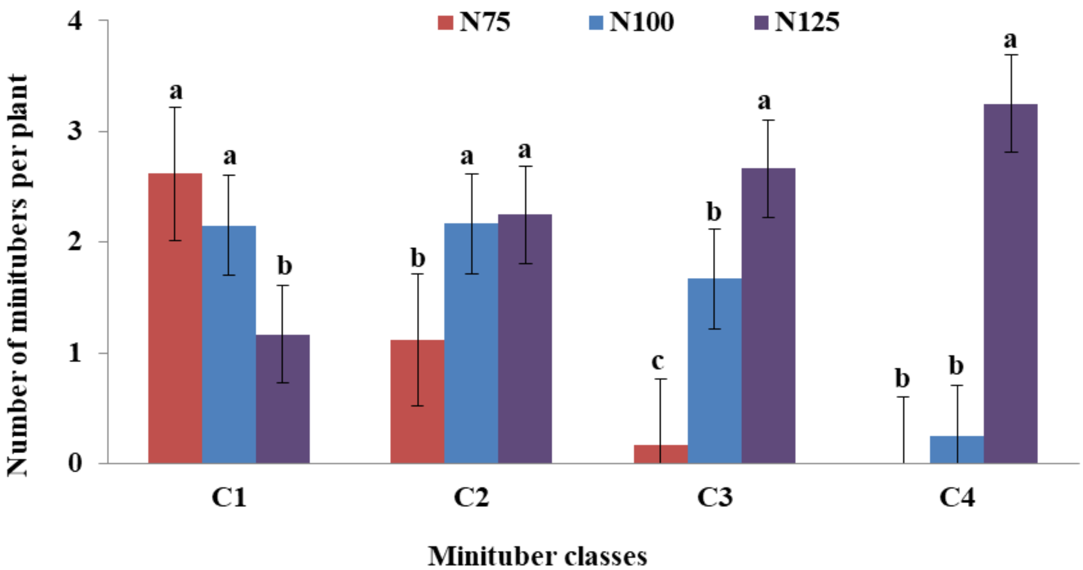

Figure 43: Main effects of nutrient stock solution concentrations on minitubers classes in experiment two

Effect of potato rooted apical cuttings varieties on minitubers classes

The minitubers classes were significantly different in the potato varieties ($p \leq 0.05$) (Figs 44 and 45). In the C1 minitubers class the varieties differed significantly in both experiments where Nyota (3 tubers), Wanjiku (3 tubers) and Shangi (3 tubers) produced the highest C1 numbers which were significantly ($p<0.05$) different from Unica (1 tuber) in experiment one.

Similar results were observed in experiment two where Nyota, Wanjiku and Shangi produced 2 tubers which were significantly different from Unica (1 tuber). In C2 minitubers classes, Nyota (3 tubers) and Wanjiku (3 tubers) produced significantly ($p<0.05$) higher minitubers as compared to Shangi (2 tubers) and Unica (1 tuber) which differed significantly from each other in experiment one. In experiment two, Nyota, Wanjiku and Shangi produced significantly higher number of minitubers (2 tubers) as compared to Unica (1 tuber). Under C3 class, Unica (2 tubers) did not differ significantly ($p<0.05$) with Nyota in the number of minitubers. Shangi and Wanjiku (1 tuber) differed significantly to Unica in the number of minitubers per plant under C3 in experiment one while in experiment two, all varieties did not differ significantly in the number of minitubers under class 3. In C4 minitubers classes, Unica (2 tubers) produced significantly ($p<0.05$) higher number of minitubers as compared to Wanjiku, Shangi and Nyota which produced 1 tuber in both experiments.

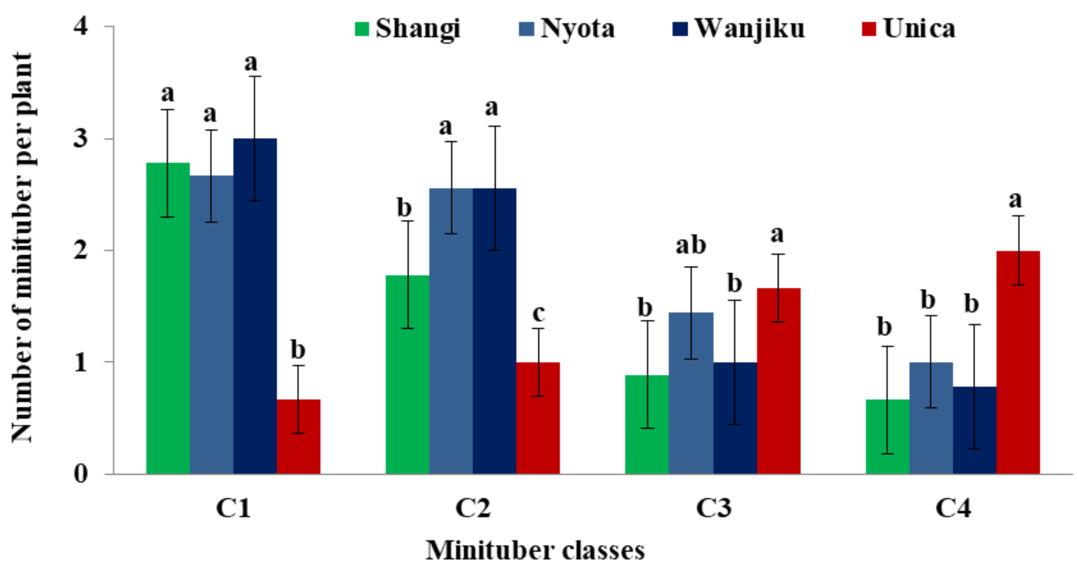

Figure 44: Effect of potato rooted apical cuttings varieties on minitubers classes in experiment one

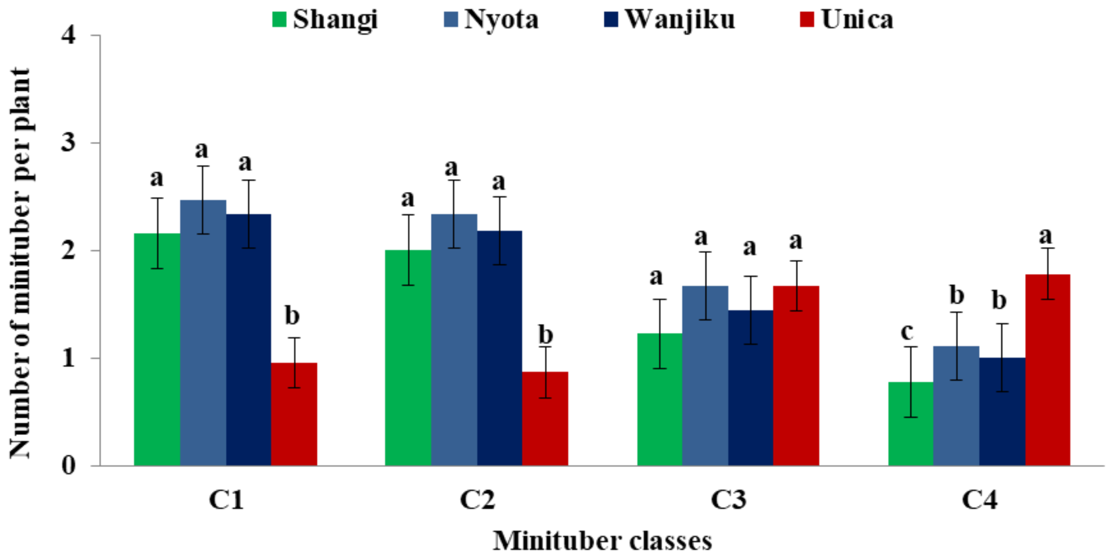

Figure 45: Effect of potato rooted apical cuttings varieties on minitubers classes in experiment two

Effect of the interaction of the nutrient stock solution concentrations and ARC varieties on the minitubers classes

There was significant interaction ($p \leq 0.05$) between the treatment combinations and varieties on minitubers classes in both experiments except for C3 and C4 in experiment one and C1 in experiment two (Table 8). Under the N75 * varieties interaction, Class one (<8g) produced the highest numbers of minitubers. Shangi produced significantly ($p<0.05$) higher number of minitubers (3.33) as compared to Unica (1.33) but did not differ significantly from Nyota (2.67) and Wanjiku (3.00) in experiment one while in experiment two; there was no significant interaction in the class 1. In class 2 (8g-16g), all varieties did not differ significantly ($p<0.05$) in the number of minitubers in both experiments. Unica and Nyota produced 1.33 minitubers followed by Wanjiku (0.67) and Shangi (0.00) in experiment one while in experiment two; Unica produced 1.60 minitubers followed by Nyota (1.00), Shangi (1.00) and Wanjiku (0.87). There was no significant interaction in class three (16g-18g) and four under N75. In C3 all varieties Unica had 1.33 tuber followed by Nyota (0.33), Wanjiku (0.33) and Shangi (0.00) in experiment one while in experiment two, there were no significant ($p<0.05$) interactions between the varieties with Unica producing 0.67 tuber while Nyota, Shangi and Wanjiku did not produce any minitubers under Class 3. Under C4, Unica produced 0.33 while all the varieties did not produce any minitubers in experiment one while in experiment two, all varieties did not produce any minitubers under the C4 class in experiment two (Table 11).

In the N100 *varieties interaction, there was significant difference in the minitubers Class 1 in experiment two. In experiment one, Wanjiku (3.00), Nyota (2.67) and Shangi (2.67) produced significantly higher number of minitubers as compared to Unica (0.67) in experiment one. In experiment two, there were no significant interactions under C1; Nyota produced 3.00 minitubers followed by Shangi (2.67), Wanjiku (2.33) and Unica (0.67). In Class 2, Nyota (2.67), Shangi (2.67) and Wanjiku (0.67) produced significantly ($p<0.05$) higher number of minitubers as compared to Unica (1.00) in experiment one. Similar trends were observed in experiment two where Nyota (3.00), Shangi (1.00) and Wanjiku (2.33) produced significantly higher minitubers number as compared to Unica (0.67). In class 3, Unica had 1.67 minitubers followed by Wanjiku (0.67), Nyota (1.00) and Shangi (0.033) in experiment one. In experiment two, there were no significant interactions between the varieties with Unica producing 2.33 followed by Wanjiku (1.67), Nyota (1.67) and Shangi (1.00). Under C4, Unica produced 1.67 minitubers and Nyota 0.33 minitubers while Shangi and Unica did not produce any minitubers under C4. In experiment two, all varieties did not produce minitubers under the C4 class except for Unica which produced (1.00 tubers) (Table 11).

In the N125* varieties interactions, Wanjiku (2.33) and Nyota (2.00) produced significantly ($p<0.05$) higher number of minitubers of C1 as compared to Unica (0.00) while Shangi (1.67) did not differ significantly from the all varieties in experiment one. In experiment two, no significant interactions were reported under C1. In class 2, Wanjiku (4.00), Nyota (3.67) and Shangi (2.67) differed significantly from Unica (0.00) in experiment one while in experiment two; Wanjiku (3.00), Nyota (3.00) and Shangi (2.33) produced significantly higher number of minitubers as compared to Unica (0.33). In class 3, no significant interactions were reported. Unica produced 2.00 minitubers followed by Nyota (3.00), Shangi (2.33) and Wanjiku (2.00) in experiment one. In experiment two, all varieties did not differ significantly in the C3 class with Nyota having 3.33 followed by Wanjiku (2.67), Shangi (2.67) and Unica (2.00). Under class 4 no significant interactions were reported in experiment one. Unica produced 4.00 minitubers followed by Nyota (2.67), Wanjiku (2.33) and Shangi (2.00). In experiment two, significant interactions were reported with Unica (4.33) producing significantly higher number of minitubers as compared to Nyota (3.33), Wanjiku (3.00) and Shangi (2.33) (Table 8).

Table 8: Interaction effects of nutrient stock solution concentration and potato varieties on minitubers classes in experiment one and two

Nutrient solutions	Potato variety	Experiment one (number of minitubers)				Experiment two (number of minitubers)			
		C1	C2	C3	C4	C1	C2	C3	C4
N75	$V_{1(Shangi)}$	3.33^{ab}	0.00^{c}	0.00	0.00	2.47	1.00^{cd}	0.00^{e}	0.00^{e}
	$V_{2(Nyota)}$	2.67^{abc}	1.33^{bc}	0.33	0.00	3.07	1.00^{cd}	0.00^{e}	0.00^{e}
	$V_{3(Wanjiku)}$	3.00^{abc}	0.67^{c}	0.33	0.00	2.93	0.87^{d}	0.00^{e}	0.00^{e}
	$V_{4(Unica)}$	1.33^{cde}	1.33^{bc}	1.33	0.33	2.00	1.60^{bcd}	0.67^{de}	0.00^{e}
N100	$V_{1(Shangi)}$	3.33^{ab}	2.67^{ab}	0.33	0.00	2.67	2.67^{ab}	1.00^{cde}	0.00^{e}
	$V_{2(Nyota)}$	3.33^{ab}	2.67^{ab}	1.00	0.33	2.67	3.00^{a}	1.67^{bcd}	0.00^{e}
	$V_{3(Wanjiku)}$	3.67^{a}	3.00^{a}	0.67	0.00	2.40	2.33^{abc}	1.67^{bcd}	0.00^{e}
	$V_{4(Unica)}$	0.67^{de}	1.00^{c}	1.67	1.67	0.87	0.67^{d}	2.33^{abc}	1.00^{d}
N125	$V_{1(Shangi)}$	1.67^{bcde}	2.67^{ab}	2.33	2.00	1.33	2.33^{abc}	2.67^{ab}	2.33^{c}
	$V_{2(Nyota)}$	2.00^{abcd}	3.67^{a}	3.00	2.67	1.67	3.00^{a}	3.33^{a}	3.33^{b}
	$V_{3(Wanjiku)}$	2.33^{abcd}	4.00^{a}	2.00	2.33	1.67	3.33^{a}	2.67^{ab}	3.00^{b}
	$V_{4(Unica)}$	0.00^{e}	0.67^{c}	2.00	4.00	0.00	0.33^{d}	2.00^{abcd}	4.33^{a}
P value		0.0013	0.0004	0.5216	0.1513	0.7755	<.0001	0.004	<.0001
Mean		2.27	1.97	1.25	1.11	1.98	1.84	1.50	1.16
CV		27.05	20.47	20.45	25.83	25.00	24.63	19.51	14.29

The means followed by the same letter(s) in the same column are not significantly different using Tukey HSD test at a 5% significance level

4.3. Effects of nutrient concentrations on the quality of minitubers seed potato varieties

Quality parameters i.e., the sizes, dry matter (DM), specific gravity and starch content of minitubers were determined from all the potato varieties (Shangi, Nyota, Wanjiku and Unica) which were grown under the different NSSCs. These are given in Table 1.

4.3.1. Effect of nutrient solution concentrations on the dry matter of minitubers potato varieties

Effect of nutrient stock solution concentrations on the minitubers dry matter

It is evident from Figure 46 that minitubers dry matter (DM) increased significantly ($p \leq 0.05$) with increase in nutrient stock solution concentrations (NSSC) in both experiments. Dry matter was significantly higher in N125 (23.90%) followed by N100 (20.58%) and N75 (17.79%) in experiment one. Similar results were observed in experiment two, where N125 produced 24.90% followed by N100 (20.98%) and N75 (17.89%).

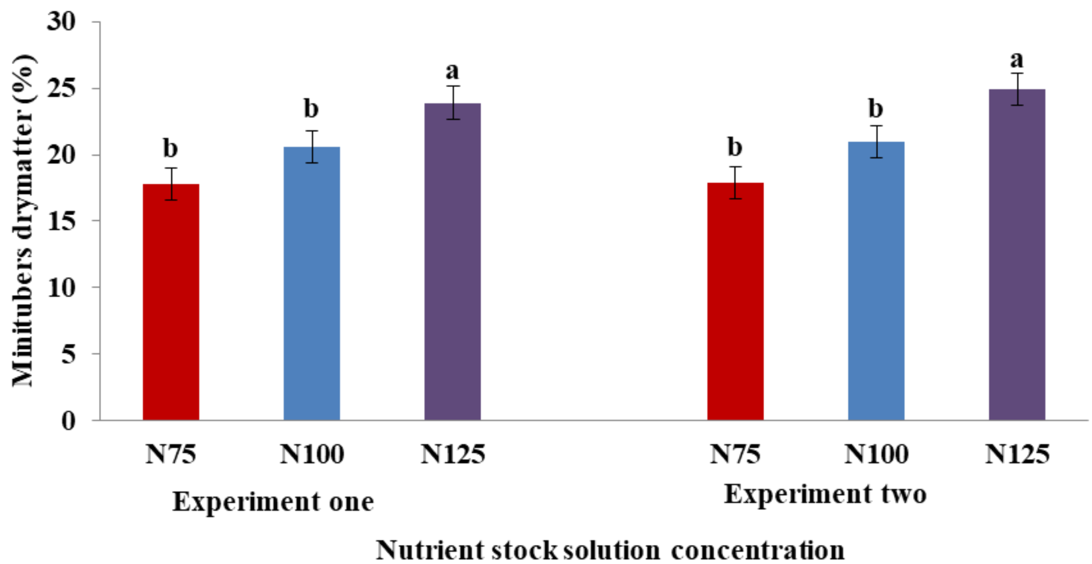

Figure 46: Main effects of nutrient stock solution concentrations on minitubers dry matter % in experiment one and two

Effect of potato rooted apical cuttings varieties on minitubers dry matter (%)

Figure 47 shows that response of rooted apical cuttings varieties to application of nutrient stock solution concentrations (NSSSC) did not have any significant effect ($p \leq 0.05$) in both experiments. Shangi had a DM of 21.06% followed by Wanjiku (20.66%), Unica (20.80%) and Nyota (20.51%) in experiment one. Similar results were obtained in experiment two; Shangi had 21.19% followed by Unica (21.13%), Wanjiku (20.83%) and Nyota

(20.79%).

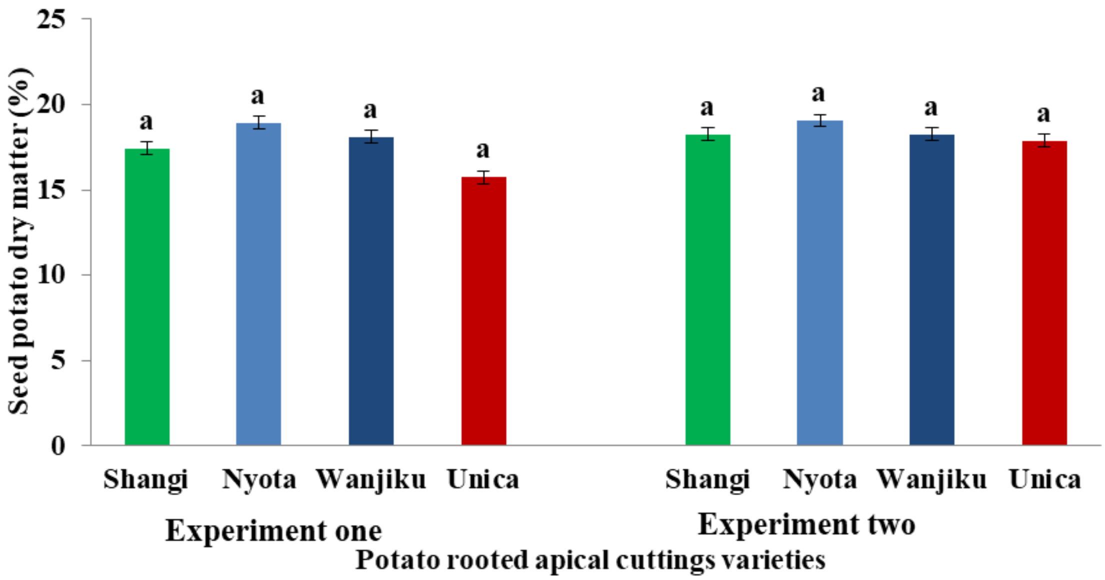

Figure 47: Effect of potato rooted apical cuttings varieties on minitubers dry matter (%) in experiment one and two

Effect of the interaction of the nutrient stock solution concentrations and ARC varieties on the minitubers dry matter (%)

There was no significant ($P \leq 0.05$) NSSC and varieties interaction effects on the minitubers dry matter (DM) (Fig. 48). Minitubers DM ranged from 24.10% to 23.57% under N125 in experiment one while in experiment two, DM ranged from 24.27% to 23.92%. Under the application of N100, DM ranged from 20.20% to 20.97% experiment one and 20.66% to 21.29% in experiment two while under N75, DM ranged from 17.57% to 18.20% in experiment one and 17.60% to 18.10% in experiment two. Increase in NSSC from 75% to 125% was observed to increase DM% linearly as described by the functions given in Fig. 48 below that had a high dependability of 99.93% in both experiments.

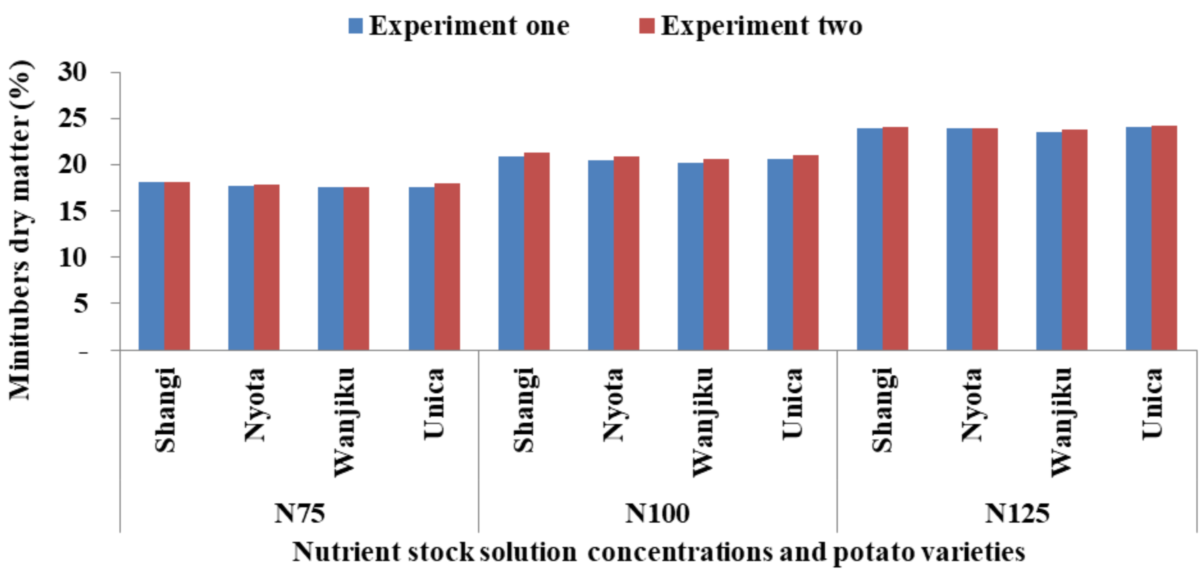

Figure 48: Interaction effects of nutrient stock solution concentration and potato varieties on minitubers dry matter (%) in experiment one and two

Regression analysis of the potato ARCs and nutrient stock solution concentration to minitubers DM (%)

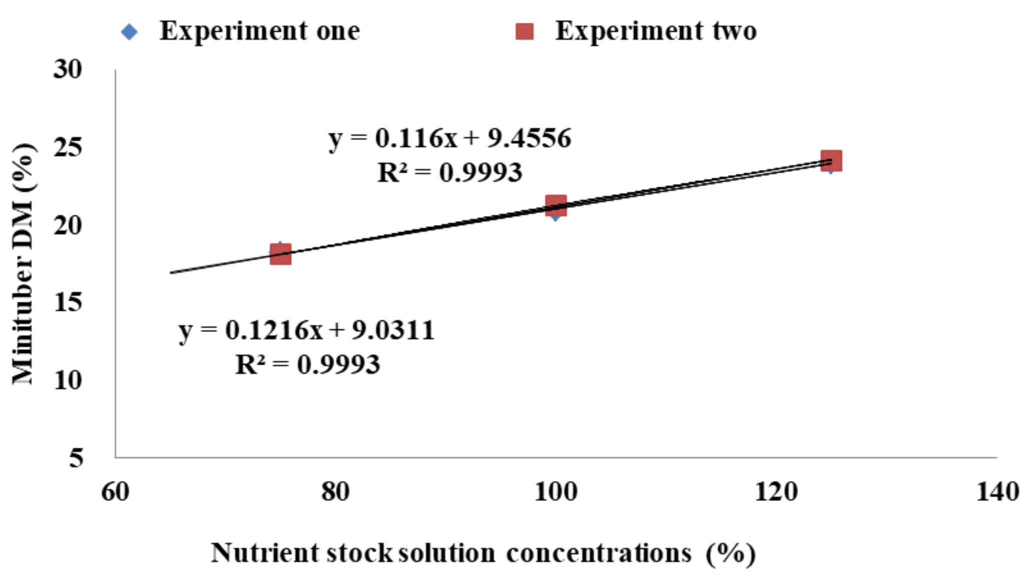

Figure 49: Relationship of nutrient stock solution concentrations to minitubers DM (%) of ARC varieties

Relationships of seed potato varieties to varied NSSC to minitubers dry matter was developed using regression analysis as given in Fig. 49. Increasing NSSC percentage resulted in increasing in minitubers DM. For every unit change in NSSC, minitubers dry matter increased by a coefficient of 0.2658 and 0.2543 in experiment one and two respectively. It is therefore possible to predict minitubers weight using the linear functions with a confidence of 90.97% and 88.94% in experiment one and two, respectively. NDVI measurements taken at 60 DAP were regressed against minitubers DM % (Figs. 50 & 51). The relationship of NDVI with DM% of minitubers was explained by fitting linear and quadratic functions which had high goodness of fit of more than 0.7057 and 0.7486 in experiment one and 0.8638 and 0.9125 in experiment 2, respectively.

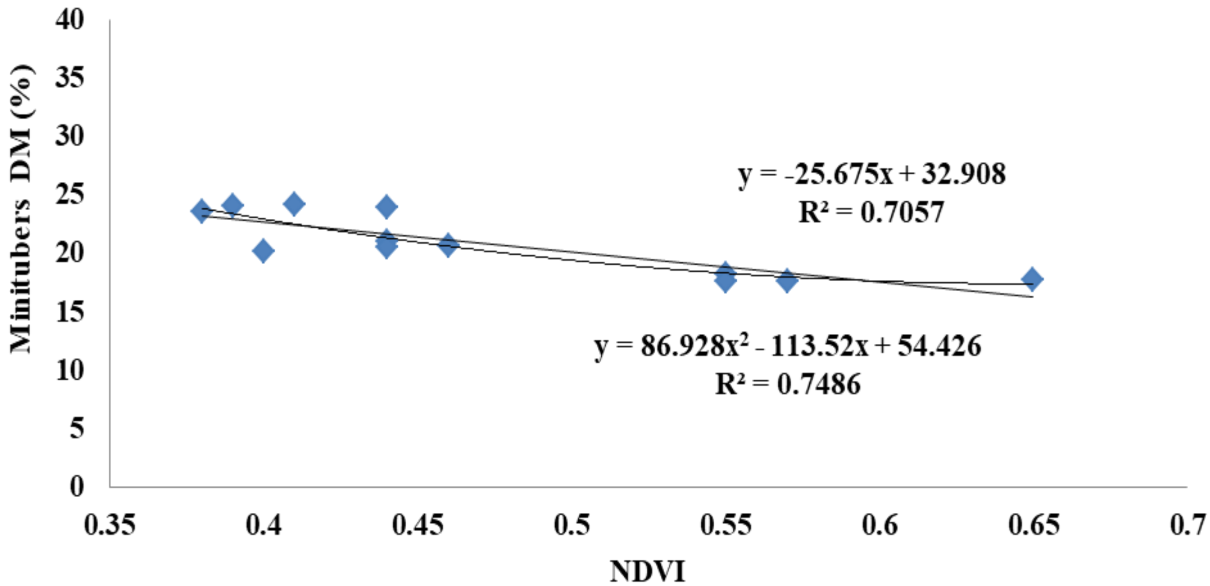

Figure 50: Relationship of NDVI at 60 DAP with DM% of minitubers grown in a hydroponic system under varying NSSC in experiment one

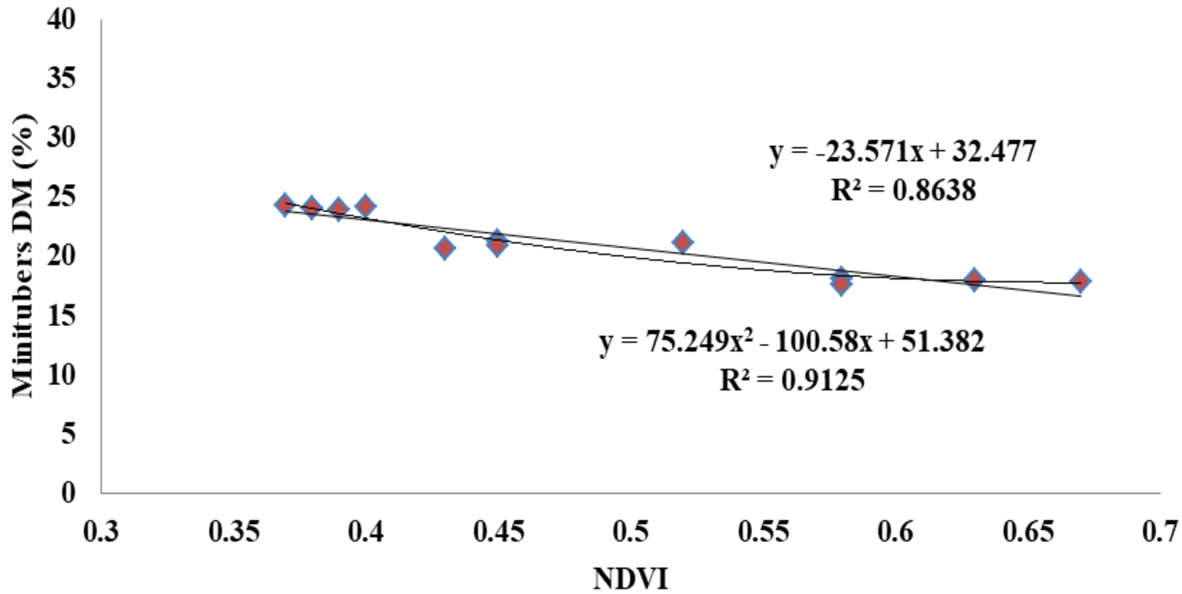

Figure 51: Relationship of NDVI at 60 DAP with DM% of minitubers grown in a hydroponic system under varying NSSC in experiment two

4.3.2: Effect of nutrient solution concentrations on the starch content of potato varieties

Effect of nutrient stock solution concentrations on starch content of the ARCs

Results in Figure 52 below shows that the starch content significantly increased ($p \leq 0.05$) with the application of increasing NSSC. Treatment N125 produced the highest starch content in experiment one (15.49ppm) and experiment two (15.58ppm) which were significantly different ($p<0.05$) from N100 (12.97ppm in experiment one and two, respectively) and N75 (11.64 ppm in experiment one and 11.63ppm in experiment two.

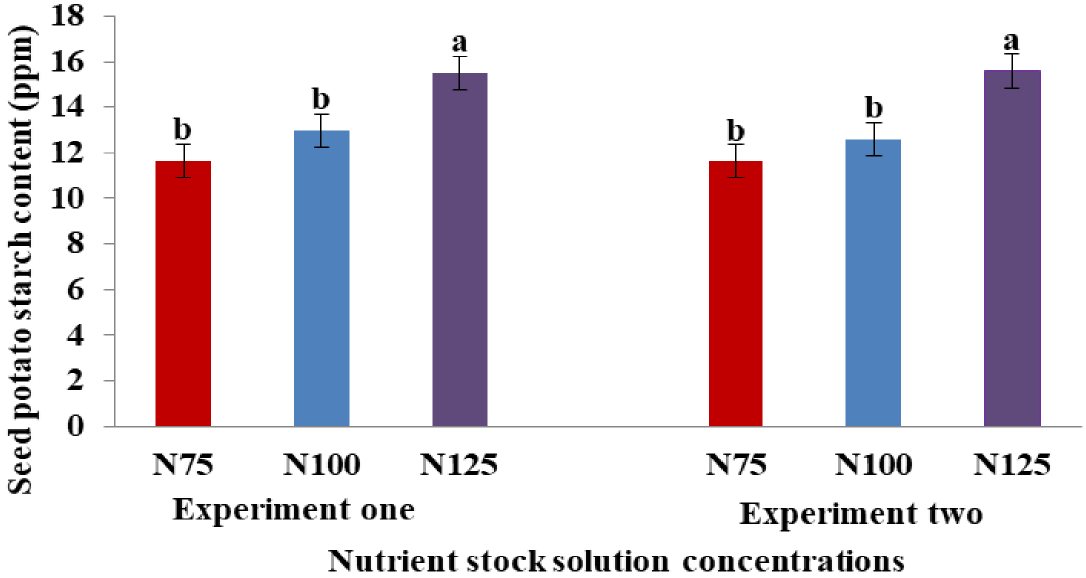

Figure 52: Main effects of nutrient stock solution concentrations on starch content of the ARCs in experiment one and two

Effect of potato rooted apical cuttings varieties starch content

There was no significant effect on the starch content of potato varieties with the application of increasing NSSC at $p \leq 0.05$ in both experiments. Shangi produced a starch content of 13.60ppm in experiment one and 13.44ppm in experiment two. This was followed by Unica (13.59ppm in experiment one and 13.48ppm in experiment two), Wanjiku (13.17ppm and 13.19ppm in experiment one and two, respectively) and Nyota (13.10ppm and 13.03ppm in experiment one and two, respectively).

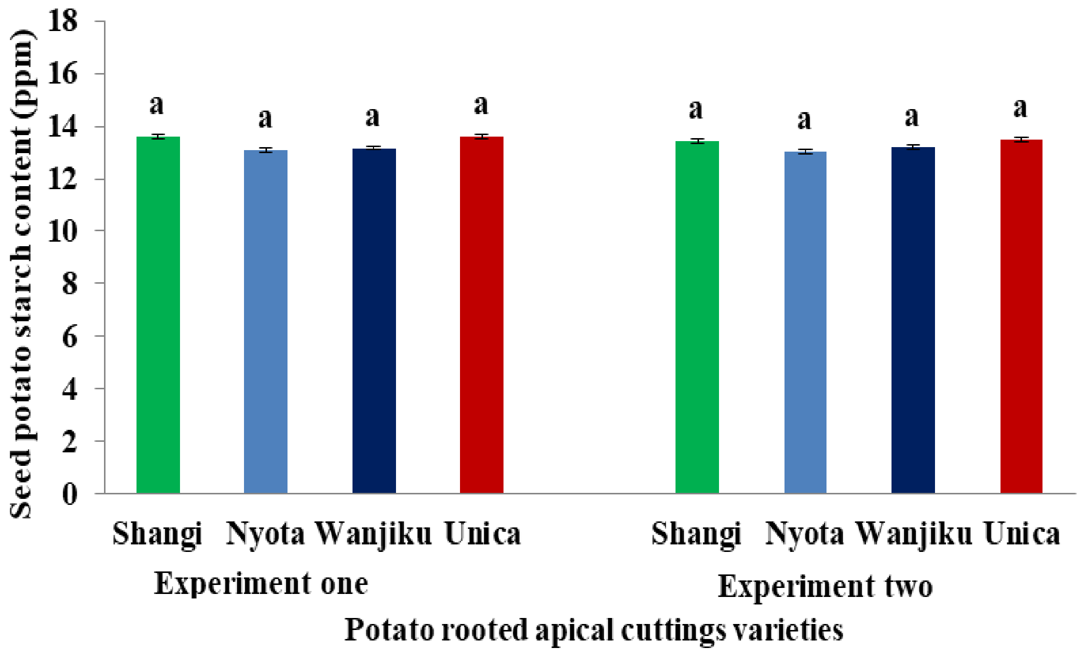

Figure 53: Effect of potato rooted apical cuttings varieties on starch content in experiment one and two

Effect of the interaction of the nutrient stock solution concentrations and ARC varieties on the starch content of ARCs

In both experiments, there was no significant interaction ($P \leq 0.05$) between the nutrient solutions and potato varieties in the starch content (Fig. 54). In the interaction between N125 and the ARC varieties, Unica produced a starch content of 15.99ppm followed by Shangi (15.60ppm), Wanjiku (15.30ppm) and Nyota (15.07ppm) in experiment one. In experiment two, Unica produced a starch content of 15.83 followed by Shangi (15.68ppm) Wanjiku (15.48) and Nyota (15.37ppm). In the interaction between N100 and potato varieties, Shangi produced a starch content of 13.44ppm followed by Unica (13.05ppm), Wanjiku (12.75ppm) and Nyota (12.62ppm) in experiment one while in experiment two, Shangi produced a starch content of 12.80ppm followed by Unica (12.65ppm), Wanjiku (12.56ppm) and Nyota (12.27ppm). In the interaction between N75 and variety, Shangi produced a starch content of 11.75ppm followed by Unica (11.73ppm), Nyota (11.62ppm) and Wanjiku (11.46ppm) in experiment one while in experiment two, Unica produced a starch content of 11.96ppm followed by Shangi (11.83), Wanjiku (11.53ppm) and Nyota (11.45ppm).

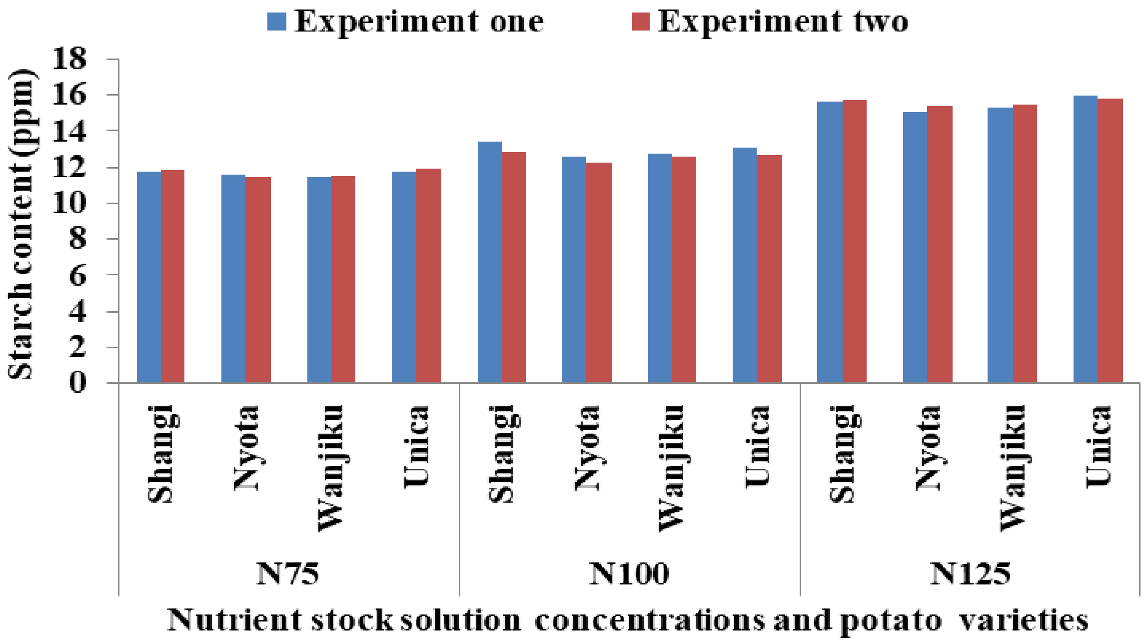

Figure 54: Interaction effects of nutrient stock solution concentration and potato varieties on starch content in experiment one and two

4.3.3: Effect of nutrient solution concentrations on the minitubers specific gravity of potato varieties

Effect of nutrient stock solution concentrations on minitubers specific gravity of the ARCs

The response to NSSC by the potato ARCs was significant at $p \leq 0.05$ in both experiments (Figure 55). In experiment one, N125 produced significantly higher specific gravity (1.17) as compared to N100 (1.09) and N75 (1.08). Similarly in experiment two, N125 produced significantly higher specific gravity (1.18) as compared to N100 (1.09) and N75 (1.06).

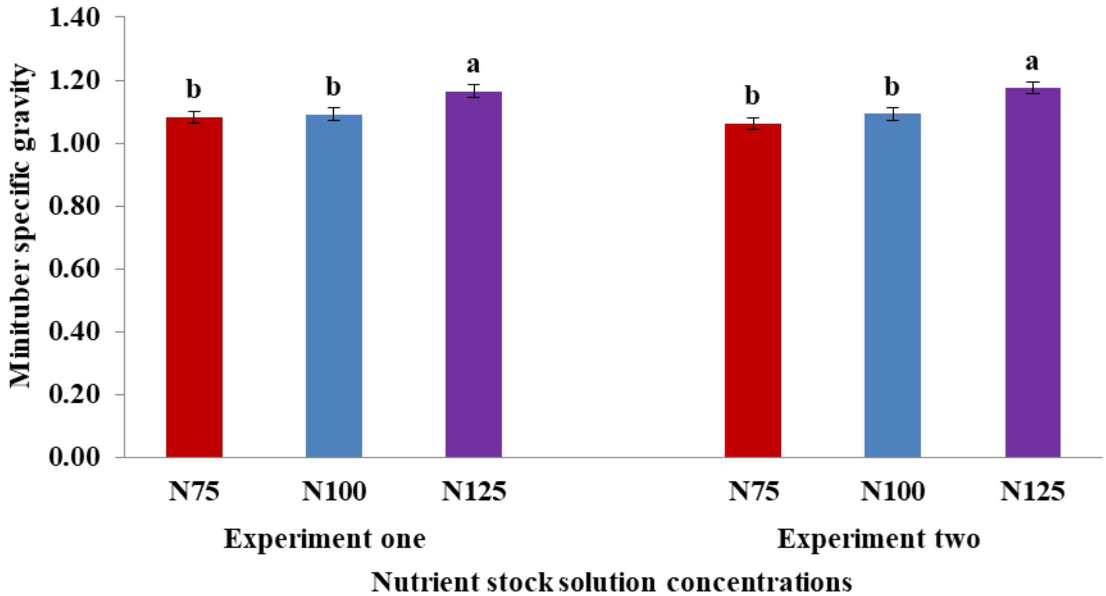

Figure 55: Main effects of nutrient stock solution concentrations on minitubers specific gravity in experiment one and two

Effect of potato rooted apical cuttings varieties on minitubers specific gravity

The varieties did not differ significantly ($p \leq 0.05$) on the specific gravity (Figure 56). Unica reported a specific gravity of (1.12) followed by Wanjiku, Nyota (1.11) and Shangi (1.10) in experiment one. Similarly in experiment two, Unica had a specific gravity of 1.13 followed by Nyota and Wanjiku (1.11) and Shangi (1.10).

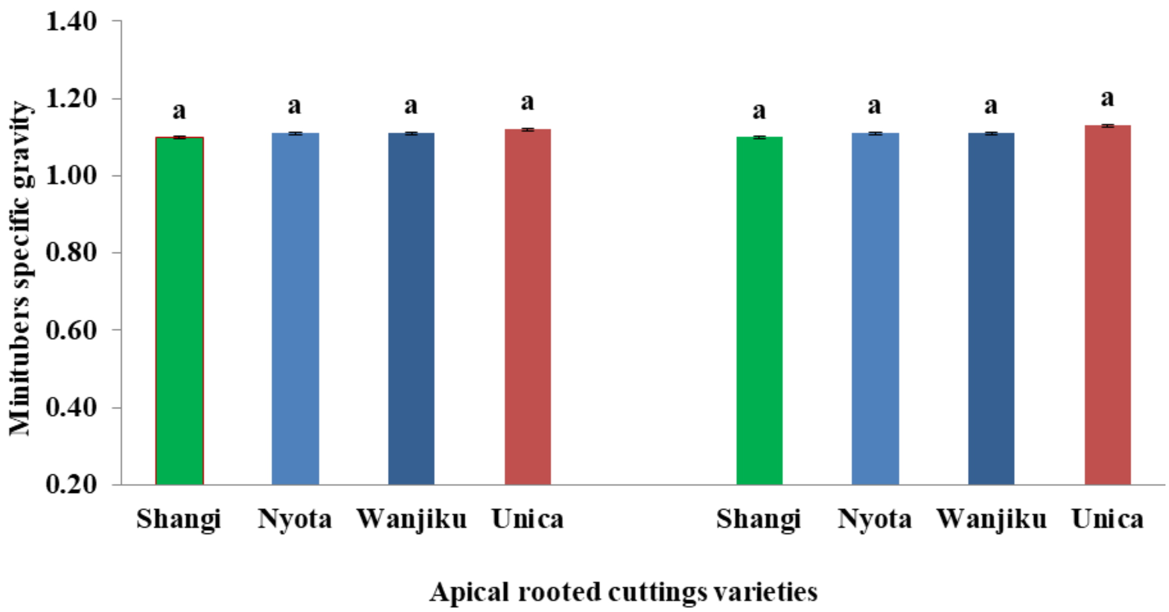

Figure 56: Effect of potato rooted apical cuttings varieties on minitubers specific gravity in experiment one and two

Effect of the interaction of the nutrient stock solution concentrations and ARC varieties on the specific gravity of ARCs

The interaction effect between the varieties and the nutrient solutions were not significant at $p \leq 0.05$ (Fig. 57). The interaction effect on varieties heights and N125 produced the highest specific gravity. In experiment one, Unica had 1.17 followed by Shangi (1.17), Wanjiku (1.16) and Nyota (1.16) while in experiment two, Unica had 1.18 followed by Shangi (1.18), Wanjiku (1.17) and Nyota (1.17). Under N100 and varieties, Unica had a specific gravity of 1.10 followed by Shangi (1.09), Wanjiku (1.09) and Nyota (1.08) in experiment one while in experiment two; Unica had 1.10 followed by Shangi (1.09), Wanjiku (1.09) and Nyota (1.08). Growing seed potato under N75 nutrient stock solution gave the least specific gravity ($p \leq 0.05$) in both experiments. Shangi gave the highest specific gravity (1.09) followed by Unica (1.08), ad Wanjiku and Nyota which gave 1.08. In experiment two, Similar results were observed where Shangi gave the highest specific gravity (1.07) followed by Unica (1.06), Wanjiku (1.06) and Nyota (1.05).

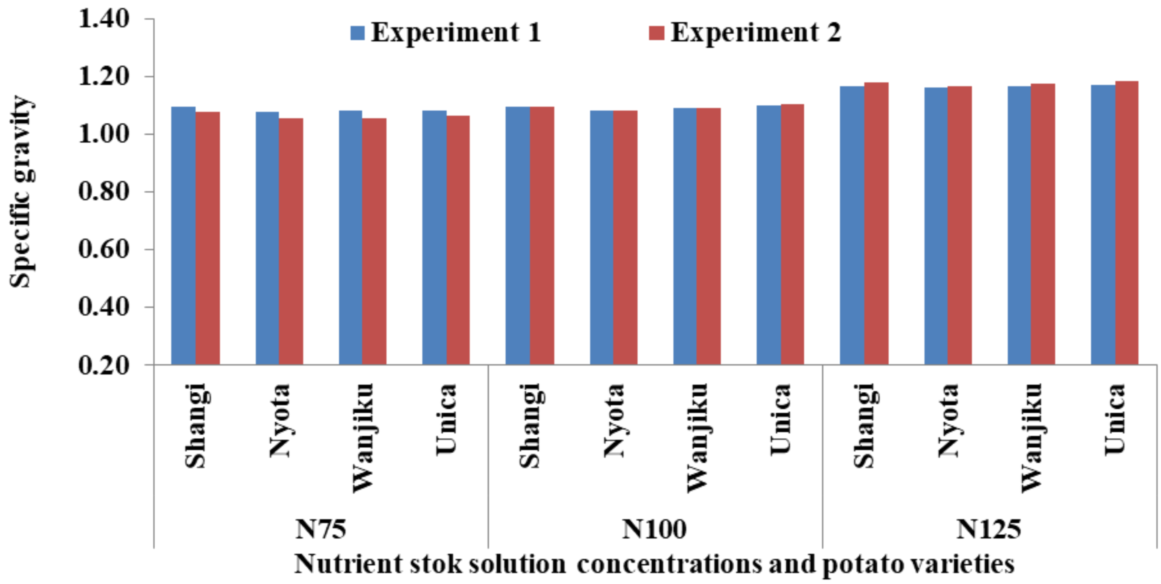

Figure 57: Interaction effects of nutrient stock solution concentration and potato varieties on minitubers specific gravity in experiment one and two

4.4. Correlation analysis

A correlation analysis was performed to determine the simple correlation between growth, yield and quality of potato as affected by different nutrient stock solution concentration and varieties (Table 9 and 10). The results of the study shows that NDVI was positively correlated to the plant survival (r=0.74*** and r=0.59***), above ground biomass fresh weight (r=0.82*** and r=0.86***), above ground dry matter (r=0.87*** and r=0.77***), minitubers number (m^2) (r=0.79*** and r=0.73***), minitubers yield t ha^{-1} (r=0.70*** and r=0.69***), starch (r=0.49** and r=0.46**), minitubers dry matter (r=0.75*** and 0.90***) in experiment one and two respectively. The results indicate that the growth parameters contributed to increase in yield. The number of minitubers significantly and positively correlated with the plant survival (r=0.65*** and r=0.51*), biomass (r=0.82*** and r=0.85***), biomass DM (r=0.80*** and r=0.86***) and minitubers yield (r=0.66*** and r=0.75***) in experiment one and two respectively. The findings also showed that the above ground biomass positively correlated with plant survival (r=0.80*** and r=0.62***), biomass DM (r=0.84*** and 0.88***), minitubers number (r=0.82*** and 0.85***) and yield t ha^{-1} (r=0.76*** and r=0.73***) in experiment one and two respectively. The tuber dry matter was significantly and positively correlated with the starch content of the tubers (r=0.42** and r=0.40***). A positive correlation was also observed between tuber dry matter and specific gravity (r= 0.11** and r=0.60***) and between specific gravity and starch content (r= 0.09** and r= 0.07**) in experiment one and two respectively.

Table 9: Correlation analysis of growth, yield and quality parameters of potato rooted apical cuttings in experiment one

PAR	NDVI	PS	B	BDM	T_{NO}	Yield	T_{DM}	Starch	SG
NDVI	1								
PS	0.74***	1							
B	0.82***	0.80***	1						
B_{DM}	0.87***	0.75***	0.84***	1					
T_{NO}	0.79***	0.65***	0.82***	0.80***	1				
Yield	0.70***	0.69***	0.76***	0.71***	0.66***	1			
T_{DM}	0.75***	0.66***	0.80***	0.84***	0.76***	0.64***	1		
Starch	0.49*	0.41**	0.43*	0.48*	0.42**	0.38*	0.42*	1	
SG	0.03^{ns}	0.15^{ns}	0.24^{ns}	0.11**	0.06**	0.17**	0.11**	0.09**	1

NDVI=Normalised Difference Vegetation Index, PS=plant survival, B=biomass fresh weight, B_{DM}=biomass dry matter, T_{NO}=tuber number, SG=specific gravity and T_{DM}=tuber dry matter **significant (p<0.05), *** significant (p<0.001)

Table 10: Correlation analysis of growth, yield and quality parameters of potato rooted apical cuttings in experiment two

PAR	NDVI	B	BDM	PS	T_{NO}	Yield	T_{DM}	Starch	SG
NDVI	1								
B	0.86***	1							
B_{DM}	0.77***	0.88***	1						
PS	0.59**	0.62***	0.63***	1					
T_{NO}	0.73***	0.85***	0.86***	0.51*	1				
Yield	0.69***	0.73***	0.69***	0.58**	0.75***	1			
T_{DM}	0.90***	0.91***	0.84***	0.57**	0.81***	0.86***	1		
Starch	0.46*	0.37^{ns}	0.38^{ns}	0.31^{ns}	0.39^{ns}	0.27^{ns}	0.40***	1	
SG	0.58**	0.52**	0.50**	0.37^{ns}	0.43*	0.78***	0.60***	0.07**	1

NDVI=Normalised Difference Vegetation Index, PS= plant survival, B=biomass fresh weight, B_{DM}=biomass dry matter, T_{NO}=tuber number, SG=specific gravity and T_{DM}=tuber dry matter **significant (p<0.01), *** significant (p<0.001), *significant (p<0.05)

CHAPTER FIVE

DISCUSSION

5.1 Effect of nutrient solution concentration on the growth of potato rooted apical cuttings varieties

In a hydroponic system, nutrient solution is a critical factor that ensures proper plant growth and development. Application of different nutrient stock solution concentrations (NSSC) influence potato growth characteristics, i.e., plant survival, height, shoot biomass and NDVI (Gbollie *et al*., 2022; Sakamoto & Takahiro, 2020).

Increasing the nutrient concentrations had a positive impact on the height of rooted apical cuttings (ARC) ranging from 5.28cm to 29.91cm at 15 and 60 days after planting (DAP) in experiment one and 5.27cm to 31.29cm in experiment two (Figs. 2 and 3). Variation in nutrient solutions can bring change to plant height (Tessema *et al*., 2017). Application of N125 led to taller plants (31.29cm) as compared to the control (N100-22.41cm) and N75 (19.15cm) at 60 DAP. According to Putra *et al*. (2019) adequate nutrient supply increases the metabolic processes such as photosynthesis, used for cell enlargement and division which leads to the overall increase in plant growth. According to Iraboneye *et al*. (2020) increasing phosphorus (P) and nitrogen (N) levels increases root development and improves nutrient uptake and enhances vegetative growth and good canopy cover, respectively. According to Zewide *et al.* (2016) availability of N could increase the availability of phosphorus, where N and P could synergistically increase plant height. The rate of plant growth under N75 was slower and this could be due to nutrient deficiency which leads to compromised growth and consequently low yields. Taller Nyota and Wanjiku plants by the 60th DAP (Figs 4 and 5) can be attributed to the different genotype adaptation and nutrient availability in the cocopeat (Chiota *et al*., 2015). Slow growth rate was observed from the 1st day to the 15th day which was similarly reported by Byarugaba *et al*. (2017) who observed slow growth rate from the 1st to 50th day which he attributed to the new environmental conditions. This slow growth rate is also known as the lag phase in crop development.

The NDVI values - a measure of growth and quality of crop – increased with maturity up to a maximum on the 60th DAP and declined afterwards up to the dehaulming stage (75 DAP) (Figs. 6 and 7). This was consequently reported by Gómez *et al*. (2019) who noted that NDVI values in potato production were highest at the peak of flowering and declined with the onset of senescence. This response could be explained by the quadratic functions as given in Figs. 6 and 7 that had a goodness of fit value ranging from 0.89-0.99. These functions can be used to predict the growth and quality of potatoes (NDVI) with over 96% confidence (goodness of fit) levels. Linear and quadratic functions can be developed using regression analyses for determining goodness of fit in predicting outputs (dependent) from input (independent) variables (Kibe & Onyari, 2007). Increase in NSSC significantly increased NDVI values with N75, N100 and N125 giving a mean of 0.42, 0.46 and 0.62 at 60 DAP, respectively. Crops supplied with N75 NSSC, experienced inadequate nutrient supply and the crops consequently exhausted any nutrients in the rhizosphere leading to low vegetation growth (Maboko *et al*., 2017). For crops at N100 and N125 NSSC resulted in better growth and healthier crop. Farias *et al*. (2023) noted that increasing nutrient concentrations increased the leaf canopy which led to higher near-infrared reflectance, resulting to higher NDVI values. Similarly Gbollie *et al*. (2022) postulated that increasing the N content through $Ca(NO_3)_2$ application, increased the vegetative growth which increased the NDVI values and subsequently seed potato yields. The NDVI positively correlated to tuber yields (0.70*** and 0.69*** in experiment one and two, respectively) and also a linear regressions developed revealed a goodness of fit of 56.63% and 78.87% in experiment one and two, respectively implying that NDVI is a good measure of tuber yields (Figs 39 and 40). Production functions are mathematical equations that explain biological responses of a crop (variety) to inputs given within the growth phases of a crop (Kibe and Onyari, 2007). Production functions developed to relate varietal maturity with NDVI - a growth and health index - measured with a Trimble handle held crop sensor (GreenSeeker) Satognon *et al*. (2021) are given in Figs. 41.

Plant survival at 15 DAP was higher than at 75 DAP across the nutrient concentrations (Fig. 14). The high survival rates at 15 DAP may be as a result of acclimatization (hardening) of the ARC done 7 days prior to planting in the greenhouse (Tsoka *et al*., 2012). The results obtained concur with those of Aarakit *et al*. (2021) where plants that have undergone hardening are able to survive even in harsh conditions. The plant survival varied with the application of NSSC at 75 DAP; N125 had 82.15% survival rates as compared to N75 (47.15%). Craine and Dybzinski (2013) opined that inadequate nutrients in the crop (at later stages of growth) induced nutrient stress which led to competition of resources leading to the ultimate death of majority of plants grown in the soils. Therefore, the application of N75 at later plant growth stages induced nutrient deficiency due to competition of nutrients in the cocopeat pool leading to low survival rates. Both at 15 DAP and 75 DAP, application of NSSC did not affect varieties percentage survival (Fig. 15). Similar observations were reported by Tsoka *et al*. (2012) where all potato ARCs varieties did not differ in percentage survival when administered different nutrient concentrations. Although there were no significant differences in survival, Unica and Nyota had a slight advantage than Shangi which could have influenced the higher yields in Unica.

Nutrient availability in plants influences biomass partitioning (Lee *et al*., 2021). Increasing NSSC from N75 to N125 increased the above ground biomass and dry matter. This was also observed by Sakamoto and Takahiro (2020) where the shoot biomass increased with the increase in nutrient solution concentrations. Adequate application of nutrients influence total leaf area that increases light interception by the crop and this contributes directly to biomass accumulation (Aarakit *et al*., 2021). Increasing nitrogen content (900 kg ha^{-1}) was also reported to increase biomass by Iraboneye *et al*. (2020). Application of adequate amounts of nutrients during the growth periods promoted the above ground biomass and leaf canopy which is positively correlated to the NDVI (Table 9 and 10). The relationship of NDVI taken at 60 DAP could be explained by fitting linear and quadratic curves whose mathematical functions had a regression coefficient of R^2 =0.9113 for experiment 1 and 0.9386 for experiment 2 (Figs. 24 and 25). Misgina (2016) reported that P boosted plant metabolic activity during early growth stages that encouraged stem elongation. Nutrient deficiency and toxicity negatively affect total biomass and productivity therefore controlling optimum levels of nutrients availability in the media, biomass production and tuber production can be maximized (Chatzistathis & Therios, 2013).

According to Lee *et al.* (2021) the significant differences on shoot biomass in varieties was attributed to the genetic makeup that supports vegetative canopy development and shoot biomass accumulation. The genotypic responses to varying nutrient availability levels are therefore an effective indication of genotypic differences in nutrient-use efficiency by the various varieties evaluated in this study (Figure 20). Therefore, for this study, Nyota variety gave a better response growth curve than other varieties followed by Wanjiku, Shangi and Unica in that order.

5.2 Effect of nutrient solution concentrations on the yield of rooted apical cuttings potato varieties

The efficiency and superior productivity exhibited by hydroponics are dependent to the constant availability of nutrients (Corrêa *et al*., 2010). Correct balanced nutrition is important for increasing potato yield. The nutrients nitrogen, phosphate, potassium, calcium, magnesium and manganese have all been shown to affect potato yields and size. Generally, nutrients application corresponds to increased plant yield but care should be taken when choosing the concentrations to apply depending on the crop requirement (Iraboneye *et al*., 2020).

The variation in the number of minitubers per plant due to the application of increasing NSSC was highly significant. Plants supplied with N125 had higher tuber number (9.33) as compared to N75 (4.00) (Fig. 29). This increase in the number minitubers with increase in NSSC could be attributed to increase in nutrient levels which increased the number of stolons through its effect on gibberellins biosynthesis in the potato plant (El-Hadidi *et al*., 2017). This was also reported by Misgina (2016) whereby increasing nitrogen, phosphorus and potassium levels increased the number of tubers per plant and tuber yield. The varieties showed variability in the number of tubers per plant harvested (Figure 30). Nyota and Wanjiku reported high tuber number (>7 minitubers per plant) indicating superiority over other varieties. This could be due to the genotypic differences of the varieties which could have translated to high tuber number per plant (Awati *et al*., 2019). Also, Chiipanthenga *et al*. (2013) observed that seed potato production is dependent of the cultivar used, hence, to achieve high seed potato yield under a hydroponic system there is need to use varieties that are known to respond well to this production system. The difference in performance of the varieties across the experiments may be attributed to environmental conditions during the two experiments (Mbiyu *et al*., 2018).

Tuber weight is an important index in yield determination and also, seed potato are sold in weight basis. It is highly affected by variety and nutrition and increase in nutrient levels tend to increase tuber weight (Aarakit *et al.*, 2021; Misgina, 2016). Based on the results, tuber weight per plant varied among the NSSCs' with N75 reporting the least weight of <5g followed by the control (<13g) and N125 (>20g) (Fig. 33). According to Putra *et al.* (2019) variation of weight with the application of different NSSC could be as a result of the variation in macro and micro nutrients which contribute to energy formation during photosynthesis that is mainly the formation of tubers. Nutrient concentrations with high N and Mg levels could increase chlorophyll formation process which is used in carbon fixation which forms carbohydrates that are used for tuber enlargement and organ formation (Putra *et al.*, 2019). Also, increasing phosphorus levels increases the tuber weight and dry weight this is due to the function of P in cell division (Fernandes *et al*., 2015). The high tuber weight was reported by in Unica (>17g)

(Fig. 34) in this study was attributed to difference in varietal characteristics, which agrees with Aarakit *et al.* (2021).

The increase in the NSSC positively influenced minitubers yield. Low yield in N75 could be due to low photosynthetic area that affect tuber formation of the potato plant (Awati *et al*., 2019). High yields observed in N125 could be due to high nutrient levels affects plant biomass partitioning and allocation of assimilates in tubers (Petropoulos *et al*., 2020). Nitrogen has the greatest impact on potato yield formation among all the essential macronutrients and its demand is comparative high during the first 4-5 weeks of growth and tuberization (Koch *et al*., 2020). In a study by Bekele *et al*. (2020) increasing K, P and N levels by 150% increased tuber yield by 114%. This is due to their roles in assimilation, transportation and storage of photosynthesis which leads to increase in yields. According to Iraboneye *et al*. (2020) increase in potassium rates to 120 kg ha^{-1} increased average potato yield by $10kg^{-1}$ due to its role in transporting nutrients and sucrose from the leaves to the tubers. Unica exhibited superior performance in yield per hectare followed by Nyota, Wanjiku and Shangi in that order. Previous studies by Mbiyu *et al*. (2018) reported that different potato varieties performed differently due to the differences in varietal genetic make–up. This was also observed by Akoto *et al.* (2020) who reported that Unica has a high yielding potential of >45 t ha^{-1}. Unica reported high yield despite having low top biomass. This was also observed by Tsoka *et al*. (2012) where high yield was observed in plants that had low biomass due to less competition between tubers and leaves in terms of sucrose loading. Quadratic regressions reported higher goodness of fit than linear regressions (Figs. 41).

The size of minitubers affects the duration of dormancy, seed vigour, stem numbers and the vigour of individual stems, disease and pest susceptibility and environmental stresses (Mbiyu *et al*., 2018). It is noticeable that different tuber sizes are produced from different varieties when different NSSC are supplied (Figs. 44 and 45). Tuber size is reported to increase with increase in nitrogen application due to its function in allocating assimilates in tubers (Petropoulos *et al*., 2020). According to Gbollie *et al*. (2022) class 4 (>18g) is the most demanded seed tuber size by seed potato farmers in Kenya. Treatments with the highest nutrient concentration produced the highest tuber number of minitubers classes C3 and C4 in all varieties (Figs. 42 and 43). Bekele *et al*. (2020) reported that increasing potassium levels increased tuber sizes due to its stimulating effect on photosynthesis, phloem loading and translocation as well as synthesis of large molecular weight substances within storage organs that may contribute to the rapid bulking of the tubers. In a study done by Fernandes *et al*. (2015) increasing phosphorus content up to the rate of 125 kg ha^{-1} led to production of larger tubers this is because P plays and important role tuber enlargement. Application of low nutrient concentrations leads to production of small-sized minitubers (C1) which tend to be difficult to store as they show higher losses during storage than larger minitubers (Mbiyu *et al*., 2018). Unica reported the biggest tuber sizes which is in concurrence with Aarakit *et al*. (2021) who reported Unica to have had the least number of small sized tubers as compared to Shangi, Wanjiku and *Dutch Robyjin* which was attributed to varietal difference.

5.3 Effect of nutrient solution concentrations on the quality of rooted apical cuttings potato varieties

To meet the increasing seed potato demand, production efficiency in the informal seed production sector should therefore be improved. The seed potato tubers produced must present good physiological characteristics such as specific density, starch and dry matter contents which are crucial in improving the vigour of seedlings and tuberization capacity of the resultant plants (Kingori *et al*., 2015). These tuber qualities are influenced by the amount of nutrient solution applied and the type of cultivar used (Hasnat *et al*., 2015).

The dry matter content (DM) of tubers is the most important character determining the quality and yield of tubers (Marwaha *et al*., 2010). Increasing NSSC from 75% to 125% of the ADC-Molo formulation increased the minitubers DM from 17.79% to 23.90% in experiment one and 17.89% to 24.90% in experiment two, respectively (Figure 46). According to Kingori *et al*. (2015) and Fernandes *et al*. (2015) increasing nitrogen (N) and phosphorus (P) content increased the photosynthetic rates which increased the vegetative growth ultimately leading to high DM content. High N content has a positive impact on photosynthesis efficiency from increasing the interception rate of radiation and photons and as a consequence, on DM partitioning to the tubers, tuber bulking and finally on tuber yield formation (Koch *et al*., 2020). According to Akoto *et al*. (2020) increasing P content increased tuber DM since it has various effects on tuber i.e., It functions in cell division and synthesis, and storage of starch in tubers hence, it can increase the size and DM%. The tuber DM however did not vary among the varieties placed in different NSSC (20.51%-21.06% in experiment one and 20.79% to 21.19% in experiment two) (Figure 47). This is contrary to Mirdad (2010) who reported that the percentage DM was significantly different among the potato varieties placed under varied nutrient regimes due to different genotypic differences between the varieties. Dry matter content of tubers may affect the end use of the product with tubers having low values (18%-20%) of DM being more suitable for cooking and less susceptible to mechanical bruising, whereas tubers with high DM content (>20%) are suitable for processing (Petropoulos *et al*., 2020). Therefore, apart from the selection of the proper variety, nutrient solution concentration can be a cost-effective means to increase the high end of the final product through regulation of tubers dry matter content (Zhou *et al*., 2017). Based on the quadratic functions, (figs 50 and 51), the relationship between the NDVI and minitubers dry matter had a goodness of fit >70%. It is therefore possible to predict the DM % of minitubers using NDVI data collected at 60 DAP using these mathematical functions. The quadratic fits were better than the liner functions. Therefore, better agronomic management that enhances the growth and health of ARCs is likely to enhance DM% in harvested minitubers early generation seeds of all the four varieties studied.

Starch is the main reserve material of higher plants and consequently the most important component in human diet. It constitute 17-21% of fresh tuber mass and determines the potato quality (Liszka-skoczylas *et al.*, 2022). From this study, it is evident that starch increased with increase in nutrient concentrations with N125 reporting 11.97ppm and 12.82ppm and N75 reporting 7.10ppm and 8.76ppm starch content in experiment one and two respectively (Figure 47). The increase in the starch content may be due to the role of P in the activation of enzymes which are involved in starch synthesis, i.e., fructose-1,6-bisphosphate and ADP- glucose pyrophosphorylase (Fernandes *et al*., 2015). Koch *et al*. (2020) further reported that, low potassium application led to significant reduction of tuber yields and starch content due to its role in enzyme regulation, photosynthesis and carbohydrates partitioning within the plants. Starch content was not significantly affected by the potato variety (Figure 48). This contradicts the results obtained by Liszka-skoczylas *et al.* (2022) where starch was affected by not only nutrition, but also the genetic make-up of the crop.

Specific gravity is considered as one of the most practical indices for potato quality as it is positively correlated with starch content, total solids and dry matter (Gikundi *et al*., 2021). It is affected by fertilizer treatments applied with increase in NSSC increasing the specific gravity. Treatment N125 reported a high specific gravity of 1.18 as compared to N100 (1.09) and N75 (1.06) (Fig. 50). The results are coherent with the findings of Bekele *et al*. (2020) who noted that increasing N, P and K fertilizers rates led to highest specific gravity (1.07) and tuber dry matter (24.34%) in potato tubers grown in soil. The potato varieties did not differ in their specific gravities ranging from 1.13 to 1.10 (Figure 51). This was in line with the findings of Akoto *et al*. (2020) where specific gravity of Shangi and Unica did not differ significantly with the application of different phosphorus fertilizer rates. A specific gravity of >1.10 reported in all varieties indicates that they are highly desirable for processing of dehydrated and fried products as it enhances high product recovery rates, lower oil absorption and less energy consumption during processing, better flavour and texture and generally high quality of fried products (Gikundi *et al*., 2021).

Correlation between the growth, yield and quality parameters

All growth parameters were highly correlated with the yield parameters. This indicates that the improvement of growth and yield can be achieved by increasing nutrient concentrations. According to Gbollie *et al*. (2022) growth variables are important components of crop production and are usually highly correlated to yield variables. The NDVI that reflects N levels of the plants was correlated with the plant survival, above ground biomass and dry matter due to the presence of nutrients in the cocopeat thus leading to increased vegetative growth. There was a positive correlation between tuber yields i.e., tuber yield, minitubers number and yields per plant which indicates that tuber yields increased with the application of nutrient concentrations. Satognon *et al*. (2021) reported that positive relationship between minitubers numbers and yield indicates that increase in yield was affected by the number of minitubers produced per plant. In a study done by Bekalo (2017) tuber is the main storage organ of photosynthates, which is more dependent on the number of plants, tuber number, size and weight. The positive correlation between above ground biomass and dry matter to yield indicates that biomass was significantly influenced by nutrient concentrations (Misgina, 2016).

Based on the results, the minitubers numbers had a positive correlation with the growth parameters. This positive association may be due to increase in nutrient concentration application especially N which could be attributed to vegetative growth of the potato plant (Zewide *et al*., 2016). There was a positive correlation between the tuber dry matter (DM) content, starch content and specific gravity. This is consistent with the findings of Zewide *et al*. (2016) who reported a positive correlation between specific gravity and tuber DM, (r=0.94**) which is an indicator that specific gravity influences the dry matter content of potato tubers. Starch content represents the dry matter content of potatoes. These positive correlations could allow recommending the importance of measuring specific gravity and using the prepared specific gravity conversion charts as a reliable indicator of tuber quality traits of potato (Mohammed, 2016).

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The following conclusions are drawn from the study:

I. Growth of apical rooted cuttings was enhanced by increase in nutrient stock solution concentrations (NSSC). Application of 125% NSSC gave the highest growth rates. Nyota gave the highest growth rates as compared to other varieties.

   a) The highest growth rate with respect to increase in height as the crop matured (days) was when the ARCs were grown under 125% NSSC application as described by the function $y = -1.92 + 3.8284x + 0.5264x^2$ and $y = -1.872 + 3.7731x + 0.5871x^2$; followed by 100% and 75% in that order (Figure 2 and 3). Nyota variety had the tallest plants ranging from 25.08cm to 26.90cm at 60 DAP while Unica (21.47cm to 22.77cm) gave the shortest plants.

   b) The NDVI increased with increase in the NSSC. The application of 125% NSSC gave the highest NDVI as described by the function $y = 0.096 + 0.1893x - 0.0207x^2$ in experiment one and $y = 0.1 + 0.2434x - 0.0286x^2$ in experiment two. Nyota variety had the highest NDVI values by the 75th DAP ranging from 0.52 to 0.53 and the lowest NDVI values were observed in Unica (0.42 to 0.44).

   c) The highest percentage plant survival ranging from 82.15% to 84.26% in both seasons were obtained under 125% NSSC. Nyota reported the highest plant survival ranging from 62.35% to 64.23% while Wanjiku reported the lowest survival rates ranging from 61.11% to 56.75% at 75 DAP.

   d) The highest above ground biomass production ranging from 58.66g to 79.04g/0.45m^2 (130.22g/m^2 to 179.47g/m^2) in both experiments was obtained under 125% NSSC. This was followed by 100% and 75% NSSC that produced 47.22g to 50.00g (104.8g/m^2 to 111.00g/m^2) and 36.41g to 43.31g/0.45m^2 (80.80g/m^2 to 96.10g/m^2), respectively. Nyota reported the highest above ground biomass ranging from 48.01g to 64.87g/0.45m^2 in both experiments.

II. The application of 125% nutrient stock solution increased the yields of the rooted apical cuttings. The highest number of minitubers per plant (>8); minitubers weight per plant (>22g) and yield (>9t ha^{-1}) were obtained with 125% NSSC, respectively Nyota and Wanjiku had the highest number of minitubers per plant (6.89 to 7.67). However, Unica had the highest minitubers weight per plant (17.86g to 20.68g) and yield (7.94 to 9.19t ha^{-1}), respectively.

III. With respect to minitubers quality, the application of 125% gave the highest minitubers quality. The highest minitubers DM (23.90 to 24.90%), specific gravity (1.13-1.10gcm^3) and starch content (11.97-12.82ppm) were reported under N125. With respect to varieties studied, Shangi had the highest percent DM (21.06% to 21.19%), Unica had the highest specific gravity (1.12-1.13) and Shangi (9.30ppm to 12.27ppm) had the highest starch content.

6.2. Recommendations

The following recommendations are given for growing early generation seed (EGS) potato under cocopeat hydroponic system:

a. For potato growers;

I. In order to achieve the highest growth, application of 125% nutrient stock solution concentration of the ADC-Molo/ CIP recommended rates is recommended. For varieties with high growth rates, Wanjiku and Nyota are recommended.

II. In order to achieve the high yield, application of 125% NSSC of the ADC-Molo rates is recommended. For developing highest numbers of minitubers, Nyota and Wanjiku varieties are recommended.

III. In order to achieve the high minitubers quality, application of 125% NSSC of the ADC-Molo rates is recommended. For high dry matter content and starch content, Shangi is recommended.

b. For further studies;

I. Further studies to determine the effects of individual nutrients in stock solutions in hydroponic and field conditions are recommended for various varieties in different environments (and countries).

II. Further research to determine the effects of NSSC on the minitubers grades and their subsequent productivity in the field is recommended.

III. Further research to determine the effect of applications of more than 125% NSSC is recommended.

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APPENDICES

Appendix A: Publication

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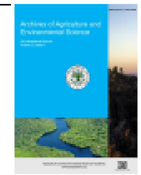

ORIGINAL RESEARCH ARTICLE

CrossMark

Effect of nutrient solution concentrations on the growth and yield of potato (*Solanum tuberosum* L.) varieties grown from apical rooted cutting in a hydroponic system

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ABSTRACT

This study evaluated the effects of nutrient stock solution concentrations on the growth and yield of potato varieties grown from apical rooted cuttings (ARCs). A greenhouse experiment was conducted at the Climate and Water Smart Agriculture Center at Egerton University, Kenya. The experiment was laid out in a split-plot arrangement in randomized complete block design, where the main plot comprised three nutrient concentrations, i.e., 75% (N75), 100% (N100) and 125% (N125) of the ADC-Molo' nutrient formulation. The subplots were allocated to four potato varieties (Shangi, Wanjiku, Nyota and Unica). The results showed that there were no significant ($p \leq 0.05$) interaction effects of the nutrient stock solution concentrations application rates on the growth attributes of ARCs. The main effects of N125 gave the tallest plants (32.29cm) at 60 days after planting (DAP), highest normalised difference vegetation index (NDVI) (0.60) at 75 DAP, plant survival rate (82.15%) at 75 DAP, and fresh weight (79.04g) and dry matter (31.26%) of aboveground biomass (AGB). Nyota variety produced taller plants (26.90cm) at 60 DAP, gave higher NDVI values (0.53) at 75 DAP, and higher fresh weight (64.87g) and dry matter (27.60%) of the AGB. Significant ($p \leq 0.05$) interactions were observed in the yield parameters. The interaction between N125 and Nyota (11.33) and Wanjiku (10.67) gave the highest number of minitubers, the highest yields were obtained between the interaction of N125 and Unica (16.38t/ha). Therefore, to achieve high growth and yields of ARCs under hydroponic system, seed potato producers should use 125% of the ADC Molo nutrient formulation.

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Appendix B: Research permit NACOSTI

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Appendix C: Analysis of variance for plant height at 15 DAP for experiment one and two

		Experiment one				Experiment two			
Source	**DF**	**SS**	**Mean square**	**F Value**	**Pr > F**	**SS**	**Mean square**	**F Value**	**Pr > F**
Block	2	2.376	1.188	1.93	0.173	5.351	2.68	3.98	0.0371
Nutrient Solution (NS)	2	48.867	24.434	39.79	<.0001	66.729	33.36	49.6	<.0001
Variety		11.428	3.809	6.2	0.004	7.985	2.66	3.96	0.0249
NS*Variety	6	4.150	0.692	1.13	0.387	0.344	0.06	0.09	0.9971
NS*Block	4	6.629	1.657	2.7	0.064	4.619	1.15	1.72	0.1901
Error	18	11.054	0.614			12.108	0.67		
Total	35	84.505				97.135			

NS= Nutrient Solution, SS= sum of squares, DF= Degrees of freedom

Appendix D: Analysis of variance for plant height at 30 DAP for experiment one and two

		Experiment one				Experiment two			
Source	**DF**	**SS**	**Mean square**	**F Value**	**Pr > F**	**SS**	**Mean square**	**F Value**	**Pr > F**
Block	2	0.381	0.190	0.21	0.815	21.393	10.696	5.2	0.0165
Nutrient Solution (NS)	2	165.223	82.611	89.75	<.0001	268.532	134.266	65.25	<.0001
Variety	3	24.373	8.124	8.83	8E-04	45.314	15.105	7.34	0.002
NS*Variety	6	18.799	3.133	3.4	0.02	0.581	0.097	0.05	0.9994
NS*Block	4	5.766	1.442	1.57	0.226	13.711	3.428	1.67	0.2016
Error	18	16.569	0.920			37.041	2.058		
Total	35	231.110				386.572			

NS= Nutrient Solution, SS= sum of squares, DF= Degrees of freedom

Appendix E: Analysis of variance for plant height at 45 DAP for experiment one and two

		Experiment one				Experiment two			
Source	**DF**	**SS**	**Mean square**	**F Value**	**Pr > F**	**SS**	**Mean square**	**F Value**	**Pr > F**
Block	2	0.956	0.478	0.24	0.791	63.684	31.842	15.68	1E-04
Nutrient Solution (NS)	2	469.278	234.639	116.27	<.0001	544.539	272.269	134.09	<.0001
Variety	3	98.832	32.944	16.33	<.0001	165.805	55.268	27.22	<.0001
NS*Variety	6	4.214	0.702	0.35	0.902	3.435	0.573	0.28	0.938
NS*Block	4	5.562	1.390	0.69	0.609	34.636	8.659	4.26	0.013
Error	18	36.324	2.018			36.549	2.031		
Total	35	615.166				848.648			

NS= Nutrient Solution, SS= sum of squares, DF= Degrees of freedom

Appendix F: Analysis of variance for plant height at 60 DAP for experiment one and two

		Experiment one				Experiment two			
Source	**DF**	**SS**	**Mean square**	**F Value**	**Pr > F**	**SS**	**Mean square**	**F Value**	**Pr > F**
Block	2	1.539	0.769	0.54	0.589	102.492	51.246	27.4	<.0001
Nutrient Solution (NS)	2	849.716	424.858	300.93	<.0001	1122.644	561.322	300.12	<.0001
Variety	3	80.224	26.741	18.94	<.0001	126.414	42.138	22.53	<.0001
NS*Variety	6	9.404	1.567	1.11	0.395	2.164	0.361	0.19	0.9748
NS*Block	4	3.139	0.785	0.56	0.698	35.852	8.963	4.79	0.0083
Error	18	25.413	1.412			33.666	1.870		
Total	35	969.434				1423.232			

NS= Nutrient Solution, SS= sum of squares, DF= Degrees of freedom

Appendix G: Analysis of variance for the NDVI at 15 DAP for experiment one and two

		Experiment one				Experiment two			
Source	**DF**	**SS**	**Mean square**	**F Value**	**Pr > F**	**SS**	**Mean square**	**F Value**	**Pr > F**
Block	2	0.001	0.001	2.31	0.1277	0.000	0.000	1.15	0.3399
Nutrient Solution (NS)	2	0.019	0.009	30.8	<.0001	0.003	0.002	9.63	0.0014
Variety	3	0.006	0.002	6.91	0.0027	0.003	0.001	5.08	0.0101
NS*Variety	6	0.006	0.001	3.29	0.0231	0.002	0.000	1.5	0.2333
NS*Block	4	0.006	0.001	4.91	0.0074	0.001	0.000	1.34	0.2952
Error	18	0.005	0.000			0.003	0.000		
Total	35	0.044				0.012			

NS= Nutrient Solution, SS= sum of squares, DF= Degrees of freedom

Appendix H: Analysis of variance for the NDVI at 30 DAP for experiment one and two

		Experiment one				Experiment two			
Source	**DF**	**SS**	**Mean square**	**F Value**	**Pr > F**	**SS**	**Mean square**	**F Value**	**Pr > F**
Block	2	0.001	0.001	0.83	0.453	0.016	0.008	10.09	0.001
Nutrient Solution (NS)	2	0.022	0.011	12.31	4E-04	0.014	0.007	8.74	0.002
Variety	3	0.013	0.004	4.65	0.014	0.022	0.007	9.05	7E-04
NS*Variety	6	0.010	0.002	1.91	0.134	0.007	0.001	1.43	0.256
NS*Block	4	0.005	0.001	1.49	0.246	0.044	0.011	13.65	<.0001
Error	18	0.016	0.001			0.014	0.001		
Total	35	0.068				0.117			

NS= Nutrient Solution, SS= sum of squares, DF= Degrees of freedom

Appendix I: Analysis of variance for the NDVI at 45 DAP for experiment one and two

		Experiment one				Experiment two			
Source	**DF**	**SS**	**Mean square**	**F Value**	**Pr > F**	**SS**	**Mean square**	**F Value**	**Pr > F**
Block	2	0.002	0.001	0.99	0.3922	0.001	0.001	0.63	0.5447
Nutrient Solution (NS)	2	0.065	0.033	32.21	<.0001	0.141	0.070	64.45	<.0001
Variety	3	0.014	0.005	4.55	0.0153	0.019	0.006	5.91	0.0055
NS*Variety	6	0.001	0.000	0.23	0.9601	0.009	0.002	1.43	0.2565
NS*Block	4	0.007	0.002	1.83	0.1677	0.036	0.009	8.13	0.0006
Error	18	0.018	0.001			0.020	0.001		
Total	35	0.109				0.226			

NS= Nutrient Solution, SS= sum of squares, DF= Degrees of freedom

Appendix J: Analysis of variance for the NDVI at 60 DAP for experiment one and two

		Experiment one				Experiment two			
Source	**DF**	**SS**	**Mean square**	**F Value**	**Pr > F**	**SS**	**Mean square**	**F Value**	**Pr > F**
Block	2	1E-03	0.000	0.21	0.8114	0.002	0.001	0.85	0.4446
Nutrient Solution	2	0.208	0.104	45.98	<.0001	0.328	0.164	160.08	<.0001
Variety	3	0.018	0.006	2.69	0.0769	0.016	0.005	5.17	0.0094
NS*Variety	6	0.017	0.003	1.26	0.3229	0.016	0.003	2.53	0.0589
NS*Block	4	0.007	0.002	0.79	0.5486	0.016	0.004	4	0.0171
Error	18	0.041	0.002			0.018	0.001		
Total	35	0.292				0.396			

NS= Nutrient Solution, SS= sum of squares, DF= Degrees of freedom

Appendix K: Analysis of variance for the NDVI at 75 DAP for experiment one and two

		Experiment one				Experiment two			
Source	**DF**	**SS**	**Mean square**	**F Value**	**Pr > F**	**SS**	**Mean square**	**F Value**	**Pr > F**
Block	2	0.016	0.008	0.59	0.5636	0.005	0.002	0.82	0.4543
Nutrient Solution	2	0.199	0.099	7.34	0.0047	0.416	0.208	70.35	<.0001
Variety	3	0.081	0.027	2	0.1498	0.017	0.006	1.88	0.1698
NS*Variety	6	0.059	0.010	0.73	0.6311	0.012	0.002	0.67	0.6717
NS*Block	4	0.077	0.019	1.42	0.2664	0.037	0.009	3.09	0.0421
Error	18	0.244	0.014			0.053	0.003		
Total	35	0.676				0.539			

NS= Nutrient Solution, SS= sum of squares, DF= Degrees of freedom

Appendix L: Analysis of variance for plant survival at 15 DAP for experiment one and two

		Experiment one				Experiment two			
Source	**DF**	**SS**	**Mean square**	**F Value**	**Pr > F**	**SS**	**Mean square**	**F Value**	**Pr > F**
Block	2	159.415	79.707	0.87	0.4363	52.258	26.129	0.45	0.645
Nutrient Solution	2	601.759	300.880	3.28	0.0610	213.457	106.729	1.84	0.188
Variety	3	2.582	0.861	0.01	0.9987	348.041	116.014	2	0.151
NS*Variety	6	97.813	16.302	0.18	0.9794	356.780	59.463	1.02	0.442
NS*Block	4	534.780	133.695	1.46	0.2563	502.470	125.617	2.16	0.115
Error	18	1651.312	91.740			1045.393	58.077		
Total	35	3047.661				2518.400			

NS= Nutrient Solution, SS= sum of squares, DF= Degrees of freedom

Appendix M: Analysis of variance for plant survival at 75 DAP for experiment one and two

		Experiment one				Experiment two			
Source	**DF**	**SS**	**Mean square**	**F Value**	**Pr > F**	**SS**	**Mean square**	**F Value**	**Pr > F**
Block	2	300.178	150.089	1.04	0.373	828.139	414.070	2.39	0.1202
Nutrient Solution	2	9301.083	4650.542	32.29	<.0001	8203.753	4101.877	23.67	<.0001
Variety	3	9.424	3.141	0.02	0.996	436.730	145.577	0.84	0.4896
NS*Variety	6	60.011	10.002	0.07	0.998	1810.079	301.680	1.74	0.1688
NS*Block	4	152.711	38.178	0.27	0.897	2967.532	741.883	4.28	0.0131
Error	18	2592.694	144.039			3119.593	173.311		
Total	35	12416.103				17365.8			

NS= Nutrient Solution, SS= sum of squares, DF= Degrees of freedom

Appendix N: Analysis of variance for the above ground biomass fresh weight for experiment one and two

		Experiment one				Experiment two			
Source	DF	SS	Mean square	F Value	Pr > F	SS	Mean square	F Value	Pr > F
Block	2	393.768	196.884	21.26	<.0001	3.364	1.682	0.14	0.871
Nutrient Solution	2	3312.025	1656.012	178.82	<.0001	9220.882	4610.440	380.42	<.0001
Variety	3	161.624	53.875	5.82	0.0058	906.064	302.021	24.92	<.0001
NS*Variety	6	8.279	1.380	0.15	0.9869	118.292	19.715	1.63	0.197
NS*Block	4	96.195	24.049	2.6	0.0711	103.044	25.761	2.13	0.12
Error	18	166.695	9.261			218.146	12.119		
Total	35	4138.586				10569.791			

NS= Nutrient Solution, SS= sum of squares, DF= Degrees of freedom

Appendix O: Analysis of variance for the above ground biomass dry matter for experiment one and two

		Experiment one				Experiment two			
Source	**DF**	**SS**	**Mean square**	**F Value**	**Pr > F**	**SS**	**Mean square**	**F Value**	**Pr > F**
Block	2	17.996	8.998	1.65	0.2195	5.327	2.664	0.57	0.5731
Nutrient Solution	2	950.149	475.075	87.21	<.0001	647.511	323.756	69.81	<.0001
Variety	3	59.946	19.982	3.67	0.0319	76.642	25.547	5.51	0.0073
NS*Variety	6	9.300	1.550	0.28	0.9367	36.728	6.121	1.32	0.2987
NS*Block	4	6.156	1.539	0.28	0.8854	5.949	1.487	0.32	0.8604
Error	18	98.055	5.447			83.481	4.638		
Total	35	1141.602				855.638			

NS= Nutrient Solution, SS= sum of squares, DF= Degrees of freedom

Appendix P: Analysis of variance for the minitubers number for experiment one and two

		Experiment one				Experiment two			
Source	**DF**	**SS**	**Mean square**	**F Value**	**Pr > F**	**SS**	**Mean square**	**F Value**	**Pr > F**
Block	2	3.556	1.778	3.69	0.0453	0.056	0.028	0.08	0.9204
Nutrient Solution	2	155.389	77.694	161.37	<.0001	170.889	85.444	256.33	<.0001
Variety	3	28.083	9.361	19.44	<.0001	31.667	10.556	31.67	<.0001
NS*Variety	6	13.500	2.250	4.67	0.0049	21.333	3.556	10.67	<.0001
NS*Block	4	2.444	0.611	1.27	0.3185	0.611	0.153	0.46	0.7652
Error	18	8.667	0.481			6	0.333		
Total	35	211.639				230.556			

NS= Nutrient Solution, SS= sum of squares, DF= Degrees of freedom

Appendix Q: Analysis of variance for the weight for experiment one and two

		Experiment one				Experiment two			
Source	**DF**	**SS**	**Mean square**	**F Value**	**Pr > F**	**SS**	**Mean square**	**F Value**	**Pr > F**
Block	2	61.512	30.756	3.91	0.039	14.150	7.075	0.66	0.5304
NS	2	2002.550	1001.275	127.16	<.0001	3728.856	1864.428	173.16	<.0001
Variety	3	444.610	148.203	18.82	<.0001	454.040	151.347	14.06	<.0001
NS*Variety	6	126.682	21.114	2.68	0.0487	78.732	13.122	1.22	0.342
NS*Block	4	25.954	6.489	0.82	0.5269	39.584	9.896	0.92	0.4743
Error	18	141.738	7.874			193.805	10.767		
Total	35	2803.04				4509.166			

NS= Nutrient Solution, SS= sum of squares, DF= Degrees of freedom

Appendix R: Analysis of variance for the yield for experiment one and two

	Experiment one					Experiment two			
Source	**DF**	**SS**	**Mean Square**	**F Value**	**Pr > F**	**SS**	**Mean Square**	**F Value**	**Pr > F**
Block	2	12.175	6.088	33.92	0.0387	2.801	1.403	0.66	0.5287
NS	2	395.580	197.795	127.27	<.0001	736.503	368.251	173.31	<.0001
Variety	3	87.798	29.266	18.83	<.0001	89.635	29.878	14.06	<.0001
NS*Variety	6	25.042	4.174	2.69	0.0485	15.567	2.595	1.22	0.3410
NS*Block	4	5.130	1.282	0.83	0.5262	7.819	1.955	0.92	0.4739
Error	18	27.975	1.554			38.248	2.1249		
Total	35	553.710				890.578			

NS= Nutrient Solution, SS= sum of squares, DF= Degrees of freedom

Appendix S: Analysis of variance for the minitubers sizes C1 for experiment one and two

		Experiment one				Experiment two			
Source	**DF**	**SS**	**Mean square**	**F Value**	**Pr > F**	**SS**	**Mean square**	**F Value**	**Pr > F**
Block	2	0.389	0.194	0.51	0.6077	1.349	0.674	1.41	0.2705
NS	2	11.056	5.528	14.56	0.0002	13.149	6.574	13.72	0.0002
Variety	3	31.667	10.556	27.80	<.0001	12.978	4.326	9.03	0.0007
NS*Variety	6	2.500	0.417	1.10	0.0013	1.536	0.256	0.53	0.7755
NS*Block	4	0.778	0.194	0.51	0.7276	1.064	0.266	0.56	0.6978
Error	18	6.83	0.380			8.627	0.479		
Total	35	53.222				38.702			

NS= Nutrient Solution, SS= sum of squares, DF= Degrees of freedom

Appendix T: Analysis of variance for the minitubers sizes C2 for experiment one and two

		Experiment one				Experiment two			
Source	**DF**	**SS**	**Mean square**	**F Value**	**Pr > F**	**SS**	**Mean square**	**F Value**	**Pr > F**
Block	2	0.389	0.194	0.54	0.5928	0.162	0.081	0.39	0.6806
Nutrient Solution	2	24.389	12.194	33.77	<.0001	9.576	4.788	23.21	<.0001
Variety	3	14.972	4.991	13.82	<.0001	11.973	3.99	19.35	<.0001
NS*Variety	6	16.278	2.713	7.5q	0.0004	14.913	2.486	12.05	<.0001
NS*Block	4	0.444	0.111	0.31	0.8690	1.191	0.298	1.44	0.2605
Error	18	6.500	62.973			3.713	0.206		
Total	35	62.972				41.529			

NS= Nutrient Solution, SS= sum of squares, DF= Degrees of freedom

Appendix U: Analysis of variance for the minitubers sizes C3 for experiment one and two

	Experiment one					Experiment two			
Source	**DF**	**SS**	**Mean square**	**F Value**	**Pr > F**	**SS**	**Mean square**	**F Value**	**Pr > F**
Block	2	1.167	0.583	0	0.9986	0.507	0.253	1.29	0.2987
Nutrient Solution	2	22.167	11.083	74.93	<.0001	38.000	19.000	96.98	<.0001
Variety	3	3.639	1.213	0.15	0.9292	0.222	0.407	2.08	0.1388
NS*Variety	6	4.278	0.713	0.89	0.5216	5.111	0.852	4.35	0.004
NS*Block	4	0.667	0.167	0.01	0.9996	2.313	0.578	2.95	0.0488
Error	18	4.833	0.269			3.527	0.196		
Total	35	36.75				50.680	50.680		

NS= Nutrient Solution, SS= sum of squares, DF= Degrees of freedom

Appendix V: Analysis of variance for the minitubers sizes C4 for experiment one and two

		Experiment one				Experiment two			
Source	**DF**	**SS**	**Mean square**	**F Value**	**Pr > F**	**SS**	**Mean square**	**F Value**	**Pr > F**
Block	2	0.056	0.028	0.11	0.8990	0.500	0.250	9.00	0.002
Nutrient Solution	2	49.389	24.694	95.25	<.0001	78.500	39.250	1413.00	<.0001
Variety	3	10.00	3.333	12.86	<.0001	5.000	1.667	60.00	<.0001
NS*Variety	6	2.83	0.472	1.82	0.1513	3.500	0.583	21.00	<.0001
NS*Block	4	0.61	0.153	0.59	0.6747	1.000	0.250	9.00	0.0004
Error	18	4.667	0.260			0.500	0.278		
Total	35	67.556				303.5			

NS= Nutrient Solution, SS= sum of squares, DF= Degrees of freedom

Appendix W: Analysis of variance for starch for experiment one and two

		Experiment one				Experiment two			
Source	**DF**	**SS**	**Mean square**	**F Value**	**Pr > F**	**SS**	**Mean square**	**F Value**	**Pr > F**
Block	2	15.385	7.693	0.42	0.6609	4.971	2.486	0.12	0.8848
Nutrient Solution	2	145.090	72.545	4	0.0366	114.309	57.154	2.83	0.0852
Variety	3	2.844	0.948	0.05	0.9837	58.915	19.638	0.97	0.427
NS*Variety	6	107.504	17.917	0.99	0.4627	57.993	9.666	0.48	0.8151
NS*Block	4	28.660	7.165	0.39	0.8097	10.988	2.747	0.14	0.9668
Error	18	326.693	18.150			363.129	20.174		
Total	35	626.176				610.306			

NS= Nutrient Solution, SS= sum of squares, DF= Degrees of freedom

Appendix X: Analysis of variance for specific gravity for experiment one and two

		Experiment one				Experiment two			
Source	**DF**	**SS**	**Mean square**	**F Value**	**Pr > F**	**SS**	**Mean square**	**F Value**	**Pr > F**
Block	2	0.052	0.026	4.79	0.0214	0.001	0.000	0.04	0.9641
Nutrient Solution	2	0.339	0.169	31	<.0001	0.492	0.246	19.17	<.0001
Variety	3	0.423	0.141	25.8	<.0001	0.491	0.164	12.76	0.0001
NS*Variety	6	0.035	0.006	1.08	0.4095	0.006	0.001	0.08	0.9978
NS*Block	4	0.051	0.013	2.32	0.0967	0.049	0.012	0.95	0.4571
Error	18	0.098	0.005			0.231	0.013		
Total	35	0.998				1.269			

NS= Nutrient Solution, SS= sum of squares, DF= Degrees of freedom

Appendix Y: Analysis of variance for tuber dry matter for experiment one and two

		Experiment one				Experiment two			
Source	**DF**	**SS**	**Mean Square**	**F Value**	**Pr > F**	**SS**	**Mean Square**	**F Value**	**Pr > F**
Block	2	45.679	22.840	1.240	0.3139	18.370	9.185	3.64	0.047
Nutrient Solution	2	1049.870	524.933	28.420	<.0001	1201.360	600.682	238.18	<.0001
Variety	3	49.731	16.577	0.900	0.4616	6.547	2.182	0.87	0.4771
NS*Variety	6	3.342	0.557	0.030	0.9998	2.085	0.348	0.14	0.9893
NS*Block	4	7.687	1.922	0.100	0.9796	41.581	10.396	4.12	0.0152
Error	18	332.417	18.468			45.396	2.522		
Total	35	1488.720				1315.34			

NS= Nutrient Solution, SS= sum of squares, DF= Degrees of freedom