KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY,

KUMASI, GHANA

SCHOOL OF GRADUATE STUDIES

DEPARTMENT OF AGRICULTURAL ENGINEERING

FACULTY OF MECHANICAL AND CHEMICAL ENGINEERING

COLLEGE OF ENGINEERING

DESIGN, FABRICATION, TESTING AND EVALUATION OF TWO AEROPONIC SYSTEMS AS ALTERNATIVE PRODUCTION METHODS FOR SEED YAMS IN GHANA

BY

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JULY 2016

DESIGN, FABRICATION, TESTING AND EVALUATION OF TWO AEROPONIC SYSTEMS AS ALTERNATIVE PRODUCTION METHODS FOR SEED YAMS IN GHANA

A thesis submitted to the School of Graduate Studies, Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, in partial fulfillment of the requirement for the

award of PhD SOIL AND WATER ENGINEERING

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BSc. Agricultural Engineering, MSc Soil and Water Engineering

July 2016

DECLARATION

I hereby declare that this submission is my own work towards the PhD in Soil and Water Engineering and that to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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DEDICATIONS

This work is dedicated to my children, Edward, Katakyie and Abena Nhyira Oteng-Darko. May God lift you to reach the highest peaks in all your life's endeavours.

ACKNOWLEDGEMENTS

My utmost thanks go to the Almighty God, who through all the changing scenes of my life, have blessed me with abundant life, health and wisdom to fulfill this dream.

I am extremely thankful to my supervisory team: Prof Nicholas Kyei-Baffour and Dr. Wilson Agyei Agyare, both of the Agricultural Engineering Department, Faculty of Mechanical and Chemical Engineering, KNUST; Dr. Emmanuel Otoo, a Principal Research Scientist at the CSIR-Crops Research Institute; and the late Dr. Emmanuel Ofori, who until his untimely death, was a Senior Lecturer at the Agricultural Engineering Department, Faculty of Mechanical and Chemical Engineering, KNUST.

My profound gratitude also goes to Dr. Stella Ama Ennin, Chief Research Scientist and Director of the CSIR-Crops Research Institute who took me under her wings in mentoring me to apt into the life of a Research Scientist of the CSIR. She has been a constant strength in my life throughout my academic pursuit, challenges and all. My heartfelt gratitude also goes to Dr. Hans Adu-Dapaah, a Chief Research Scientist and former director of the CSIR-Crops Research Institute for his numerous counsel and inspiration.

I would like to acknowledge the West African Agricultural Productivity Programme (WAAPP), its National Coordinator, Madam Azara Ali Mamshie and its NCOS Coordinator, Dr. Regina Sagoe, for supporting this PhD work. I would also like to appreciate the generosity of the Africa Yam Project, coordinated in Ghana by the CSIR-Crops Research Institute and funded by the Bill and Melinda Gates Foundation in financing the construction of a pump house for this work.

My sincere gratitude also goes to Dr. Joseph Nketiah Berchie, Head of the Resource and Crop Management/Socioeconomics Division (CSIR-CRI) and Dr. Joseph Nii Lante Lamptey for their selfless counsel. To my office colleagues, Dr. Ernest Baafi, Eric Owusu Danquah, Shadrack Amponsah, Felix Frimpong, Kennedy Agyeman, Stephen Yeboah, Hillary Mireku Bortey and Joseph Adomako, I say God richly bless you in enduring my numerous questions and pestering. My thanks also go to Clement Ayaga, Alhassan Kwadwo and Clement Oppong Peprah all of the CSIR-Crops Research Institute for their immense technical assistance during the screenhouse and field evaluations associated with this work.

What could I have done without my family's support? Thank you to my husband, Peter Oteng Darko for his staunch support in my academic career; my uncle Lawrence Kofi Asabere and my grandmother, Victoria Oteng for their tenacious and diligent upbringing of two very troublesome twin girls. To my big sister, Irene Amankwaa-Addo and my twin sister, Priscilla AmankwaaOwusu, my father, Yaw Amankwah Kyerematen and brothers Joshua, Emmanuel and Akwasi Kyerematen, I say thank you. To my mother, the late Lydia Ama Achiaa Asabere, I can only say that I wish you were here to see this day and to my adopted sons, Godfred Appiah Biney and Richard Oteng-Agyei, I say am proud of you.

Patricia Oteng-Darko

July 2016

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ABSTRACT

Yam is one of the most important dietary sources of energy for households in West-Africa. Yam stores relatively longer than most root crops and this attribute have gained it recognition as a food security crop in Ghana. More effort has been put into its research and production as has been seen by numerous government interventions over the years. However, inadequate access and high cost of seed yams have prevented farmers from intensive sustainable production. New technologies to increase and make available quality seed yams to farmers can boost yam production, increase food security and improve farmers' livelihoods. In this regard, two aeroponic systems were developed and evaluated. The two systems; power-dependent (pressurised) and power-independent (gravity-fed) were evaluated using a split-split plot design at the CSIR-Crops Research Institute. The evaluations were carried out to assess the technical and agronomic performance of the systems. The aeroponic units were the main plots, the nutrient concentrations the sub-plot, and the yam varieties the sub-sub plot. Data collected on performance of the various treatments were subjected to analysis of variance and judged significant at $p<0.05$. Technical evaluation of the two aeroponic systems gave Christensen's Coefficient for water distribution uniformity values were 97.52 % and 94.49 % for the powerdependent and power-independent systems respectively. Agronomic performance showed significant differences in number of mini-tubers harvested and weight of mini-tubers under the different aeroponic systems. Field evaluation of harvested mini-tubers also showed significant differences in final yields under the various nutrient concentrations. Economic analysis of the two systems showed a benefit-cost ratio in favour of the power-independent system. Various recommendations were made after a repeat of the experiment. The power-independent system would be disseminated to smallholder farmers for seed propagation.

CHAPTER ONE

INTRODUCTION

1.1 General Introduction

Yams (*Dioscorea spp*.) are among the most important staple foods in the world, especially in some parts of the tropics and subtropics (Okigbo and Ogbonnaya, 2006). It belongs to the family *Dioscoreaceae* (genus *Dioscorea*). Yams are native to tropical regions throughout the world. They are cultivated for their edible tubers, which in some species can grow up to about 2.4 m long and weigh up to 45 kg (Okigbo and Ogbonnaya, 2006). Yam is largely carbohydrate and is one of the cheaper sources of the nutrient to humans (Kochlar, 1981). Yams are major sources of nutrients (carbohydrates, phosphorus calcium) and vitamins such, iron and vitamins such as thiamine, riboflavin, and vitamins B and C (Coursey, 1967).

Yam is one of the most important dietary sources of energy produced within the tropics and plays a major role as a food and trade commodity in West-Africa. It stores relatively longer than most root crops (e.g. cassava), availing itself on the market for a considerable part of the year. This attribute has gained it recognition as a food security crop in Ghana. In Ghana, yam is produced mostly in the Guinea-Savannah and Forest-Savannah transition zones with commercial yam production areas such as Mampong, Ejura, Kintampo, Atebubu, Wenchi, Kete-Krachi, Yendi, Bole, Tamale and Wa (Twumasi, 1986). However, reasonable production occurs in almost all regions. About 80% of yam produced in Ghana is white yam, which is much preferred among the yam varieties (Tetteh and Saakwa, 1991).

Ghana is a major yam exporter in the world, exporting 20,841t in 2008 (MiDA, 2009). There are a lot of challenges with yam production in Ghana, chief among them being unavailability and high cost of seed yams. Growing yams in Ghana is labour intensive and land demanding because of its over reliance on traditional production techniques. Furthermore, farmers rely on traditional method of milking for seed generation. As a vegetatively propagated crop, all parts of the yam, with a bit of the tuber skin attached (known as setts) is expected to germinate even though most farmers prefer using the yam "head". The size of ware yam harvested usually depends on the size of sett used in its cultivation. Farmers therefore prefer using whole setts, however big or small for planting. To generate such whole setts, farmers use a technique known as "milking". This process involves early harvesting of ware yams to pave way for a second tuber that can be used as seed only in early maturing varieties. After "milking", if the second tuber regrowth is not met with favourable weather conditions, the farmers cannot get enough seed to use in the next season's planting, thus having to leave a substantial part of the ware yam as seed for planting.

1.2 Problem Statement

Yam is an intensively cultivated root/tuber crop in Africa, only following cassava in terms of production volumes (Mignouna *et al*., 1998) with mean yields of about 10 t/ha. It is a food security crop in most of sub-Saharan Africa (Delebo, 2008). In 2007, yam production worldwide was almost 52 million tonnes with 96 % of this coming from Africa (IITA, 2006). There is a high labour requirement in yam production. Challenges also persist in the availability of high quality yam seeds, mechanization and staking especially in the forest areas, weed control and harvesting, which account for over 40 % of the total yam production cost (Nweke *et al*. In: Okoro, 2008).

Yams are predominantly grown by small scale farmers in Ghana. Most of these farmers propagate their seed yams using traditional methods such as "milking" or harvesting the ware yams early and the use of "yam heads" or parts of the yam that can easily sprout. The setback with these methods is that they do not produce enough and/or good quality seed yams (MiDA, 2008). Also, if the second plant propagation (after "milking") is not met with favourable weather conditions, farmers could lose most or all of their seed yams and end up with nothing to plant the next season. This can result in the farmer spending more money than initially intended, in the acquisition of seed yams for the next season's planting. This arrangement is even subjected to the availability and affordability of seed yams on the market, which is not the case in most cases.

1.3 Project Justification

Research has produced methods that results in a higher propagation ratios for yams. These include the minisett technology with a multiplication ratio of 1:30, *in-vitro* tissue culture multiplication with a ratio of 1:200 and *in-vivo* yam vine multiplication with a ratio of 1:240 (CSIR-CRI, 2012) which has not been fully disseminated. Unfortunately, adoption of these technologies is low, and to a high degree, not attained the needed impact despite its numerous advantages.

The minisett technology developed and promoted by International Institute for Tropical Agriculture (IITA, 2006) and CSIR-Crops Research Institute (CSIR-CRI, 1991) in Ghana is still striving to attain high adoption by farmers. Minisett is based on a principle targeted at increasing the number of setts derived from one tuber. In this technique, one tuber can be sliced, with tuber skin attached, into about 40 pieces ranging in weight from 50-100 g each. The cut pieces are dipped in a solution containing pesticides to disinfect the setts before planting (MiDA, 2010).

Despite the high propagation rate and low disease infestation of the minisett technology, many farmers still rely on the age old method of using tubers of ware yam or milked yam for planting.

Plants require light, water, nutrients, oxygen and carbon dioxide for photosynthesis. Soil can be a supplier of nutrients, but is not necessary in and of itself - hence the effectiveness of hydroponic and aeroponics. Water is also becoming more and more scarce as a commodity and as global population increases, the concern over water and soil quality also continues to grow.

New technologies for growing foods that are not overly dependent on soils and water are becoming not only a distinct advantage, but a necessity. The aeroponics and hydroponics technologies have been demonstrated in several ways to be a significantly more water- and energy-efficient means for food production. Hence, the hydroponics and aeroponics technology is being adapted for use in this research to propagate seed yam.

In aeroponics, plants are grown in an air or mist environment without engaging soils or any soil aggregate or soil medium (Arunkumar and Manikand, 2011). Aeroponics gives room for easy access to plant roots since it is not planted in any aggregate media (Pagliarulo and Hayden, 2002). The growth chamber and fertigation system employed in aeroponics also give room for complete regulation of the root zone setting, including temperature, humidity, pH, nutrient concentration, mist application frequency and duration. Plants grown using aeroponics often show signs of accelerated growth and early maturity (Mirza *et al*., 1998). These abilities have made the technology a popular research tool for studying root growth and nutrient uptake (Barak *et al*., 1998). Aeroponically generated seed yams can improve the seed multiplication ratio of yams and thus make available more seed yams on the market. It can also reduce disease incidence of seed yams which results in yield losses.

Aeroponics, if successfully used in the propagation of seed yams, can significantly increase the incomes of farmers, improve access to quality seed yams all year round (by making it more accessible and affordable to commercial growers and small scale farmers) and reduce the production costs of yams. This would improve farmers' livelihood and also enhance food security in the country.

1.4 Objectives of the Study

The overall objective of this research was to determine the feasibility of generating seed yams from aeroponic systems.

1.4.1 Specific Objectives

To achieve the main objective of this work, the following sub-objectives were developed:

i. Design, set up and test two types of aeroponic systems (power-dependent and powerindependent) for propagating seed yams ii. Evaluate the two aeroponic systems for their ability to agronomically propagate minitubers successfully iii. Assess the ability of the resulting mini-tubers to be used for propagating seed yams and iv. Determine the economics of using either of the two aeroponic systems to commercially produce seed yams.

1.5 Research Questions

The following questions were formulated to guide the study:

1. Are there differences in the fabrication and operation of the two designed aeroponic systems?
2. Are there differences in growth and yield of seed yams from the two aeroponic designs?
3. Can the mini-tubers generated from either of the systems be used to propagate seed yams?
4. What are the cost implications of using either of the two systems to propagate seed yams?

1.6 Research Hypotheses

The following research hypothesis guided the studies:

The alternative and null hypothesis for objective one

The Null hypothesis (H_O): System performance of the power-dependent set up is same as the power-independent set-up.

The alternate hypothesis (H_A): System performance of the power-dependent set up is not the same as power-independent set-up.

The alternative and null hypothesis for objective two

The null hypothesis (H_O): Agronomic performance of vine cuttings grown using the powerdependent system is same as that of the power-independent system

The alternate hypothesis (H_A): Agronomic performance of vine cuttings grown using the powerdependent system is not the same as that of the power-independent system

The null and alternative hypothesis for objective three

The null hypothesis (H_O): Agronomic performances of resulting mini-tubers from both the power-dependent and power-independent aeroponic systems are same

The alternative hypothesis (H_A): Agronomic performances of the resulting mini-tubers from the power-dependent and power-independent systems are not the same.

The null and alternative hypothesis for objective four

The null hypothesis (H_O): There are no economic differences in the design, fabrication and operation of the two aeroponic systems.

The alternative hypothesis (H_A): There are economic differences in the design, fabrication and operation of the two aeroponic systems.

1.7 Limitations of the Research

The following are the limitations of this research:

1. The initial set-up of the two aeroponic systems was capital intensive.
2. One of the systems evaluated was power-dependent and vulnerable to power outages (a more common event in Ghana as it faces an energy crisis). Prolonged power interruptions could have led to irreversible damages to the plants, thus additional costs were incurred in providing for a standby generator.
3. The aeroponic technology involves a lot of expertise and also requires constant attention and maintenance.

1.8 Organization of the Research

This thesis is organised into six (6) chapters. The first chapter constitutes the general introduction to the research, detailing the background, justification, objectives, research questions and hypothesis and the limitations of the study.

Chapter Two reviews literature on yams and its production in Ghana defines and explains aeroponics, its advantages and uses in research as well as its limitations. Also a general overview is given on the types of aeroponic systems based on their components, accessories and operation.

Chapter Three details the designs, fabrication and setting up of the two aeroponic systems and also reports on the materials and methods used in the technical evaluation of the two aeroponic systems as well as results from the evaluation. It gives detailed description of the aeroponic designs, its

setting up and operational characteristics as well as the experimental designs used in their evaluation.

Chapter Four reports on the materials and methods used in the agronomic evaluation of vines planted on the aeroponic systems as well as evaluation of the resulting mini-tubers from the aeroponic propagation. The methods explain the type of research designs adopted for the agronomic evaluations of the systems. It also includes various data collection methods and analysis.

Chapter Five presents the data, calculations/derivations and results of analysis from the various agronomic experiments. It further interprets and discusses results obtained from the study.

Chapter Six presents a summary of the major outcomes of the research, the conclusion made from the analysis and proposes areas for further research as well as recommendations for policy makers.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter describes yam and seed yam production in Ghana. It further defines aeroponics, gives a brief history and describes the types of aeroponics, applications and the propagation media involved in aeroponic cultivation.

2.2 Botany (Classification) and Distribution of Yams

According to the USDA classification, yams belong to the kingdom *Plantae*, sub kingdom

Tracheobionta, super division *Spermatophyta*, division *Magnoliophyta*, class *Liliopsida*, subclass *Lilidae*, order *Liliales*, family Dioscoreaceae and genus Dioscorea. Yams are twiners or herbs and are sometimes achlorophyllous and saprophytic. The leaves have a distinctive petiole, small sheathing bases with reticulate-veined lamina (Kress, n.d). The flowers are actinomorphic, unisexual (dioecious) or bisexual (Kress, n.d). Yam (Dioscorea spp. L) is a vegetatively propagated tuber food crop which belongs to the family Dioscoreaceae and classified among monocotyledonous herbaceous annual or perennial climbing or trailing crop plants (Demuyakor *et al.*, 2013).

Many members of the yam specie originate from subtropical and tropical habitats (Kress, n.d). Kress (n.d) puts the number of species at 750 with eight or nine genera, many of which produce tuberous roots which contain poisonous alkaloids which can be destroyed by boiling. Hahn *et al*. (1987), however, puts the number of species at over 600 out of which only six are cultivated for food in the tropics. The edible species includes: *D. cayenensis* (yellow guinea yam), *D. rotundata* (white guinea yam), *D. bulbifera* (aerial or bulbils yam), *D. alata* (water yam), *D. esculenta* (Chinese or lesser yam), *D. trifida* L., *D. japonica*, *D. dumetorum* (trifoliate or bitter yam), *D. hispida*, and *D. oposita* (FAO, 2010; Purseglove, 1972; Degras, 1993).

According to FAO (2010), in 2005, 96 % of global yam production was in tropical Africa, with the rest coming from countries such as, Japan, Colombia, the Caribbean islands of Cuba, Haiti and Jamaica, the Philippines, Brazil, with Portugal being the only country in Europe that produces yams. The crop is extensively produced in West Africa where they are steeped in cultural history and revered as a cultural symbol of fertility (Bridge *et al*., 2005).

2.3 Yam Cultivation and Utilization in Ghana

Yam is an important crop which is produced throughout most parts of the Ghana (Twumasi, 1986). The country is the second largest producer of yams in the world, following Nigeria with nearly 6.3 million tons of yams produced in 2011 (MoTI, 2013). Yam demand is found in both the domestic and international market (MiDA, 2009). It is a major source of income for both farmers and traders of the crop and also serves as a major staple food in most parts of the country (MiDA, 2009).

Yam is the only major root crop with higher digestible energy protein content than rice and also exceeds the protein content of cassava by approximately 400 % (Bradbury and Holloway, 1988). It is thus considered to be the most nutritious of all the tropical root crops (Wanasundera and Ravindran, 1994). Yam is also a good source of minerals, fibre, vitamins A and C (O'Sullivan, 2010). Yams are used in the preparation of local dishes. It is used in the preparation of *fufu,* a common staple. It can also be fried or boiled and eaten with sauce or roasted/boiled and mashed into *Ɛtɔ.* Majority of the yam produced in Ghana are cultivars of *D. rotundata* and *D. alata* (Demuyakor *et al*., 2013), *D. Cayensis* as well as some wild species of *D. praehensilis* (Otoo *et al.*, 2012). According to Otoo *et al.* (2012), the relative importance of these species determines the extent of their usage resulting in loss of some landraces over time. There is ready market for the crop as there is a high demand on both the local and export markets (Osei *et al*., 2013). The yam value chain is a source of lucrative employment for various actors on the chain including bulkers, wholesalers, exporters, retailers and local food vendors. However, for all its importance, not much has been done to the crop in terms of value addition.

Support for yam production and research in Ghana has seen the staple being captured in most agricultural productivity policy documents. The Medium Term Agricultural Development Policy

(MTADP) and the National Agriculture Research Strategy (NARS), established in 1994, focused on yam as a priority crop for research in order to boost production and decrease post-harvest losses (Bancroft, 2000). Under the Second Food and Agriculture Sector Development Policy (FASDEP II), the Ministry of Food and Agriculture (MoFA) intended to achieve food security via the promotion of five staple food crops (i.e. cassava, cowpea, maize, rice and yam). Since yam is one of these five staple food crops, it received government support in research and production to enhance productivity (MoFA, 2007).

Large-scale cultivation of the crop in Ghana is in the Afram plains, the three northern regions, Brong Ahafo and Ashanti Regions (Osei *et al*., 2004). Yams require soils that are conducive for easy penetration and tuber development and also have high organic matter levels (Ezumah, 1986). Depending on the variety, yams take about six to eight months to reach harvest maturity (Tetteh and Saakwa, 1991).

Yams are planted either on ridges or mounds. Mounding however, is the more traditional method which due to its tedious operations is being replaced with the newer ridging technology which eliminates the drudgery associated with mounding operations (Ennin *et al*., 2009).

2.4 Seed Yam Production in Ghana

Yams can be reproduced sexually from true botanical seeds, aerial tubers, underground tubers and vine cuttings. Propagation by botanical seeds and aerial tubers in Ghana is only done by researchers for breeding purpose. Propagation through vines, which in previous years was only done by researchers, is also gaining attention with yam farmers in the country. The most common form of propagation is by underground tubers either planted as whole setts or minisetts. In Ghana, the traditional methods of seed yam still remain dominant. Several rapid multiplication techniques for

seed yam production have been developed globally. These include the mini-sett technology, the vine multiplication technique, tissue culture multiplication and aeroponics

2.5 Definition of Aeroponics

The International Society for Soilless Culture defines aeroponics as a system where roots are continuously or discontinuously grown in an environment saturated with fine drops (a mist or aerosol) of nutrient solution (Carruthers, 1992). Aeroponics culture is an efficient, profitable technology for growing plants without soils (Pardossi *et al*., 2011). For regions with large dense populations and/or little or no arable lands, the technology is a valuable means for crop production (Schoenstein, 1996). The aeroponic technology has improved immensely on the plant density of crops due to its ability to eliminate competition among plants. Compared to hydroponics, aeroponics gives room for optimized root aeration and consequently, increased yields (Soffer and Burger, 1988). The technology is also efficient in its water and nutrient uses..

According to Mugundhan *et al.* (2011), aeroponics is not only a way to produce foods on a large scale, but it can also be employed as a household hobby. In fast urbanising environments such as can be found in most developing countries, aeroponics is a technology that can ensure food security and reduce the carbon footprints and transaction costs associated with mass movements of food from production areas to the urban areas.

2.5.1 Advantages of aeroponics in crop production

The following are some advantages of aeroponics as have been outlined by the following authors: Mugundhan *et al.*, 2011; Pagliarulo and Hayden, 2002; Arunkumar and Manikand, 2011; Mirza *et al*., 1998; Barak *et al*., 1998; Mbiyu *et al.*, 2012 and Ziegler and Rolfe, 2009:

i. Aeroponics growing is ecologically friendly (conserves water and nutrients) and safe.

ii. Roots and crops from aeroponic production are free of soils and soil-borne organisms or diseases and contaminants iii. Plant growth and development cycles are accelerated resulting in early maturity and harvest.

iv. Aeroponically cultivated crops are consistent in its phytochemical properties as a result of stability of nutrient concentrations used in fertigation.

v. Elimination of water and nutrient competition in aeroponics gives room to higher planting densities and thus increased yields.

vi. Efficient use of water and nutrients due to reutilizing ability of the nutrient solutions used.

vii. Elimination of soil fertility and degradation issues in crop production

viii. Production can be done independent of climatic conditions thus ensuring a continuous production cycle.

ix. Availability of fresh produce close to consumer and market.

x. Aeroponics technology provides the opportunity to produce where demand is thereby reducing freight and transaction cost.

2.5.2 Disadvantages of Aeroponics in crop production

Aeroponics depends on electrical systems like timers and pumps which controls most of the production activities. Failure or breakdown of the system can spell disaster for the plants or the whole aeroponic system. Technology and technical knowledge demand of the system is also very high. Aeroponics plants also need close care, attention and support and will succumb to diseases and crop failure if not frequently monitored (Mugundhan *et al.*, 2011). In addition to these, the following are some disadvantages of aeroponics cultivation of tuber crops (Arunkumar and Manikand, 2011; Mugundhan *et al*., 2011):

i. Even though total darkness is a demand in aeroponic systems, it cannot be maintained entirely because of the tendency to monitor the root environment.

ii. Some production operations (e.g. staking of plants and manual harvesting) of the system are labour-intensive.

iii. Initial capital cost investment into aeroponics technology for crop production is relatively high.

2.5.3 History and Applications of Aeroponics

The first aeroponic system was developed in Italy at the University of Pia by Dr. Franco Massantini, (Carruthers, 1992). The system was made up of a pipe backing up three cultivation trays with sprinklers built-in and shielded with polystyrene (Carruthers, 1992). This system was later improved into a vertical, multi-layered system.

In the initial stages of the technology's development, it was only employed as a research tool and not for economic crop production. The first researcher used the system to study air culture growing (Carter, 1942). The system was named fifteen years later by Went (1957) as "aeroponics". In 1999, funded by NASA, R. Stoner, developed an inflatable low-mass aeroponic system for high performance food production on earth and space (Singh n.d). Initial ideas of plant production systems for space-based applications, such as lunar or Martian bases, depend on hydroponic nutrient and water delivery systems (NDSs) (Bugbee and Salisbury, 1989; Kliss and MacElroy, 1990; Steinberg *et al*, 2002).

Aeroponics has been employed effectively and efficiently in the production of several, ornamental, medicinal and horticultural plants (Biddinger *et al*., 1998; Schoenstein, 1996; Pagliarulo and Hayden, 2002). Mateus-Rodrigueuz *et al*. (2014) studied the genotype by

environment effects on potato mini-tuber seed production using an aeroponic system. Results showed that there was an increase in the vegetative cycle for all the genotypes grown with aeroponics as compared to what was expected.

The aeroponic technology has also been used in Korea for potato seed tuber production under tropical and subtropical conditions (Kang *et al*., 1996; Kim *et al.,* 1999). Using aeroponics for mini-tuber production under temperate conditions was also found to substantially improved yields (Ritter *et al.,* 2001). At the International Potato Centre (CIP) in Peru, yields of over 100 mini-tubers /plant were obtained (Otazu, 2010). Studies reporting mini-tuber yield of 800 tubers/m^2 at a plant density of 60 plants/m^2 over a five month period with weekly harvests was done by (Farran and Mingo 2006). Lommen and Struik (1992a:b) found that the timing and number of the harvests were the vital aspects in boosting mini-tuber production. Experiments have been done to evaluated clone survival and rooting of chrysanthemum (herbaceous cuttings) and ficus (woody cuttings) as influenced by various levels of dissolved oxygen concentrations (Carruthers, 1992).

In addition to commercial crop production, aeroponic systems have been extensively engaged for root systems evaluations including root micro-organisms, drought response, oxygen effects on root growth and cultivar effects (Mavoungou *et al*., 1982; Hung and Sylvia, 1988; Robertson *et al*., 1990a; Sylvia and Jarstfer, 1992; Khan and Sinclair, 1992; Soffer and Burger, 1988; Shtrausberg and Rakitina, 1970; Wagner and Wilkinson, 1992; Hubick *et al*., 1986; Truong and Beunaid, 1978). Water stress effects on plants were evaluated by Hubick *et al.* (1986) using aeroponics. Hayden (2006) evaluated aeroponic and hydroponic systems for medicinal herb, rhizome and root crops. Aeroponics has also been used successfully for the production of different ornamental and horticultural species (Biddenger *et al*., 1998; Molitor *et al.*, 1999; He and Lee 1998;). Zhao *et al.*

(2010) also applied aeroponics to investigate the effect of elevated root-zone CO_2 on plant morphological parameter and nutrient uptake.

Aeroponics technology has been established in several African countries for the production of potato mini-tubers (Lung'aho *et al*., 2010). Mbiyu *et al*. (2012) examined the use of aeroponics technology for potato mini-tubers propagation in Kenya. The IITA also initiated the use of aeroponics to generate seed yam from vine cuttings. Maroya *et al*. (2014) generated one to two mini-tuber harvests per plant, four months after planting.

2.6 Types of Aeroponic and Hydroponic Systems

The following describes several types of hydroponic and aeroponic systems. Aeroponic systems can be described as vertical or horizontal, low pressure or high pressure and commercial.

2.6.1 Nutrient Film Technique

The nutrient film technique (NFT) uses no aggregate media in its operations. Suspended plants are misted constantly with nutrient solutions delivered by a pump with no timers (Mugundhan *et al.*, 2011). The plants holding trays are tilted at an angle for easy drainage as shown in Plate 2-1.

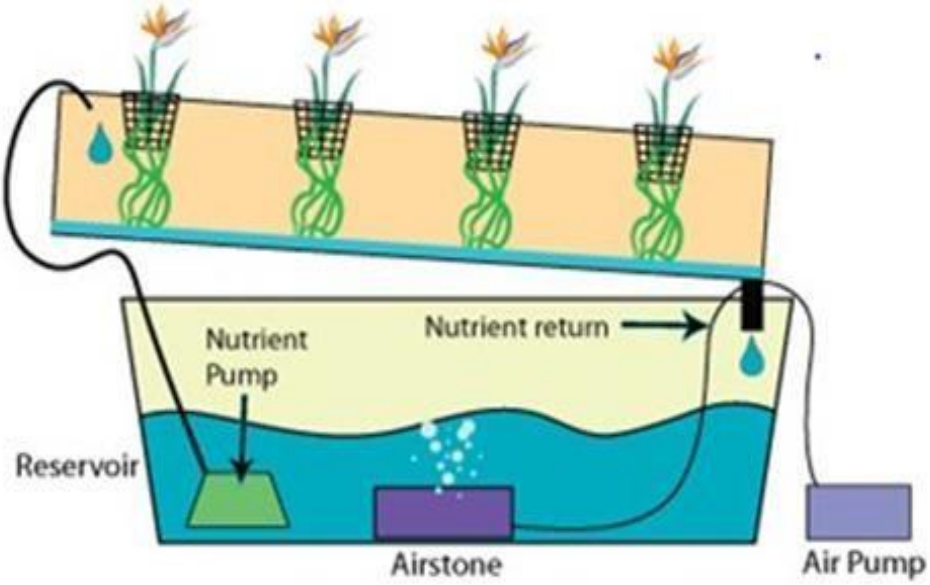


Plate 2- 1 Schematic representation of the nutrient film technique

2.6.2 Ebb and Flow System

This system is also known as the "Flood and Drain" system (Banwait, 2008)., is a much more advanced and complicated system it is more complicated and advanced and uses a submersible pump with an attached timer to intermittently flood the growth tray with nutrient solution (Mugundhan *et al*., 2011). The nutrient solution drains back into the reservoir which is located directly beneath the growth tray.

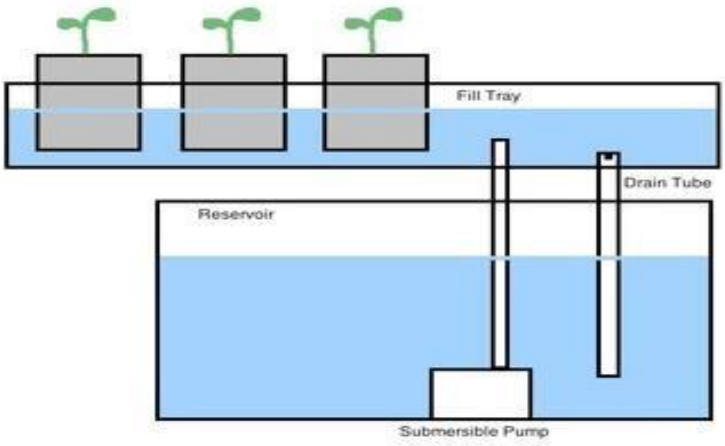


Plate 2- 2 The ebb and flow system (Source: Hydroponics, n.d)

2.6.3 Drip Irrigation Aeroponic System

This is a system which employs drip emitters (or drippers) to deliver nutrient solution directly to the base of each plant (Jones, 2009) (Plate 2-3). The system can be continuous or intermittent, recovery or non-recovery (Mugundhan *et al*., 2011). Recovery systems utilises the used nutrient solution for a number of times and are thus cost effective (Banwait, 2008).

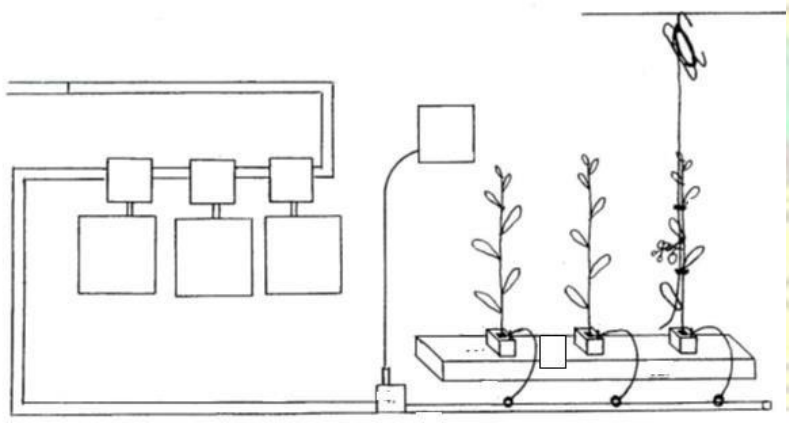


Plate 2- 3 Aeroponics using drip irrigation

2.6.4 Floating Raft Systems

This system also known as the mat system uses styrofam rafts drilled with holes and floating directly on the nutrient solution (Sweat *et al*., 2003). This system is usually used for propagating shallow rooted plants (Moran, 2014).

2.6.5 Vertical/Horizontal Systems

Aeroponic systems can also be classified as vertical or horizontal systems. If laid in an upright position with rows vertical to the ground, it is termed as a vertical system (Plate 2-4). Examples of these are hanging aeroponic bags and stacked pots (Tyson *et al*., n.d). Horizontal systems are built, raised horizontally to the floor, with walking alleys in between as shown in Plate 2-5.

Plate 2- 4 Vertical Aeroponic Systems a. A-Frame b. Vertical Stacking Source:

Biocontrols (n.d)

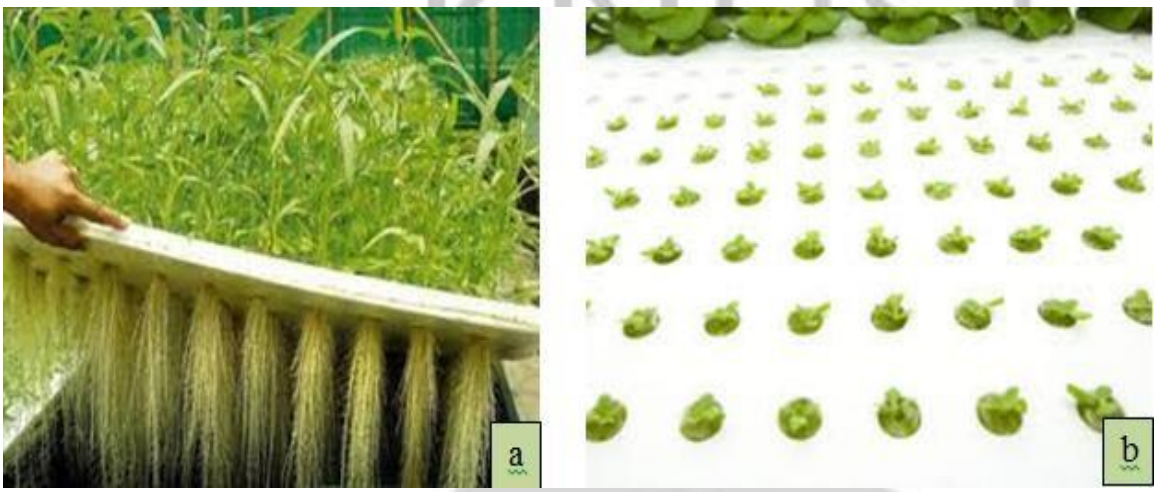


Plate 2- 5 Horizontal aeroponic system a. System showing roots b. System showing plant holding tray

Source: Farmxchange (n.d)

2.6.6 Commercial Aeroponic systems

These are advanced systems used for the production of crops with high value (Jensen, n.d). They involve nutrient regulation systems for nutrient and water delivery, thermal control systems, sensors and devices to improve growth and maturation (Plate 2-6).

Plate 2- 6 Commercial aeroponic systems

Sources: a. Biocontrol (n.d); b. Worldwatch (n.d)

2.7 Components of an Aeroponic system

The aeroponic system has three major components (Bigelow *et al*., 2010). The first is the chamber environment. This is the physical environment of the screen house, such as temperature and humidity, which needs to be monitored and controlled. The second part is the control block/unit (Bigelow *et al*., 2010). This part is responsible for monitoring and affecting the growth chamber environment through fertigation systems, sensors, heaters, etc. The third part of the system is the plant holding and growth system consisting of the growth chamber and plant holding tray. This part of the system provides support to the plant and gives access to the plant roots.

In aeroponic systems, there are a number of factors that must be carefully monitored and some that must be controlled. According to the International Committee for Controlled Environments (ICCE), the minimum measuring and reporting guidelines are: watering schedule, temperature, atmospheric moisture, radiation, carbon dioxide, air velocity, electrical conductivity, pH, nutrition and growth chamber dimensions (Bigelow *et al.*, 2010).

2.7.1 The Greenhouse/Screen-House Facility

The key features to consider in a screen house are the amount of ventilation, the amount of radiation, the specification and the design (Worley, 2011) (Plate 2-7). Shading blinds can be fitted outside or inside the greenhouse to shade young plants (Plate 2-7a); fitting them outside will keep the temperature down (Runkle, n.d).

Plate 2- 7 Different types of screen houses a. screenhouse with black shadenet b. screenhouse with polyethylene roofing c. Screenhouse with flat roof d. concave screenhouse

Source: Grower supply (n.d)

2.7.2 Growth Boxes/Growing Chamber

The growth chamber houses the roots of the plants and serves as the enclosing medium for nutrient delivery and drainage. Their dimensions are usually dependent on the type of crop and production purposes. Growth chambers are made opaque to avoid the penetration of light into the root chamber, thus mimicking some soil properties.

2.7.3 Growing media

There are several growing media for aeroponic plant propagation. Since aeroponics is a soil-less cultivation, most seeds and seedlings are propagated using other growth media (Chiipanthenga *et al*., 2012; Suhaimi *et al*., 2012). A good growing media must be able to:

i. Provide anchorage and plant support; ii. Reserve and hold up plant nutrients and water; and iii. Provide ate gas exchange between the roots and the atmosphere.

Some of these media are rockwool, perlite, vermiculite and others.

2.7.3.1 Rockwool

Rockwool (Plate 2-8) is a propagating media that is usually used in its granular or loose form (Plate 2-8). Rockwool use in aeroponics originated from Denmark in 1969 (Resh, 1995). Rockwool is a combination of limestone, basalt, coke and volcanic rock which converted to a fibrous mineral wool through the application of very high temperatures ranging from I500 °C to 3000 °C (Resh, 1995). They are usually cut into 2.5 cm cube with a hole 6 mm deep at the centre for use in plant propagation (Mugundhan *et al.,* 2011).

Plate 2- 8 Rockwool a. Pressed rockwool b.Wet rockwool with seedlings

Sources: a. Hydroponics net (n.d) b. Forums garden web (n.d)

Rockwool is sterile, has no cation exchange capacity, odourless, uniform and light in weight. It is non-degradable and relatively expensive and not easily available on the market (Succop, 1998).

2.7.3.2 Perlite

Perlite is a naturally occurring volcanic rock that is processed into white angular or pearl-like pebbles (Tyson, n.d). Its ability to expand in response to heat and hold water has found it being employed as a horticultural media (Tyson, n.d; Succop, 1998). The media is also odourless, has high air porosity, easy to drain and sterile (Succop, 1998)

Plate 2- 9 Perlite a. Crushed perlite b. block perlite

Sources: a. Archiproducts web (n.d) b. Perlite-hellas web (n.d)

2.7.3.3 Vermiculite

Vermiculite (Plate 2-10) is the mineralogical name of a collection of hydrated laminar magnesium-aluminium-iron silicates which resemble mica in appearance (Dupré Minerals,

2008). When subjected to heat, vermiculite exfoliates or expands into worm like particles (Dupré Minerals, 2008).

Plate 2- 10 Vermiculite a. rock vermiculite b. Crushed vermiculite in growing trays

2.7.3.4 Peat

The International Peat Society (n.d) defines peat as a mixture of decomposed plant material that has accumulated in a water-saturated environment in the absence of oxygen (Plate 2-11). It has a high moisture retention property and thus serves well as propagation media.

Plate 2- 11 Peat a. mashed b. rock peat

Source: a. Grow Organic (n.d) b. Mother Earth News (n.d)

2.7.3.5 Mix Raised Beds

This consists of a potting-mixture combination of perlite, peat, vermiculite and similar substrates mixed together (Plate 2-12). These are usually used for the propagation of potted plants.

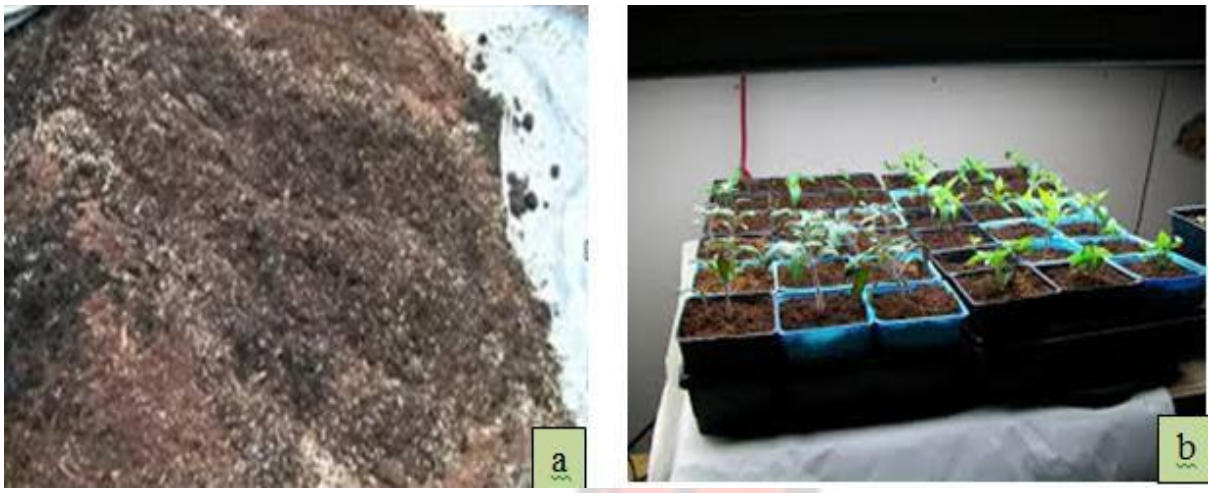


Plate 2- 12 Growing media a. mixed media b. mixed media in propagation boxes

Source: a. wn.com (n.d) b. Frugal Hydroponics (n.d)

2.7.3.6 Sawdust

Sawdust is a waste product from sawn wood. Sawdust can be used to propagate seeds due to its ability to retain moisture. This same ability leaves the media congenial for attracting pathogens and spreading diseases. It is therefore not favourable for propagating aeroponic seeds and seedlings.

Plate 2- 13 Sawdust

2.7.4 Environmental Regulators

Environmental regulators allows for control of the environmental conditions around the root zone, the plant and the screen/greenhouse. Some of the devices that help in regulating environmental factors are described as follows:

2.7.4.1 Thermometer

Thermometers are used to monitor the temperatures of aeroponic greenhouses. Some thermometers are pre-set to an allowable maximum and minimum temperature and thus automatically triggers a cooling or heating system as and when required in the greenhouse (Grow Quick, n.d).

2.7.4.2 Hygrometer

A hygrometer is an instrument used for measuring the moisture content (humidity) in the atmosphere (NC State University, n.d). Most aeroponic cultivators use hygrometers to help in fertigation scheduling.

2.7.4.3 Heaters/coolers

With aeroponics cultivation, some green and screen houses have to be heated during the winter or cooled during summers or in extreme heats. Specially designed heaters and coolers are used in such extreme cases to regulate the temperatures of the screen or greenhouses for optimal plant growth. Shade nets also accomplish the task of maintaining appropriate micro-climatic conditions to the plants in screen houses (Overseas, n.d). Shade nets, regardless of colour, minimise radiation reaching crops in the screen or greenhouse and can influence the radiation direction (Stamps,

2009). However, the value of the shading factor of the net determines the amount of radiation that would be blocked (Stamps, 1994).

2.7.5 Fertigation and Feeding System

Fares and Abbas (2009), define fertigation as the application of fertilizers to crops through irrigation water. Fares and Abbas (2009) further describe fertigation as the application of fertilizers in the right combination, concentration and pH for every irrigation cycle. For aeroponic systems, fertigation can be done through the use of pumps, pipes, filters, irrigation timers/controllers, misters or emitters and other irrigation equipment.

2.7.6 Pumping Station and Accessories

The main function of the pump is to send pressurised nutrient solution to the growing chambers. Pump capacity is dependent on the system's production capacity as well. Controllers/timers are usually connected to the pump using solenoid valves to help regulate the flow and distribution of water and nutrients. The solution is released through a sequence of distribution pipes, filters and valves before final distribution to the plant roots through the emitter, mister or fogger.

2.8 Nutrient Requirements and Management in an Aeroponic System

An aeroponic nutrient solution offers the plant roots water and needed nutrients. In aeroponics, all essential elements are added to the nutrient solution in the form of soluble fertilizer. Water used in the formulation of nutrient concentration must be consistent in its quality, free from pesticides, microbes or algae (Jensen and Rorabaugh, n.d).

The essential elements, or mineral elements that must be present for proper plant growth and development are nitrogen, potassium, phosphorus, calcium, magnesium, iron, sulphur, manganese,

copper, boron, molybdenum, zinc, and chlorine (Cl) (Grusak, 2001). Hydrogen, oxygen, and carbon needed by the plants can be found in the air and the water and thus does not need to be provided (Grusak, 2001).

Plant elements are classified into two different groups depending on their relative amounts to the total constitution of the nutrient solution. Nitrogen, potassium, phosphorus, hydrogen, carbon, oxygen, calcium, magnesium, and sulphur are required in relatively large amounts and are so called macro-elements, whereas copper, iron, manganese, zinc, boron, chlorine and molybdenum are needed in comparatively petty amounts and are thus called micro-elements (Grusak, 2001; Calcino *et al*., n.d).

Aeroponic nutrients should hold every essential element needed by plants for optimal plant growth (Jensen and Rorabaugh, n.d). The nutrient should be well balanced to ensure that nutrient deficiency does not occur and nutrient solution does not contain excess of any element that might result in toxicity (Hydroponics BC, n.d).

Plants have differing responses and needs to various nutrient concentration levels and thus formulation of nutrient solutions is plant specific. The composition of nutrient solutions for all types of plants will contain elements needed for effective plant growth. (Home Hydro Systems, n.d). Table 2-1 shows the nutrient concentrations of two nutrient solutions used in the production of potato tubers in two published studies. Aeroponic nutrient solutions can be delivered to the plant roots by continuo spraying or dripping.

Table 2- 1 Nutrient concentrations used in the production of seed potatoes

Reference	**Macro and micro elements (mg/l)**

	NO_3^{2-}	NH_4^+	P	K	Ca	Mg	S	Fe	Cu	Mo	Mn	Zn	B
Correa *et al.*, 2005	160	12	42	239	152	11.2	40	1.68	0.24	0.032	1.28	0.6	0.8
Factor *et al.*, 2007	145	26	40	295	162	40	64	2.0	0.05	0.05	1.0	0.3	0.3

The timing or misting frequency of nutrient and water application should also be changed to reflect the changing needs of the plants during its various growth stages as large plants and plants that have set fruit, such as tomatoes, need more frequent feedings than do those that do not have any fruit and are not going to grow very large (Grow Quick, n.d).

2.9 Propagation Methods and Crop Management

Various propagation methods can be used in aeroponic cultivation. This section describes the methods and ensuing crop management methods for aeroponic cultivation.

2.9.1 Propagation Methods

There are two propagation methods that are widely used for starting plants in hydroponics and aeroponic systems. These are germination by seed and root or vine cuttings. In the first instance, seeds are usually pre-germinated in growing media and transplanted onto the aeroponic units. In the second instance, cuttings from a healthy plant are planted directly onto the system and fertigated for root establishment. In some instances growth hormone are used to expedite root formation.

2.9.2 Disease Control

Plants propagated using aeroponics need vigorous disease control. Disease infestation can threaten the whole system and plants and thus have to be prevented and controlled. Different types of pesticides are available for disease control in aeroponic systems and using beneficial life forms can be one way to control unwanted pests (Patterson and Ramirez, 2012).

2.9.3 Harvesting and Handling of Mini-tubers

For seed tubers, harvesting can be done when tubers weigh 8 g or more and thereafter, harvests can be carried out every 10 to 14 days (Otazu, 2010). Harvesting can be done sequentially in aeroponic plants. Harvests can be planned for early mornings when temperatures are still cool (Otazu, 2010). Seeds should be allowed to cure in a dry and clean environment for two to three weeks before placing them into cold storage or a diffused light store (Otazu, 2010).

According to Otazu (2010), one major disadvantage of sequential harvests is that when the season is over, harvested mini-tubers become non uniform regarding sprouting. Tubers harvested during the first months of harvest will sprout first; the ones harvested last will sprout later and this will also cause irregular emergence after planting (Otazu, 2010). Although this irregularity does not seem to affect yield, it can partially be corrected by storing the first harvested tubers in cold stores, then, a month before the season is over, by placing all of them in a diffused light storage (Otazu, 2010).

2.10 Factors Affecting Production of Mini-Tubers in Aeroponic System

The aeroponic technology is not as easy or perfect as it sounds and it is investment-intensive and time demanding (Green Tools, n.d). The system depends virtually entirely on pumps, timers and sprayers, thus power failure and other breakdowns can be disastrous for the plants and whole system (Green Tools n.d). Other factors affecting mini-tuber production is are temperature and humidity, air exchange and ventilation, misting frequency and nutrient concentration, light and sanitary conditions

2.11 Storage and Growing of Yam Mini-Tubers

The aeroponic technology for yam mini-tuber production is quite recent technology with research into storage and handling still ongoing. However, since the technology was adapted for use from potato, this research intends to adopt the storage methods of the potato min-tuber. In this method mini-tubers are stored in open mesh bags at 39°F and a relative humidity of 95% until it is ready for planting (Love *et al*., n.d).

2.12 Cost Benefit Analysis of Aeroponic systems

Producing large quantities of high quality mini-tubers at low cost is essential for an economically viable supply of seed yam (Mateus-Rodriguez *et al*., 2013). Evaluating the aeroponic system for its ability to produce mini-tubers at a low cost is an essential part of this research. MateusRodriguez *et al.* (2013) evaluated the aeroponic system for its ability to economically produce mini-tubers of potato.

2.13 Knowledge Gaps in Aeroponic Propagation of Yam Mini-Tubers

Using aeroponics in propagating seed yams is a recent technology and thus still lacks some vital information such as storage conditions and agronomic practices associated with planting minitubers for seed yams. This research will fill some of these knowledge gaps further giving recommendations for future research areas to fully address the main concerns of using aeroponics for mini-tuber propagation.

CHAPTER THREE

DESIGN AND TECHNICAL EVALUATION OF THE AEROPONIC SYSTEMS

3.1 General Introduction

This chapter elaborates on the materials and methods used in this research work. It outlines the design and fabrication processes including the systems design and design components, experimental design used in the screenhouse evaluation, methodology for the field evaluation and nutrient composition analysis.

3.2 Aeroponic Systems Design

The functional requirement of this aspect was to design two fully functional, low-cost aeroponic growth systems, that is:

- Pressurised system with misters (power-dependent) and
- Gravity-fed system with drip emitters (power-independent).

3.2.1 Systems Design of the Power-Dependent Aeroponic System

The power-dependent or pressurized aeroponic system (PAS) utilized electrical power in its operations. It utilised a high pressure pump which was used to atomize the water through small orifice misters to create water droplets of 50 microns or less in diameter. Fertigation was automatically timed using irrigation timers at two minutes on and thirty minutes off.

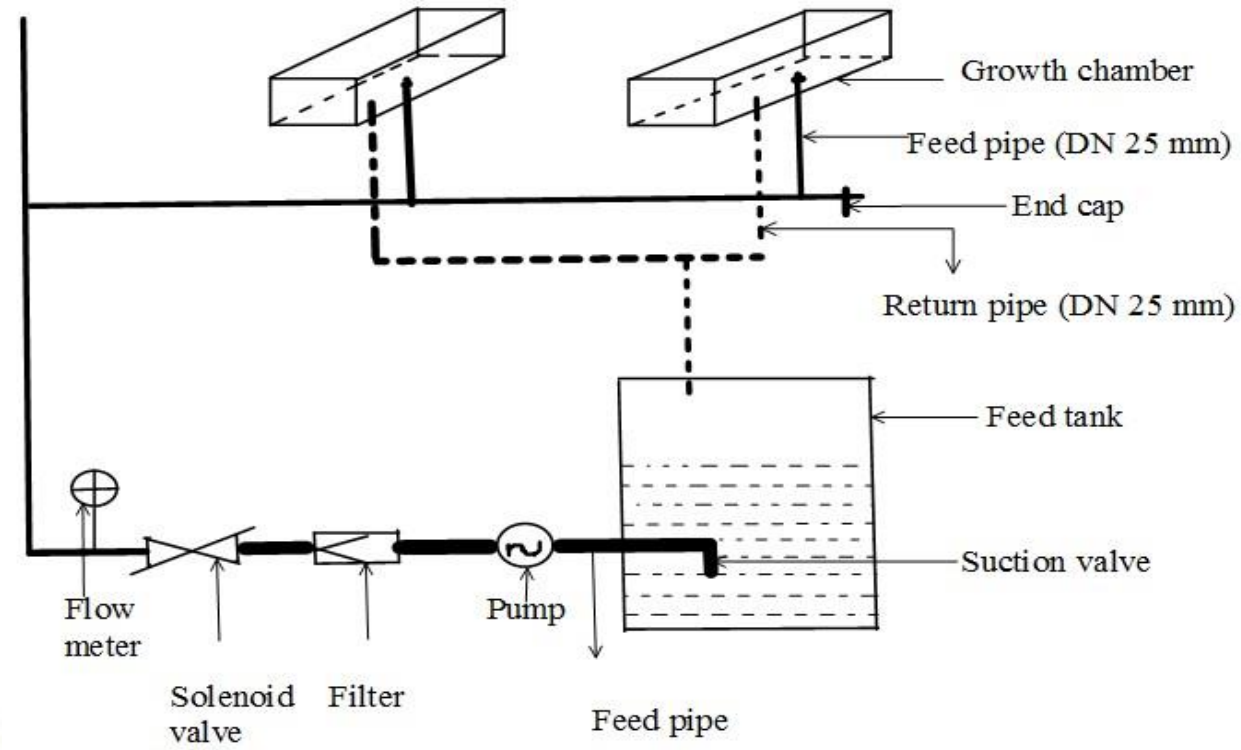


Plate 3- 1 Schematic representation of the pressurised system

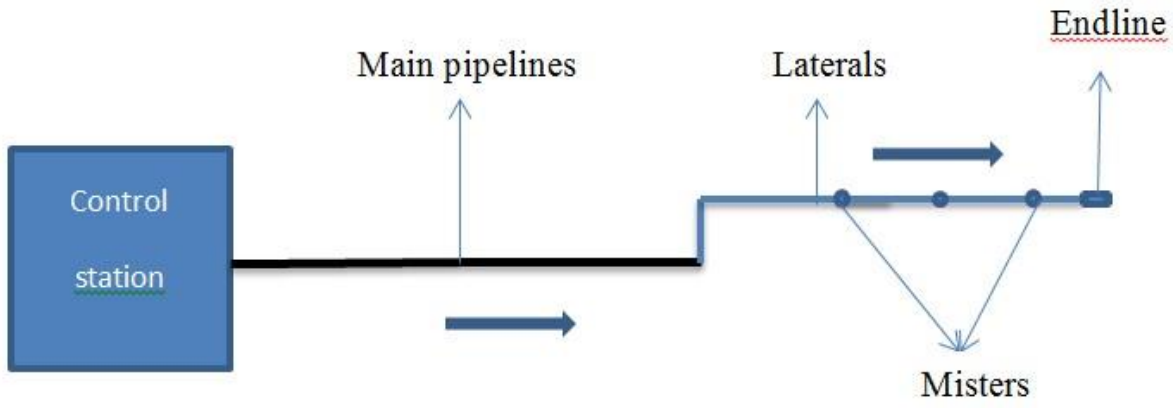


Plate 3- 2 System flow chart for the pressurised aeroponic unit

3.2.1.1 Design and Selection of Emitter

The diameter coverage and height of the growth chamber was considered or used in the selection of the emitter. Since a spray was required in irrigation/fertigation of the roots, a single nozzle micro mister was selected. The number of emitters per lateral was determined based on the number of growth chambers on the lateral. Each growth chamber was designed to have one emitter base on the size (length, breath and height) of the growth chamber. Thus, each lateral had 3 emitters.

3.2.1.2 Lateral Design

The lateral length was designed based on the number and arrangement of the growth chamber. According to the experimental design for the agronomic evaluation, three yam varieties, grown in three different chambers, were irrigated with the same nutrient solution at a particular time. Thus, three tote boxes (growth chambers) were arranged horizontally (end to end) on a table. The total length of the three arranged boxes was taken. A length of 0.5 m was added to that of the three growth chambers to compensate for the inlet and endlines of the laterals. The total length of the three tote boxes was determined to be 1.5 m (with a length of 0.5 m for each). Compensating with the adjusted 0.5 m length gave a total lateral length of 2.0 m. The lateral flow rate was determined using the formula given by Phocaides (2000).

Lateral flow rate (LFR) =emitters per lateral × emitter flow rate…… Equation 3- 1

$$LFR = 3 \times 30 \text{ l/h}$$

$$= 90 \text{ l/h}$$

3.2.1.3 Determination of the size of the pipelines

The selection of pipe sizes was based on the equation by Phocaides (2000).

$q = kd\ H^{*}$……. Equation 3- 2

Where;

- q = discharge of emitter,
- H = Pressure at the emitter
- k and d are coefficients; and
- * is an exponent characterized by the emitter flow regime and the flow rate curve as a function of pressure.

The friction factor method, characterized by Equation 3-3 was used in sizing the laterals.

$F_f = \frac{Po \times Pv}{Lc}$ …….. ……. Equation 3- 3

Where;

- F_f = Allowable Psi per 100" of pipe (psi/100" = 9.8 kPa/100m)
- P_o = Operating pressure of emitter
- P_v = Allowable percentage pressure variance L_c = Longest run of lateral line (critical length)

Friction pressure loss was computed using Equation 3-4.

$H_f = [0.2083]\left(\frac{100}{C}\right)^{1.852}\left(\frac{Q^{1.852}}{d^{4.866}}\right) \times 0.433$ …….. Equation 3- 4

Where,

- H_f = Friction loss per 100'

- C = Coefficient of retardation based on pipe material
- Q = Flow discharge
- d = Inside diameter of pipe

Alternatively, the lateral friction loss was calculated using an irrigation calculation online based on Equation 3-3 and 3-4. For a 16 mm PVC pipe with 3 misters having a flow rate of 30 l/h (spaced 1 m apart), the frictional loss was estimated to be negligible by the calculator. Hence the 16 mm PVC pipe was chosen to be the ideal pipe size for the laterals.

According to Phocaides (2000), the main pipeline is carefully chosen in sizes such that the frictional losses do not surpass approximately 15 % of the total dynamic head needed at the beginning of the systems piped network. Phocaides (2000) further stated that the flow velocity in the main pipeline should be kept under 1.7 m/s in plastic tubes and 2 m/s in other pipes (steel, aluminium, etc). Since the main pipeline supplies directly to the laterals without branching, a 25 mm PVC pipe was chosen based on Equation 3-5.

$$V = Q/A \quad \text{…… Equation 3- 5}$$

Where,

- V = Flow velocity
- Q = Discharge
- A = Pipe cross-sectional area

3.2.1.4 Head Control

The component parts of the system are complete with pump, filters, non-return valve, union joints and shut off valve. The total pressure head required for the system was designed based on Phocaides (2000) sum of the following pressures:

i. Emitter pressure, ii. Frictional loss in lateral line, iii. Frictional loss in the valves and pipe fittings, iv. Differences in elevation, and

v. Loss of pressure in head control.

The brake horse power was determined using Equation 3-6 by Phocaides (2000):

$$BHP = Q \times TDH \div 270 \times e_1 \times e_2 \quad \text{.....Equation 3-6}$$

Where,

- Q = flow capacity in m^3/h,
- e_1 = Pump Efficiency,
- e_2 = Driving Efficiency,
- TDH = Total Dynamic Head, and
- 270 = constant for metric units gives pump efficiency to range between 0.5 – 0.8

Thus BHP = 90 l/h $\times \frac{3}{270} \times 0.7 \times 0.7$

=0.49 hp

Consequently, a pump with a horse power of 0.5 was chosen. Since the 0.5 hp pump came with inlet and exit valves of 25 mm, 25 mm pipes and fittings were used in the design and fabrication.

3.2.1.5 Design and Selection of Growth Chamber

The agronomic evaluation of this research sought to evaluate the growth and yield performance of three yam varieties propagated by the two systems. It therefore became imperative to design a

system that can house each variety in a single unit whilst at the same time give room for connecting in series to the next unit.

Plastic tote boxes of 0.5 m x 0.4 m x 0.3 m in dimension and made locally in Ghana by Century Plastic Products Limited were chosen for the following reasons:

i. Made of plastic material that can withstand rot and infestation from constant contact with water and nutrients and ii. Its ability to be worked on (cutting and spraying).

Once the pipe sizes to be used in the fertigation system were known, holes were punched through the sides (centrally) to pave way for the insertion of the pipes through the tote boxes. Same was done beneath the tote boxes to allow for drainage.

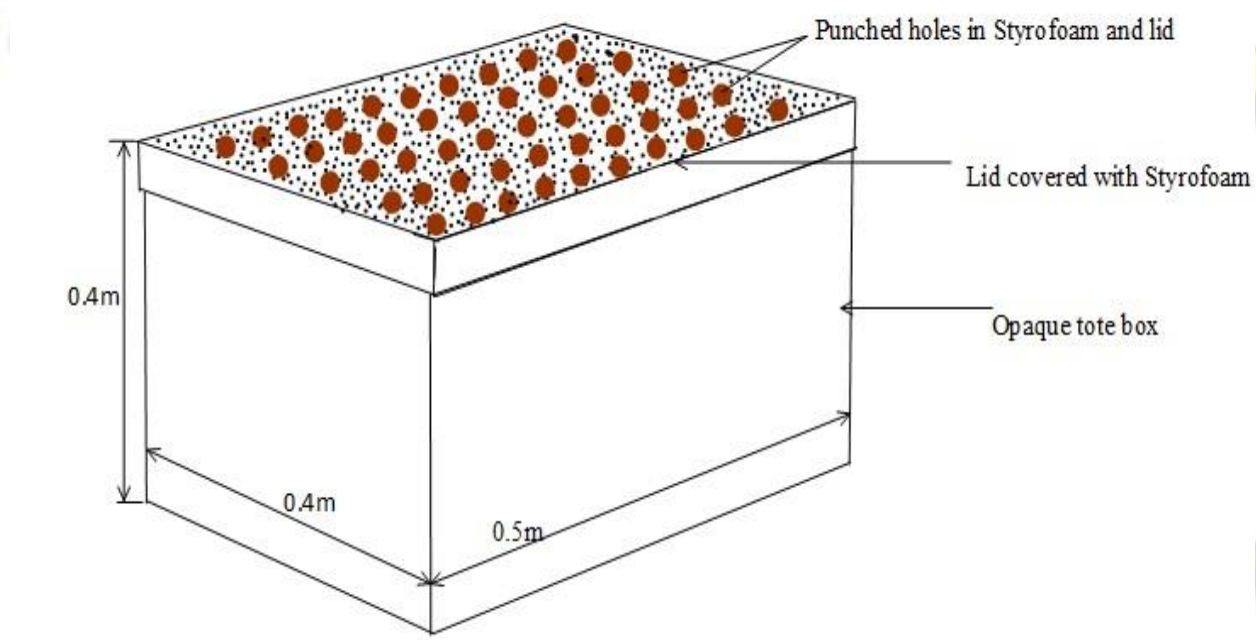


Plate 3- 3 Design specifications of the growth chamber and plant holding tray

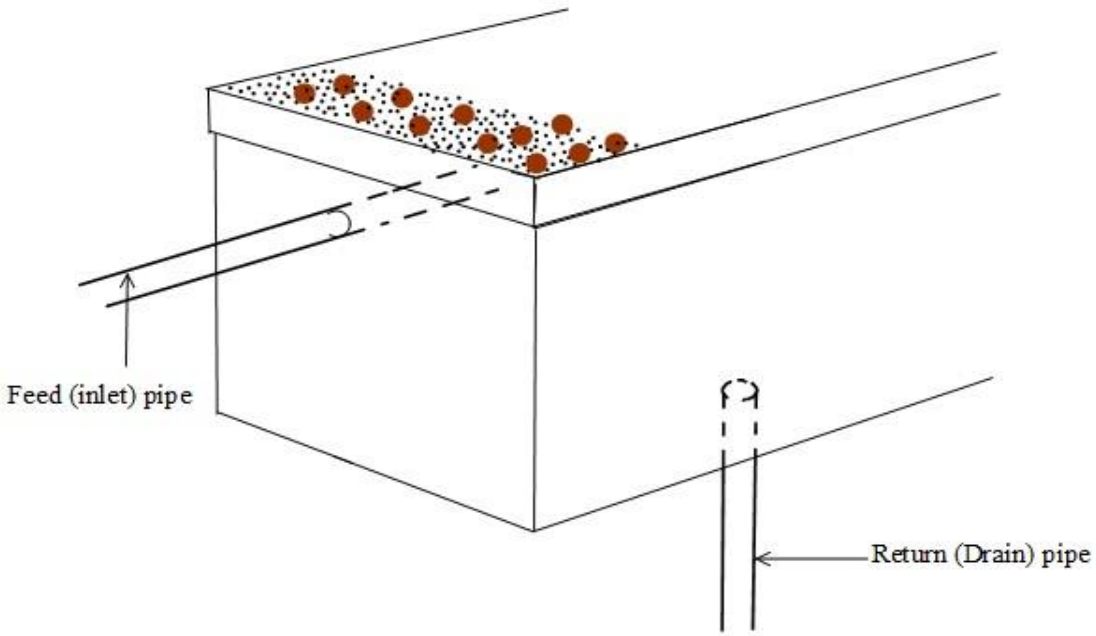


Plate 3- 4 Feed and return pipes of the growth chamber

3.2.1.6 Design and Selection of Feed Tank

Based on the design flow rate of 30 l/h, a 150 m^3 feed tank was selected to hold the nutrients and water.

3.2.2 Systems Design of the Power-Independent Aeroponic system

This is a gravity-fed aeroponic system (GFAS) that does not depend on electricity or any other source of electrical power for its operation. The nutrients are fed to the plants by gravity through pipes with drip emitters. The feed tank was elevated at 2.5 m, a height conducive for gravity flow. A flag emitter was inserted into the laterals at a spacing of 6 cm for nutrient delivery to the base of the plant and subsequent flow to the roots.

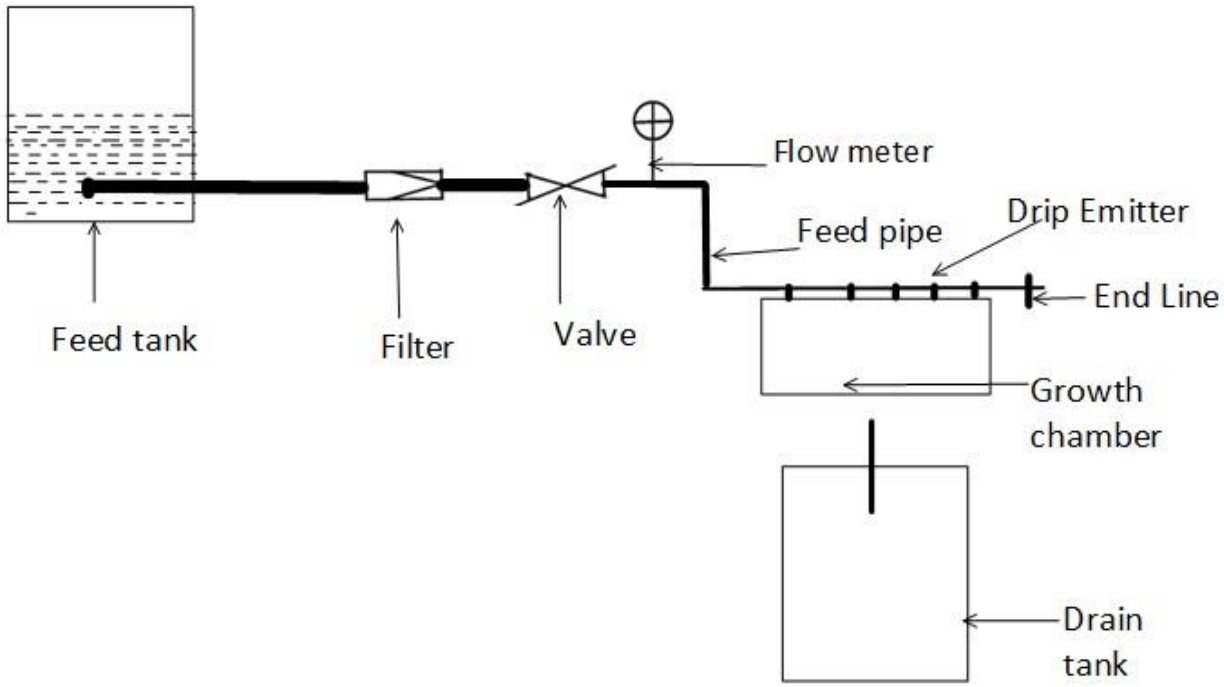


Plate 3- 5 Schematic representation of the gravity-fed system

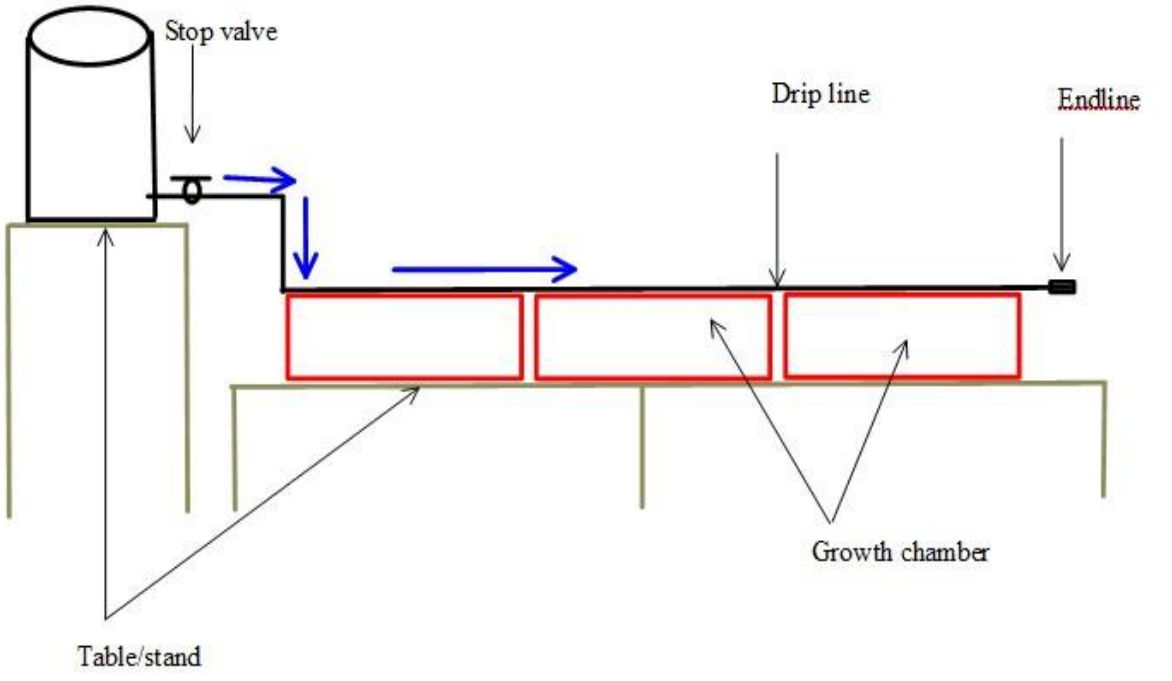


Plate 3- 6 System Flow Chart for one gravity-fed aeroponic unit

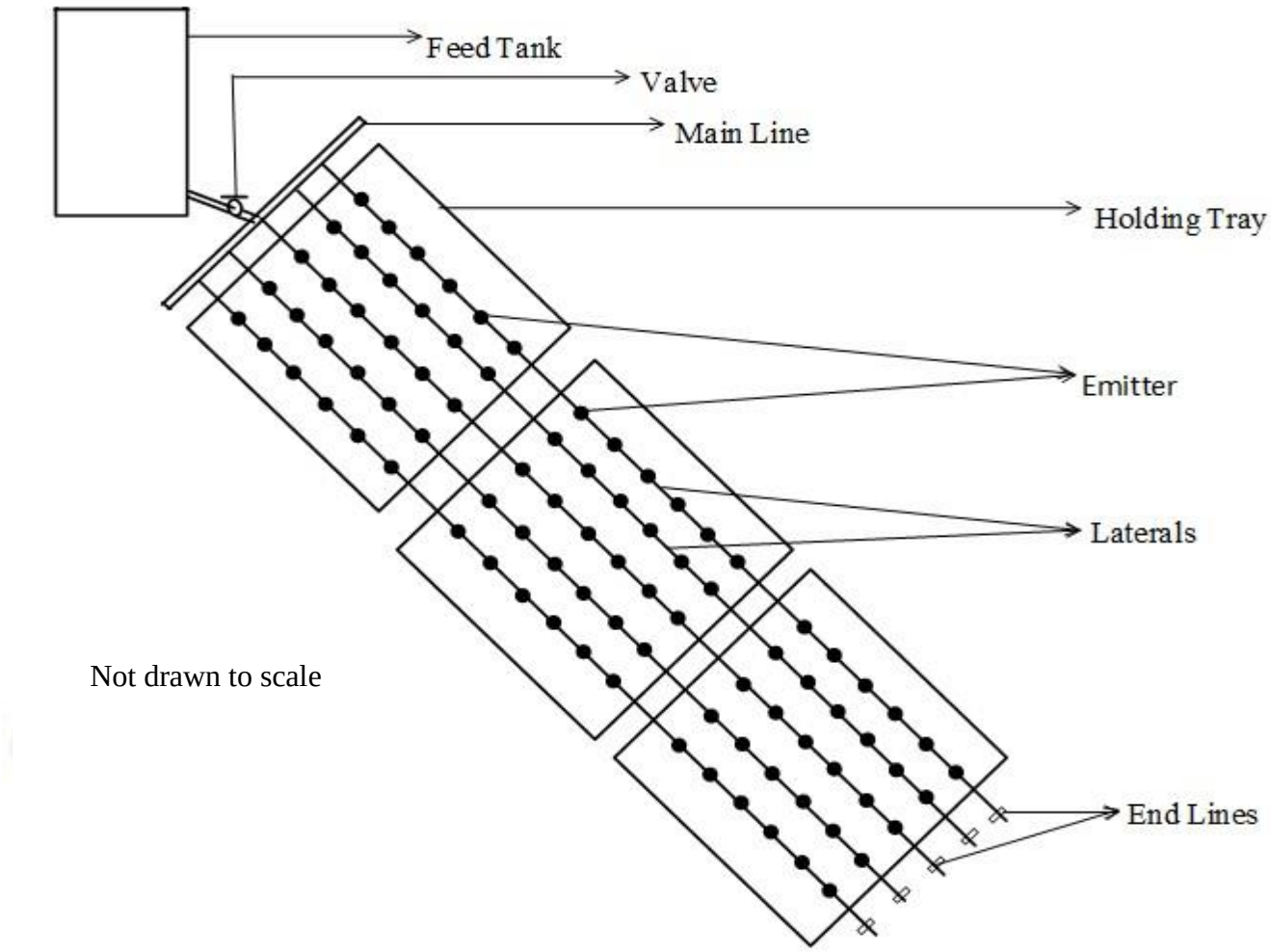


Plate 3- 7 Schematic representation showing laterals and emitters

3.2.2.1 Selection of emitter

Choosing emitters for aeroponics is more complicated than choosing it for soil applications. Gravity-fed aeroponic system relies on emitters to distribute water and nutrients around the roots of the plants. A flag emitter with a manufacturer's discharge of 2 l/h was chosen for use due to its ability to be inserted directly or close to the root zone of the plant. Pieces of styrofoam were laid on top of the plant holding tray to absorb and distribute excess moisture from the emitters.

3.3 System Components Description and Installation of the Aeroponic Systems

Each of the two system designs has components that makes it unique and different in its operation. These components are described as follows for the two systems.

3.3.1 Component Description of the Pressurized Aeroponic System

This describes the materials used for the construction of the various components. Each component is described separately and dimensioned in S.I. Metric Units.

3.3.1.1 Growth/misting chamber

The growing chamber consists of a rigid tote box of 0.5 m x 0.4 m x 0.3 m painted black on the outside to avoid the penetration of light into the chamber. Avoiding light into the chamber prevents the growth of algae in the root zone. The box was constructed to stand on rectangular wooden tables; 2 m x 0.8 m x 0.8 m high (Plates 3-8 and 3-9)

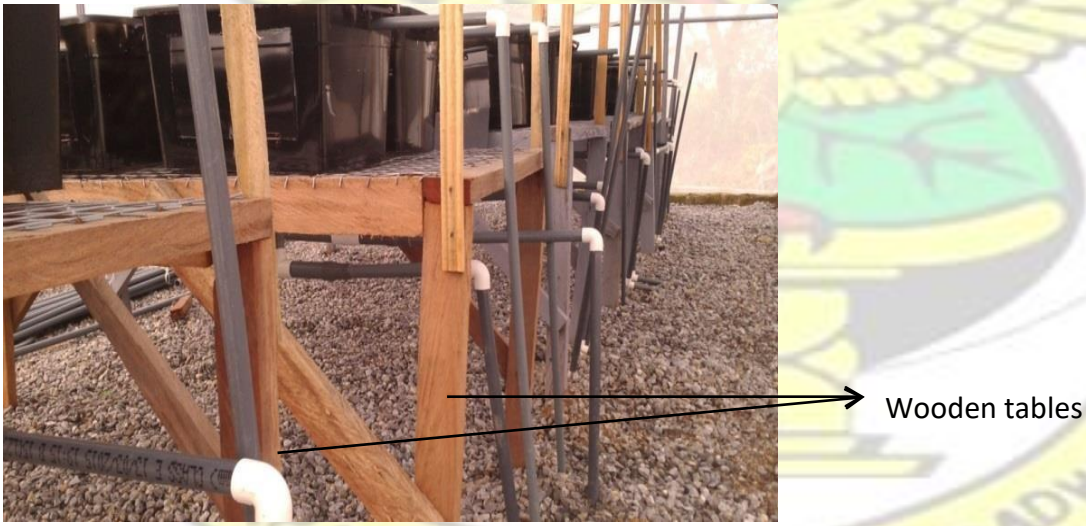


Plate 3- 8 Setup showing growth chamber and stands (tables)

A window opening was cut on the side of the box and fixed with hinges to allow for easy access to the root chamber without opening the lid. An outlet PVC pipe (25 mm) was connected at the central bottom of the growth chamber to drain excess nutrient solution for onward collection of the excess solution back into the feed tank for recycling (Plates 3-8 and 3-9).

Fe[illegible]e 15 mm

Plate 3- 9 Setup showing feed and drain pipes

3.3.1.2 Seedling holder

The seedling holder consisted of the tray lid of the tote box fitted with silicone to prevent air entry into the growth chamber. Circular openings 8 cm between columns and 6 cm between rows were punched on the lid (resulting in 30 holes per lid) with a 16 mm copper pipe resulting in a hole of 16 mm diameter as shown in Plate 3-10. These spaces were fitted with 16 mm PVC pipes 10 cm in length. Inside these pipes were fitted styrofoam to hold the vine cuttings.

Plate 3- 10 Growth box with lid showing punched holes

3.3.1.3 The pipe network

There were two types of pipe connections in the system: the inlet or feed pipes and the outlet or drain pipes. The inlet/feed pipe (as shown in Plate 3-11) comprised a 16 mm PVC pipe linking the pumps to the growth chambers via bends and risers. A 16 mm pipe cut to a length of 2 m was fitted through to the three tote boxes. Inside each tote box, a mister was fitted on this pipe to fertigate the chamber. One end of the pipe was fitted with an end cap whilst the other end was joined by a bend to a 1.2 m high riser which was in turn connected to a 16 mm bend to link the connection from the feed tank.

Plate 3- 11 Setup showing inlet/feed pipes through tote box

The outlet or drain pipes were made up of 20 mm and 25 mm diameter PVC pipes. The main outlet from the tote box was made up of a 25 mm pipe which was later reduced to 20 mm before finally connecting it to the feed tank. Beneath the last tote box in a series connection, a pipe length of 20 cm was connected by 25 mm equal bend. This linked up with a 25 mm pipe joined by an equal tee draining the next tote and subsequently to the next tote until the final drain linking the feed tank as shown in Plate 3-12.

Plate 3- 12 Setup showing drains with equal tee couplers

3.3.1.4 Misting system

The misting system comprised of the feed tanks, feed and drain pipes and the mister. Water pumped from the feed tank was conducted to the misters for root misting through the feed pipes. The feed pipes were 16 mm in diameter. An inflow PVC (16 mm) pipe was positioned 10 cm below the seedling holder through the sides of the tote box and equipped with 360º pattern misters centered from each side of the growing chamber. The misters used were a two part emitter comprising a black base with 4 mm thread and snap-on black cap (Plate 3-13). The mister dispersed water particles and discharges them via a high velocity vortex action. A drain duct was punched (centered) on the bottom of the tote box to drain and clean the system.

Plate 3- 13 Feed Pipes showing misters

3.3.1.5 Electrical and pumping system

The electrical system consisted of an incoming power (240 V power cable) connected to wiring connection which led to solenoid switch that controlled an electric pump and irrigation timers. The power rating of the pumps used was 0.37 kW at 0.5 hp. It took a full load current of 2.6 A at a rated voltage of 220 V. Its maximum head was 38 m with a maximum discharge of 42 l/min. A 25 mm PVC suction pipe was coupled from the feed tank through a 25 mm valve socket to a 25 mm delivery pipe outside the feed tank. A riser (Plate 3-14) made up of 25 mm PVC pipe cut to a length of 1m, was connected by 25 mm equal bend from the delivery pipe outside the feed tank to a 25 mm valve socket fitted to the inlet valve of the pump. The outlet valve of the pump was fitted with a 25 mm valve socket connected to a 25 mm PVC pipe 20 cm in length. The PVC pipe was further connected to a union joint. From the union joint was connected another 20 cm length of a 25 mm PVC. A 25 mm ball valve was fitted to this pipe to prevent undesired gravity flow into the pump

and its pipe network. The ball valve was opened to allow forward flow out of the pump. It was closed to also prevent reverse flow into the pump. From this connection, the pipe was then reduced with a 25 mm x 16 mm reducer that connects the 16 mm feed pipes linking the growth chamber.

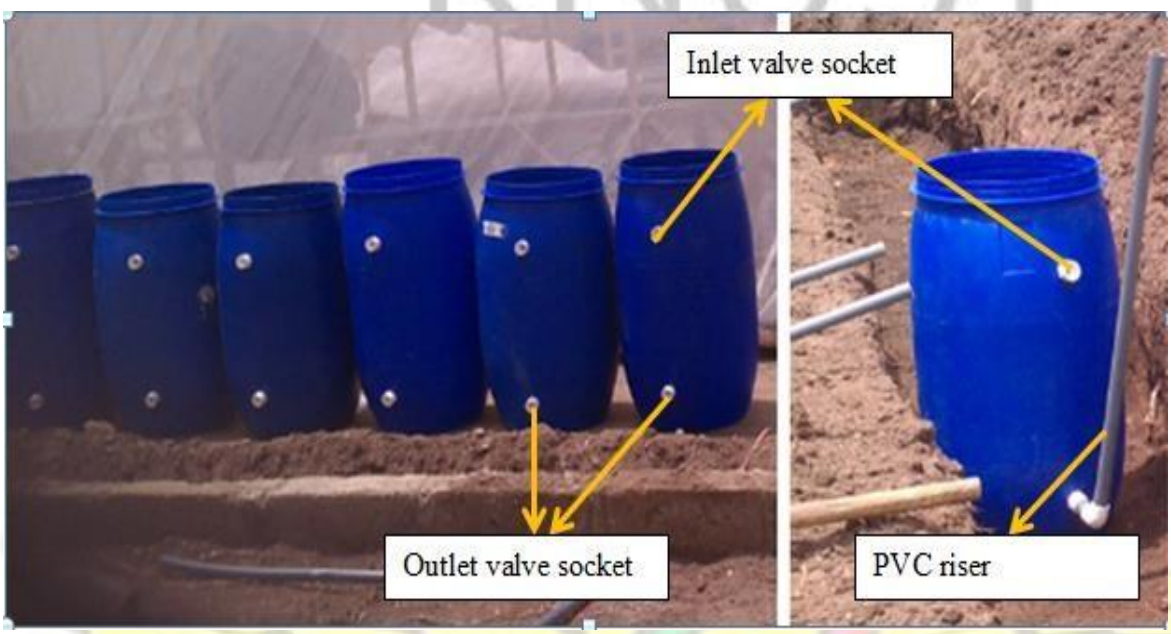


Plate 3- 14 Feed tank showing inlet, outlet and riser

3.3.1.6 Irrigation Timers

Fertigation of plants in this system was automated with the help of irrigation timers. The timers used were the Anly brand, AH3-3. It had an operating voltage of 220 V, rated frequency 50/60 Hz and reset time of 30 minutes. It worked at an ambient temperature of -10~+50 ºC and an ambient humidity of 85 % as shown in Table 3-1.

Table 3- 1 Specifications of the irrigation timers

Parameter	Specification
Operating voltage	AC 220 V
Allowable operating voltage range	85~110 % of rated operating voltage

Rated frequency	50/60 Hz
Contact rating	250 V AC 5 A (resistive load)
Reset Time	Max 30 min
Power consumption	
Life	Mechanical: 5,000,000 times Electrical: 100,000 times
Ambient Temperature	-10~+ 50 ºC
Ambient humidity	Max 85 % RH
Weight	Approx. 88 g

3.3.2 Component Description of the Gravity-Fed Aeroponic system

3.3.2.1 Growing chamber and seedling holder

The growing chamber for the gravity-fed system was same as described above for the pressurised system with the exception been the absence of pumps and misters in the growing chamber. The plants were fed by drip emitters connected to the laterals. Each plant was supported by a styrofoam in a small 16 mm PVC cut 10 cm in length and inserted into the punched holes of the growth tray/lid.

3.3.2.2 Feed tank

The feed tank was made up of 25 l plastic bucket with lid. The base of each bucket was punched with a 25 mm copper pipe. Inside this punched hole was inserted a 25 mm valve socket connected to a 25 mm PVC pipe connected through valves to supply the nutrient solution.

3.3.2.3 Pipe network

The inlet pipe of the gravity-fed system was made up of 16 mm PVC pipes connected to the feed tank through a 16 mm valve socket. A 16 mm valve was installed on this line to be closed and opened when needed. On the 16 mm PVC pipe, which was 40 cm in length were punched holes 2 mm in diameter and 8 cm apart. The holes were fitted with a 2 mm PE drip pipes laid on top of the seedling holder to a length of 2 m. The ends of these pipe lines were folded over and tied securely with a binding wire to prevent any leakage.

Plate 3- 15 Drip-fed system showing drip lines

The drainage system here was almost the same as described for the pressurised system. However, this system was not closed-looped; thus the drained nutrient solution was collected into a 15 l plastic bucket dubbed the drain tank. Nutrient solution collected in this tank is manually poured back into the feed tank to be recycled.

3.4 Technical Evaluation of the Aeroponic Systems

The technical evaluation of the aeroponic systems was done based on the performance indicators for a sprinkler and drip irrigation system.

3.4.1 Materials and Methods

3.4.1.1 Measuring mister discharge of the PAS

A three metre length of water hose was coupled to the nozzle of a mister and whilst the pump and mister were operating, the water was directed into a bucket over a 10 minute period. The volume collected into the bucket was measured with a measuring cylinder and recorded. This was repeated three times. The mean volume was found by dividing the sum of all the volumes taken by three. Discharge was calculated by dividing the mean volume by the time taken to accumulate the recorded volume. This procedure was repeated for the remaining misters to determine the individual discharges.

3.4.1.2 Measuring mister operating pressure and swath radius of the PAS

The mister operating pressure was taken using a pitot tube connected to a pressure gauge. Each mister was allowed to operate without being restricted by the growth chamber to determine the swath radius. The swath radius was calculated as the distance from the centre of the mister to the end of the wetted perimeter.

3.4.1.3 Measuring pump operating pressure of the PAS

The pump operating pressure was measured using a pressure gauge connected to the discharge end of the pump. This was done for all the pumps and an average was taken.

3.4.1.4 Determining uniformity of application and system efficiency of the PAS

Uniformity of application and irrigation efficiency are two performance measures used to evaluate an irrigation system. These can be inferred from the mean application rate (MAR) and distribution uniformity (DU). The mean application rate (MAR) is defined as the average rate (mm/h) that water is applied to the wetted area of the soil. Distribution uniformity is a ratio of the smallest accumulated depths in the distribution to the average depths of the whole distribution (Ascough and Kiker, 2002).

From the procedure used to determine the mister discharge, 25% of the catch cans with the lowest volumetric output was selected to form the lower quartile. The irrigation depth was determined by measuring the water in each catch can with a gauge calibrated in mm. The mean depth was determined by dividing the total of lower quartile catch depth by the number of catch cans forming the lower quartile. The uniformity of application was determined using Equation 37 by Merriam and Keller (1978).

$$DU = 100\% \frac{\text{Average lower quartile depth of application}}{\text{overall average depth of application}} \quad \text{.....Equation 3-7}$$

Where DU is distribution uniformity

3.4.1.5 Determining flow rate of the GFAS

To determine the discharge of emitters of the gravity-fed aeroponic system, catch cans were placed beneath each flag position along the 2 m drip lines resulting in 90 catch cans for each distributing tank. The valve was opened and irrigation water was collected into the catch cans for an hour. Water collected from each can was poured into a calibrated measuring cylinder to get the volume of water in litres. The flow rate was calculated using Equation 3.8.

$$Flow\ rate,\ Q = \frac{V\ (l)}{T\ (h)}$$ ……..Equation 3.8

Where,

V = volume of water collected (l) and

T = time used in collecting the said volume in hours.

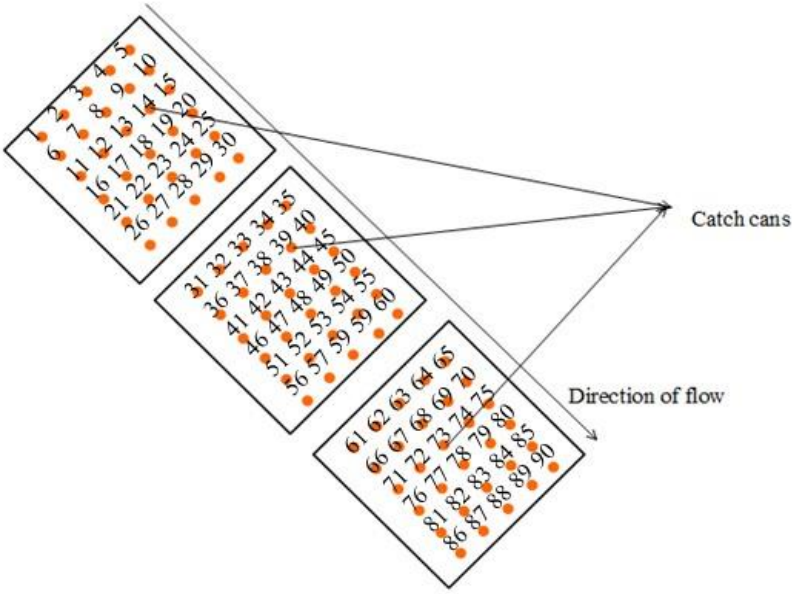


Plate 3- 16 Grid view illustrating position of catch cans

3.4.1.6 Determining the distribution uniformity/coefficient of variation of the GFAS

The uniformity coefficient was determined using the formula for the Christiansen's uniformity coefficient (CU) in Equation 3-9 by Christiansen (1942).

$$CU = 100\% \left[1 - \sum_{k=0}^{n} \left(\frac{x}{mn}\right)\right]$$ ……Equation 3-9

Where,

- Σx = the sum of the absolute deviations from the mean (mm or ml) of all the observations
- m = mean application depth measured (mm or ml) and
- n = number of observations (catch cans)

3.4.2. Analysis of Data from Technical Evaluation

Data collected from the technical evaluation were subjected to statistical analysis using Genstats version 9.2. Mean separation was done using the Fisher's unprotected LSD. The effects were judged for level of significance at $p<0.05$.

3.4.3 Results and Discussion from Technical Evaluation of the Aeroponic systems

The results from the technical evaluation of the two aeroponic systems are discussed in this subsection. Technical evaluations of aeroponic systems were conducted just in the same way as with irrigation systems. Thus, the results of the technical evaluation of the aeroponic system were discussed following results from evaluations from other irrigation systems.

3.4.3.1 Mister discharge of the PAS

The results from measuring the mister discharge are as shown in Figure 3-1. There were no significant differences between any of the mister discharges or swath radius. The results, however showed a positive linear correlation between mister discharge and swath radius.

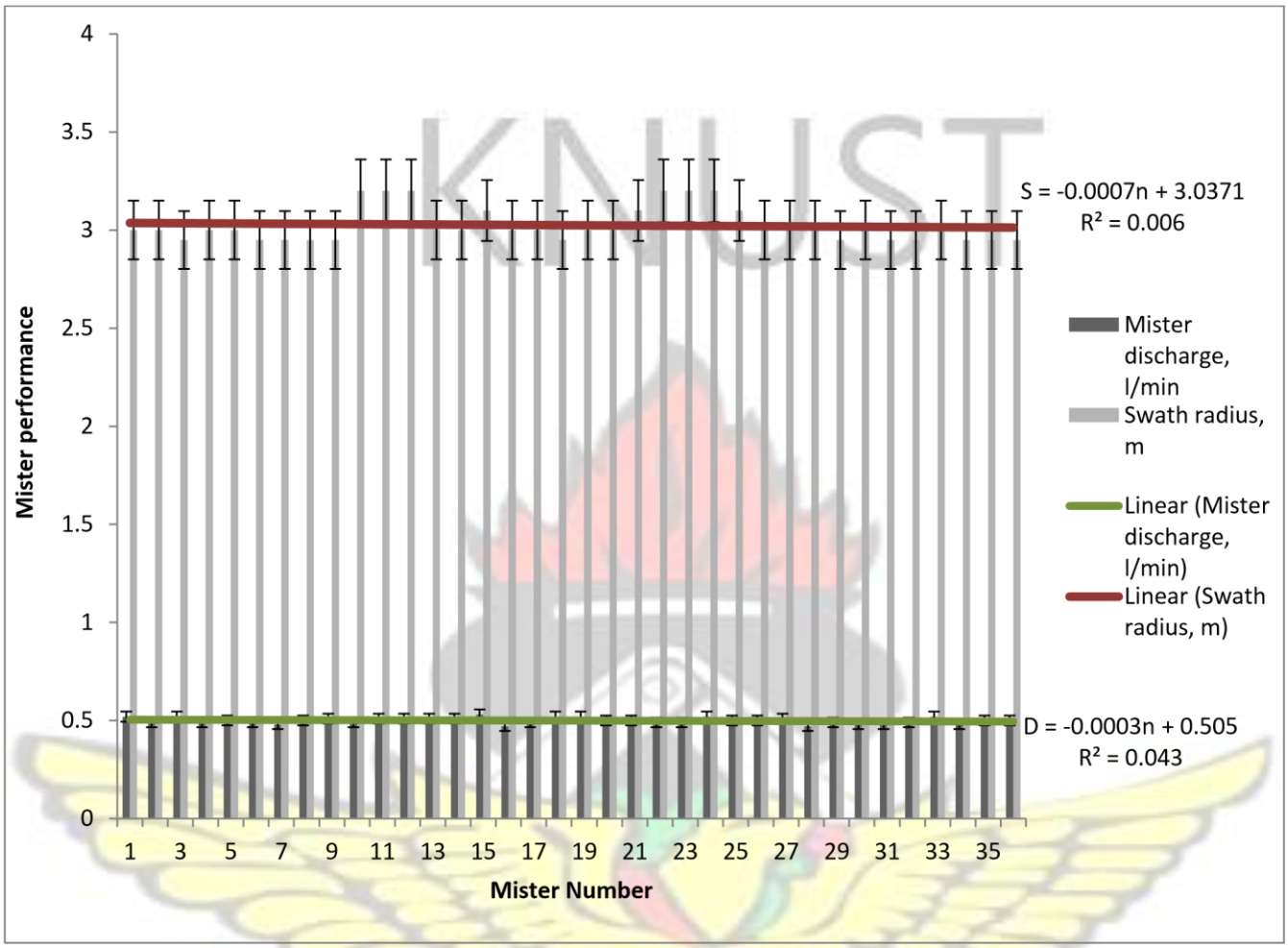


Figure 3- 1 Mister performance showing mister discharge and swath radius

3.4.3.2 Mister operating pressure and swath diameter

The manufacturer's operating pressure for the mister was 50 kPa whereas the mean operating pressure of the misters was 59.64 kPa. The misters were performing 19.28 % higher than the manufacturer's operating pressure. This can be attributed to the fact that the experimental design used demanded only three misters per pump whereas the pump operating pressure could have powered twice this number. Swath diameter is also a measure to determine the uniformity and reach of water application in a pressurised system. There was a linear relationship between mister

operating pressure and the swath diameter (Figure 3-2) suggesting a positive correlation between the two.

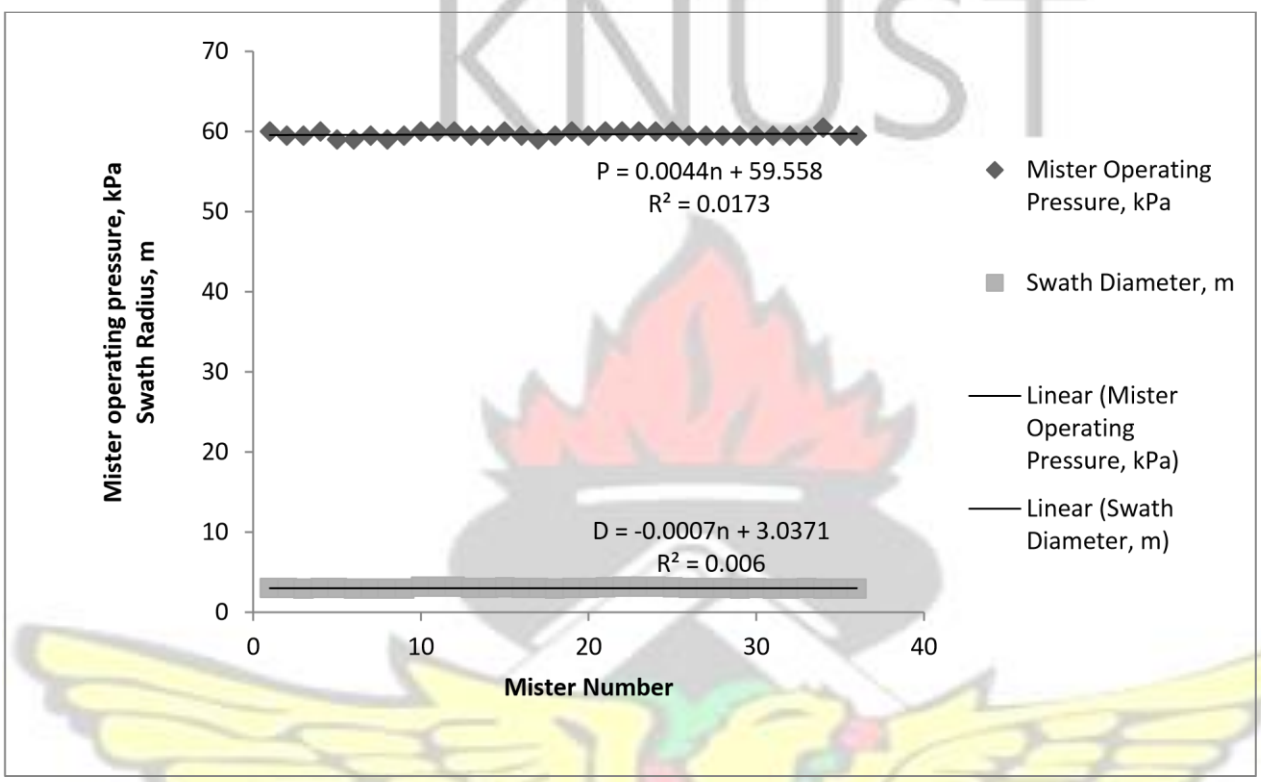


Figure 3- 2 Relationship between mister operating pressure and swath diameter

Data collected from misters were further subjected to an analysis of variance to determine if significant difference existed in the interactions between operating pressure and swath diameter. Table 3-2 showed that no significant differences existed in the interaction between mister operating pressure and swath diameter (MIPR.SWDR). Since swath diameter shows the distribution and extent water and nutrients application in the growth chamber, significant differences between these interactions is suggestive that distribution in the box varies and thus not uniform. This could subject areas within the growth chamber to different treatments and thus introduce a higher coefficient of variation within the chamber. Thus this result showing no significant differences indicates efficient and effective distribution of nutrients within the set up.

Table 3- 2 Anova for interaction between operating pressure and swath diameter.

Source	d.f	s.s	m.s	v.r	F.pr
MIPR ignoring SWDR	3	7.28	2.43	3.36	0.03*
MIPR eliminating SWDR	3	1.5251	0.50	0.70	0.56
SWDR ignoring MIPR	3	24.43	8.144	11.27	<0.001**
SWDR eliminating MIPR	3	18.79	6.22	8.61	<0.001**
MIPR.SWDR	1	0.25	0.24	0.34	0.563
Residual	26	18.79	0.72		
Total	35	45	1.29		

MIPR = Mister operating pressure

SWDR = Swath diameter

** Significant at p<0.01 * Significant at p<0.05

3.4.3.3 Uniformity of application of the PAS

Using Christensen's coefficient of uniformity (CU), and the Distribution Uniformity, the uniformity of application for the power-independent system was determined to be 97.52 % and 96.16 % respectively. The CU attained falls within the acceptable range for both high value crops CU > 84 % and for general field and forage crops: CU > 75 % (Michael, 1999; Keller and Bliesner, 1990). The high distribution uniformity documented could be attributed to the suitable selection of the types of misters, mister spacing and efficient operating pressures of the pumps and misters. These high values could also be attributed to the fact that there were minimal frictional and leakage losses in the system set up, resulting in a very low pressure differential in the system between the main and laterals. The pressure differential in the system was at a minimum, thus maintaining pressure uniformity along the flow system.

3.4.3.4 Flow rate of perforated pipes/emitters

Emitter flow rates ranged from 0.10 – 0.12 l/h (Figure 3-3). The low level of variation in the system could be attributed to the pressure compensating effect given to the system. This was done by tilting the tables, holding the growth chambers and the drippers at a 0.1 % slope away from the fertigation tanks. The emitter flow rates were thus compensated in pressure by the slope hence the uniformity or minimum variation in its values. This method is usually employed on drip irrigated fields to compensate for pressure differences of the fields (Julius *et al.*, n.d ; Smeal, 2007; Wu *et al*., 2010). Employing this method also resulted in an opposing slope in the drainage pipes. Hence, the drainage pipes were also sloped at 0.1 % for easy flow of fertigation water back to the collecting/drain tank.

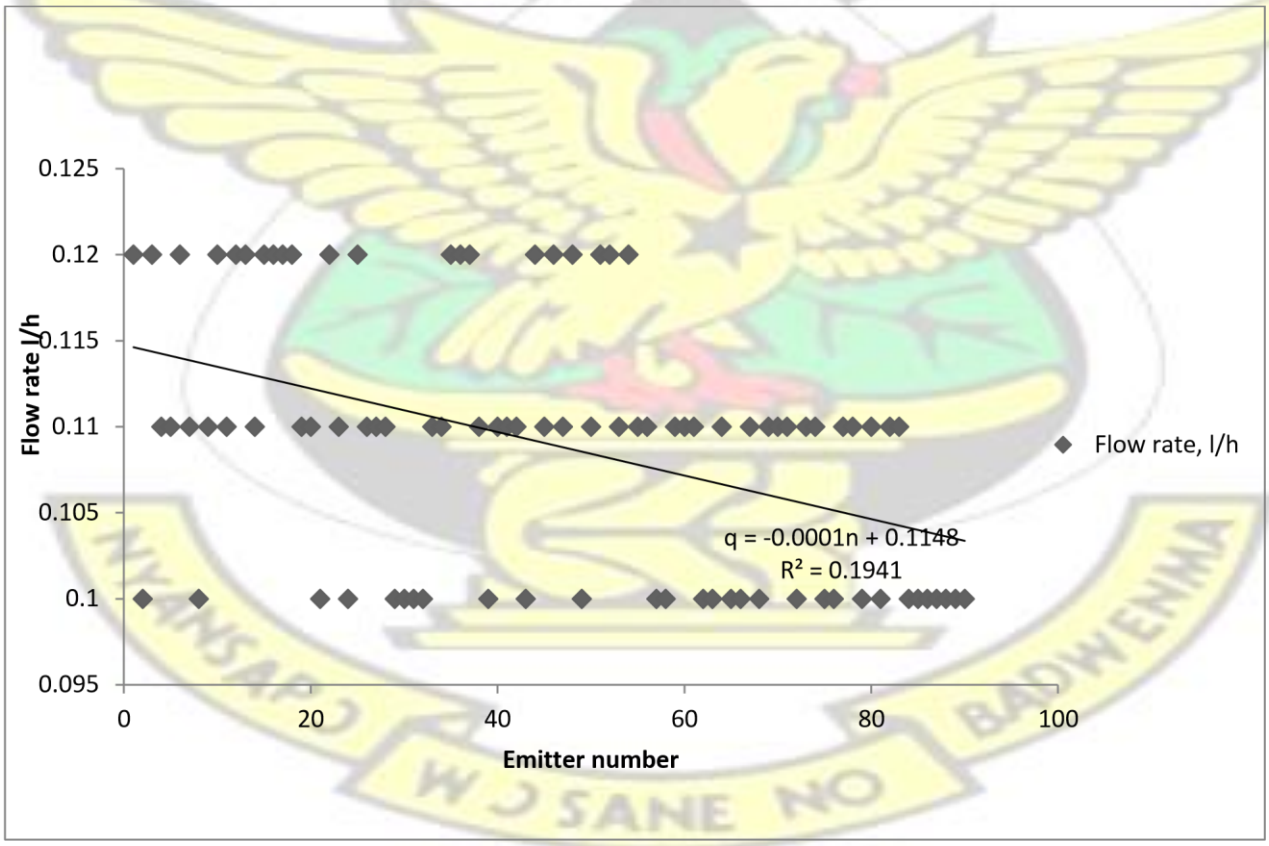


Figure 3- 3 Emitter flow rate of the gravity-fed system

3.4.3.5 Distribution uniformity

Gravity-fed systems are known for their inherent lower water pressures. This if not well monitored can create variations in the emitter operation and water distribution. The method employed in ensuring a uniform flow rate also invariably affected the distribution uniformity of the system. A Du and CU of 90.80 % and 94.49 % respectively were attained from the evaluation of the gravity-fed system. For micro sprinkler and drip systems, DU's of 90 % are usually said to be ideal (Burt *et al*., 2000).

Table 3- 3 Parameters for calculating CU and DU

Emitter Number	Flow rate, l/h	Absolute Deviation	Emitter Number	Flow Rate l/h	Absolute Deviation	Emitter Number	Flow rate, l/h	Absolute Deviation
1	0.12	0.011	31	0.10	0.009	61	0.11	0.001
2	0.10	0.009	32	0.10	0.009	62	0.10	0.009
3	0.12	0.011	33	0.11	0.001	63	0.10	0.009
4	0.11	0.001	34	0.11	0.001	64	0.11	0.001
5	0.11	0.001	35	0.12	0.011	65	0.10	0.009
6	0.12	0.011	36	0.12	0.011	66	0.10	0.009
7	0.11	0.001	37	0.12	0.011	67	0.11	0.001
8	0.10	0.009	38	0.11	0.001	68	0.10	0.009
9	0.11	0.001	39	0.10	0.009	69	0.11	0.001
10	0.12	0.011	40	0.11	0.001	70	0.11	0.001
11	0.11	0.001	41	0.11	0.001	71	0.11	0.001
12	0.12	0.011	42	0.11	0.001	72	0.10	0.009
13	0.12	0.011	43	0.10	0.009	73	0.11	0.001
14	0.11	0.001	44	0.12	0.011	74	0.11	0.001
15	0.12	0.011	45	0.11	0.001	75	0.10	0.009

16	0.12	0.011	46	0.12	0.011	76	0.10	0.009
17	0.12	0.011	47	0.11	0.001	77	0.11	0.001
18	0.12	0.011	48	0.12	0.011	78	0.11	0.001
19	0.11	0.001	49	0.10	0.009	79	0.10	0.009
20	0.11	0.001	50	0.11	0.001	80	0.11	0.001
21	0.10	0.009	51	0.12	0.011	81	0.10	0.009
22	0.12	0.011	52	0.12	0.011	82	0.11	0.001
23	0.11	0.001	53	0.11	0.001	83	0.11	0.001
24	0.10	0.009	54	0.12	0.011	84	0.10	0.009
25	0.12	0.011	55	0.11	0.001	85	0.10	0.009
26	0.11	0.001	56	0.11	0.001	86	0.10	0.009
27	0.11	0.001	57	0.10	0.009	87	0.10	0.009
28	0.11	0.001	58	0.10	0.009	88	0.10	0.009
29	0.10	0.009	59	0.11	0.001	89	0.10	0.009
30	0.10	0.009	60	0.11	0.001	90	0.10	0.009

CHAPTER FOUR

MATERIALS AND METHODS

4.1 General Introduction

This chapter relates the materials and methods used in the various agronomic evaluations and the economic analysis of the two aeroponic systems. This chapter thus describes the materials and methods used in these evaluations.

4.2 Agronomic Evaluation of the Aeroponic systems

The significance of this agronomic evaluation was to determine the functionality of the two aeroponic systems to be used as a propagation medium for yam mini-tuber production.

4.2.1 Determination of Nutrient Concentration Levels and Preparation of Nutrient Solution

An experiment was set up to determine the ideal nutrient concentration for propagating the minituber whilst simultaneously evaluating the two aeroponic systems (power-dependent and powerindependent). The experiment was conducted in a screenhouse (having a floor dimension of 10 m x 9 m) at the CSIR-Crops Research Institute, Fumesua, in the Ejisu-Juaben Municipal Assembly.

Nutrient concentrations used in the evaluation was derived based on formulations used by Correa *et al*., (2005) and Factor *et al*., (2007) for producing sweet potato mini-tubers. Most of the highest concentrations of the macro and micro-elements used by these two authors were each selected and adjusted at two levels, plus/minus 50 % as shown in Table 4-1. The micro nutrients were derived through a numerical adjustment.

Table 4- 1 Derived nutrient concentrations for the various formulations

Nutrient formulation	**Macro and micro elements (mg/l)**												
	NO_3^{2-}	**NH^{4+}**	**P**	**K**	**Ca**	**Mg**	**S**	**Fe**	**Cu**	**Mo**	**Mn**	**Zn**	**B**
C1	80	13	21	147.5	81	20	32	1	0.12	0.025	0.64	0.3	0.8
C2	160	26	42	295	162	40	64	2	0.24	0.05	1.28	0.6	0.8
C3	240	39	63	442.5	243	60	96	3	0.45	0.075	1.92	0.9	0.8

Nutrient concentration four (C4) used tap water with no added nutrients for fertigation. This also served as the control in the experiment.

The nitrogen percentage on the various packs of nutrient fertilizer was taken as the actual nitrogen (Argo, 2003). To calculate the actual percentage of phosphorus and potassium from the P_2O_5 and K_2O in the fertilizer, the listed values of each component written on the pack was multiplied by

0.43 and 0.83 for potassium and phosphorus respectively as described by Argo (2003). All the minor nutrients in the fertilizer used were in their Ethylene Diamine Tetra-Acetic acid (EDTA) chelated form and were used without amendments. Argo (2003) describes chelates as organic molecules that envelope the ion and protect it from interacting with other ions in the solution that may make it unavailable to the plant. To ascertain the various nutrient concentrations, samples were taken from each feed tank for a thorough physico-chemical analysis at the CSIR-Water Research Institute.

4.2.2 Generation of Explants for Vine Cuttings

Explants to be used for the vine cuttings were generated in a screen house at the CSIR-Crops Research Institute. The planting materials used were three varieties of yam, namely *Pona*, *Dente* and *Mankrong Pona*. *Dente* was sourced from a farmer at *Ejura*, *Pona* from a farmer at *Kintampo* whereas *Mankrong Pona* was sourced from the CSIR-Crops Research Institute.

The soil media used was sterilized to avoid introducing weeds and pathogens into the screen house and subsequent infection of the plants. Visually healthy seed yams (twenty each) of *Dente*, *Pona* and *Mankrong Pona* that have broken dormancy were selected and treated with water containing fungicide (Mancozeb and Demosan) and insecticides (Karate, actelic). The treated seed yam was air-dried under light shade for 24 hours before planting in individual pots on the 26th of February 2015. Pots were irrigated and labelled after planting.

Plate 4- 1 Potted yam plants in the screen house

Intensive moisture management was done during the first 20 days after planting to avoid total vine rot. Moisture management was done by hand watering with 500 ml of water every three days.

4.2.3 Experimental Design for the Evaluation of Aeroponic Systems

The experimental design used was a split-split plot design with aeroponic units as the main plot, nutrient concentration as the sub-plot and yam varieties as the sub-sub plot. There were two levels of the main plot (the pressurised aeroponic system and the gravity-fed aeroponic system), three levels of the sub-plot (yam varieties: *Dente*, *Mankrong Pona* and *Pona*) and four levels of nutrient concentrations randomized in the sub-sub plot resulting in 18 treatments with three replications.

4.2.4 Propagation and crop nutrient management

Transplanting using vine cuttings was done when the explants reached the active meristematic stage. The first screenhouse planting was done using one node cutting to ascertain rooting and

tuberisation. All cuttings were washed with sterilized water. In planting the one node cuttings, the cutting was inserted into the hole with the node beneath the growth tray whereas the leaves remained above the growth tray. With the two node cutting, one of the nodes was bared of all leaves. The cuttings were inserted into the holes with the leaves left above the holding tray and held in place by low density foam. Cuttings were planted at a spacing of 6 cm x 6 cm on the trays of the aeroponic units.

Fertigation was carried out by misting the nodes and subsequently, roots of the plant during its growing period for the whole period of planting. The same nutrient solution (as per treatment) was used to fertigate the same subplots of the pressurised and gravity-fed systems. A 150 l nutrient tank was buried in the soil at floor level and used to store the nutrient solution for pumping and distribution through the closed system. A 0.5 hp surface pump was used to dispense the nutrient solution through the system using 16 mm PVC pipe. Inside each container (serving as growth chambers), a 16 mm PE irrigation line was placed on which was installed the misters.

The growth chambers of the pressurised aeroponic system had one mister each installed. Fertigation was scheduled for two minutes of irrigation every 20 min throughout the 24 h of daily operation. An irrigation timer (as has been described), for automation of pump activities was used for irrigation scheduling.

Plate 4- 2 Gravity-fed system planted with vine cuttings

Nutrient monitoring was conducted using electrical conductivity and pH meter. Data was collected on parameters such as pH, nutrient solution and screen house temperatures; electrical conductivity and screen house humidity on a daily basis. Corrections were made to the pH and electrical conductivity as and when needed by either adding more nutrients or diluting nutrient solution with pipe-borne water to keep the pH in the range of 5.5–6.5 and the EC between 1.5 and 2.0 dS/m, the ideal values for aeroponic growth.

4.2.5 Harvesting and storage

There were four successive harvests at monthly intervals after the varieties reached harvest maturity. The first mini-tuber harvest for *Pona* and *Mankrong Pona* was done four months after planting (when the first mini-tubers reached at least 6 g) and subsequently 14 days thereafter. The

first mini-tuber harvest for *Dente* was also done 5 months after planting and subsequently 14 days thereafter.

4.2.6 Data collection and analysis

Electrical conductivity and pH readings were taken every other day for each of the nutrient concentrations. Pump performance and flow data were also taken and analysed with Genstats v 9. Agronomic data was collected on the following parameters: root initiation; new leaf initiation; number of roots per plant, number of leaves per plant, plant height and root length at 2 weeks after planting (WAP) and subsequently fortnightly; fresh and dry weight of mini-tubers at harvest; and foliar diseases, nematode and insect scores at 12 WAP and at physiological maturity.

4.2.7 Post-harvest evaluation of mini-tubers

Harvested mini-tubers were put in baskets and labeled for storage in the yam barn at the CSIRCrops Research Institute. The mini-tubers were evaluated to assess their ability to be used in propagating seed yams. Mini-tubers in storage were monitored for dormancy and after dormancy characteristics. Data collected in storage were mini-tuber weight, percentage rot and time to sprouting. Three forms of evaluations were done to assess the agronomic performance of the mini-tubers generated from the aeroponic units using the various nutrient concentrations. The treatments used in this evaluation were: direct planting of non-dormant seeds in the field, direct planting of dormant seeds and pre-germination of non-dormant seeds.

4.3 Agronomic Evaluation of Aeroponically-Generated Mini-Tubers

Three different experiments were done to assess the viability and capability of the resulting minitubers to be used in propagating seed yams. All the three experiments were performed using a split-split plot design with treatments completely randomized in the blocks. The main plots were subjected to mini-tubers produced from the two aeroponic systems. The sub plots were allocated to mini-tubers produced using the various nutrient concentrations. The sub-sub plots were allocated to mini-tubers from the various varieties.

4.3.1 Direct planting of non-dormant seeds in the field

A 20 m x 20 m (400 m^2) plot was demarcated for the experiment. The field was ploughed and harrowed. Three rows of ridges per plot were constructed 40 cm high and spaced 50 cm apart as shown in Plate 4-3. Alleys of 1 m were left in between treatments. There were 24 subplots each 10 m^2 in size.

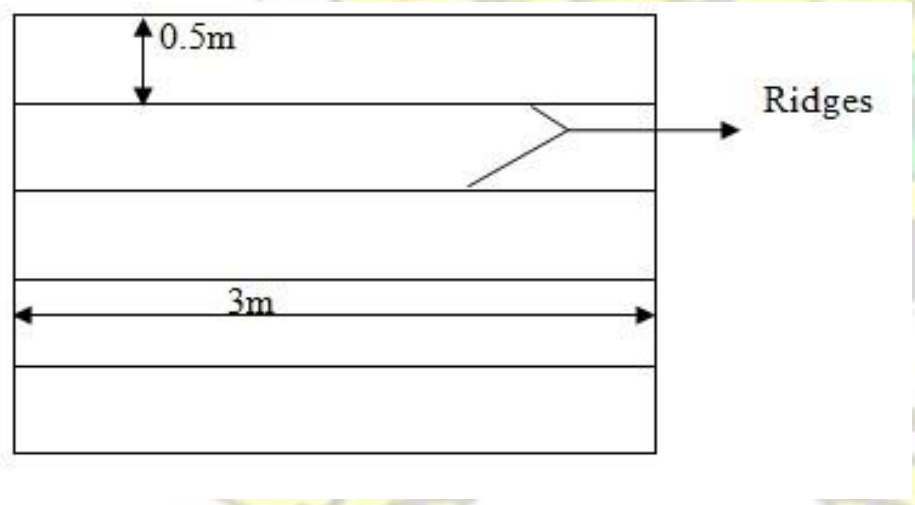


Plate 4- 3 Field layout showing ridges for planting

Mini-tubers were treated with a solution of insecticide (dursban**)** and fungicide (benlate) and planted by hand one seed per hill at a spacing 50 cm x 50 cm. Pyrinex was applied at planting to kill emerging weeds. Ridges were mulched after planting for good emergence. Weeding was done as and when necessary. Supplementary irrigation was done once every week until emergence.

4.3.2 Direct planting of dormant seeds

Potted experiments were carried out in the screenhouse using the same experimental design as described for the direct planting of non-dormant seeds. Soils from the field was sterilized and put in 6 litre plastic pots filled one third full. Freshly harvested mini-tubers were treated with a mixture of insecticide (Dursban**)** and fungicide (benlate), kept under shade and allowed to dry overnight. The treated mini-tubers were planted by hand at one seed per pot. Each pot was irrigated manually with 500 ml of irrigation water after planting and subsequently, once every week until emergence.

4.3.3 Pre-germination of non-dormant seeds

In this treatment, mini-tubers were nursed in a screenhouse using sterilised saw dust as a propagating media. Mini-tubers were again treated with a mixture of insecticide and fungicide. The mini-tubers were distributed evenly on the saw dust spread in a basket. A thin layer of saw dust was again spread over the mini-tubers. The baskets were then irrigated manually with 1500 ml of irrigation water and subsequently irrigated once every week until emergence.

4.3.4 Harvesting and storage

Final harvest was done two weeks after senescence. Data was taken on yield and yield components. Harvested tubers were stored on shelves in a yam barn until ready for use.

4.3.5 Data collection

Four plants were tagged in each treatment for data collection. Agronomic data taken included days from sowing to emergence (50 % emergence), days from planting to first root initiation, days from planting to tuber initiation, days from planting to physiological maturity (80 % senescence). The following data were also taken after crop establishment and at harvest: plant height, vine girth, maximum leaf area, and total number of leaves per plant, number of vines per plant, total number of plants per treatment, total biomass and tuber weight. Crop establishment was determined when 80 % of planted mini-tubers rooted and new leaves were observed.

4.3.6 Data analysis

Data collected from the field evaluation were subject to statistical analysis using Genstats version 9.2. Mean separation was done using the Fisher's unprotected LSD and the effects were tested at $p < 0.05$.

4.4 Economic analysis

A thorough benefit-cost analysis was done for the systems developed. The analyses took into consideration production and installation costs, and used several profitability indicators described by Espinosa *et al.* (1996). Total production cost comprised fixed and variable costs. The fixed costs were inclusive of the expenses incurred in infrastructure, equipment and materials used in the installation of the aeroponic units. Fixed assets were depreciated using the sum of years depreciation and assuming salvage values of GHC 15000.00 and 4000.00 for the power-dependent and power-independent aeroponic systems repsectively.

Variable costs were those expenses incurred in getting fertilizers, conducting water analysis, personnel and maintenance costs (Mateus-Rodriguez *et al*., 2013). A five year loan representing 100% of fixed costs and variable cost for the first year of production was assumed for both the power-dependent and power-independent aeroponic systems. The loan repayment amounts were considered fixed yearly for the variable lifetime (five years) and amortised (using Equation 4-1) during each agricultural season (Miragem *et al*., 1982).

$$A = \left(\frac{i*p*(1+i)^n}{(1+i)^n}\right) * 12 \quad \text{.....Equation 4-1}$$

Where:

A is the yearly payments, i= monthly interest rate, p = loans initial amount (total fixed costs) and n = total number of payments

The following assumptions were made in relation to the economic analysis:

i. Lending rate of 32 % per annum for loans of 3 to 5 years was used.
ii. Inflation rate of 18.70% (BOG, 2016) iii. Mini-tuber yields remain constant iv. Cost of seed yam (*Mankrong Pona*) is GHC 2.0 for the first year and inflates by 18.7% each year using 2016 as the base year.

Tax exemption was employed in the calculation of net benefits in accordance with the Internal Revenue Act 2000 (Act 592) of Ghana (Ghana Revenue Authority (n.d). In all analysis, cash flow was considered for only the production of *Mankrong Pona* an improved variety of the CSIR-Crops Research Institute. Thus, for the aeroponic systems developed, it was assumed that each system

would be planted with *Mankrong Pona*. For both aeroponic systems, the seed yam produced was calculated using Equation 4-2:

$S = nmx(A * P)$…….....Equation 4-2

Where:

S = Number of seed yam produced per year n =

number of mini-tuber produced per vine cutting m

= number of seed yam produced per mini-tuber x =

production cycles per year

A = Number of aeroponic growth boxes

P = Vine planting density per aeroponic growth box

Using the economic analysis methods employed by Mateus-Rodriguez *et al*. (2013) the cash flow of the production activity, or the difference between income and expenditure, was used to define financial viability of the two systems.

Two scenario analyses were done to investigate ways in which production cost can be reduced to improve the benefit-cost ratio and rate of return and of the two systems. In an effort to reduce the screen and pump house costs, an improvised system using wooden shade houses were used in the two scenario analyses. The first scenario used the same screenhouse but an improvised pump house (which reduces pump house cost by 50 %) whereas the second scenario used both improvised screenhouse (cost reduced by 50 %) and pump house (cost reduced by 50 %) for both the power-dependent and –independent aeroponic systems. Personnel costs were, however, not reduced in the two scenario analysis.

CHAPTER FIVE

RESULTS AND DISCUSSION

5.1 General Introduction

This chapter presents the results of the physico-chemical analysis, agronomic evaluations and economic analysis of the two aeroponic systems.

5.2 Results from Agronomic Evaluation of Aeroponic systems

5.2.1 Physico-Chemical Constitution of Nutrient concentrations

Nutrient solution is considered to be among the important factors affecting crop yield and quality under aeroponics production systems (Trejo-Tellez and Gomez-Merino, n.d). Results from the nutrient analysis showed the following nutrient concentrations for C1, C2, C3 and C4 as presented in Table 5-1. Sodium ranged between 7 mg/l for C4 and 260 mg/l for C4, potassium between 1.10 and 15.6 mg/l, magnesium between 1 and 11.6 mg/l and total iron between 0.015 and 2.06 mg/l as shown in Table 5-1 ammonia and manganese ranged from <0.005 to 0.793 mg/l. Chloride ranged between 6.00 and 49.60 mg/l and sodium also between 7.00 and 260 mg/l. Fluoride was less than 0.005 whereas carbonates were also negligible in all solutions. Nitrite and Nitrate ranged between 0.033 and 3.67 mg/l. Magnesium and calcium hardness (as $CaCO_3$) were also between 4.20 and 65.10 mg/l.

Total dissolved solids (TDS) were 690.0, 1037.0, 1236.0 and 53.3 mg/l for C1, C2, C3 and C4 respectively. Total alkalinity (as $CaCO_3$) ranged between 16.8 and 505.0 mg/l. Conductivity was

1150, 1729, 2060 and 88.9 µS/cm for C1, C2, C3 and C4 respectively whilst pH was also 5.82, 4.75, 5.68 and 6.10 for C1, C2, C3 and C4 respectively. Conductivity and pH were all in the ranges suitable for aeroponic propagation at the formulation stage. They were adjusted to the initial values every 16 days after new nutrient formulation.

Table 5- 1 Nutrient Concentrations of the four nutrient solutions used

Parameter	C1	C2	C3	C4	UNIT	Method no.
Turbidity	31.6	206	284	2.00	NTU	3
Colour (apparent)	375	375	375	5.00	Hz	2
pH	5.82	5.75	5.68	6.10	pH Units	4
Conductivity	1150	1729	2060	88.9	µS/cm	1
Tot. Suspended. Solids (TSS)	143	116	181	<1.00	mg/l	5
Tot. Dissolved Solids (TDS)	690	1037	1236	53.3	mg/l	6
Sodium	123	260	225	7.00	mg/l	30
Potassium	15.6	5.90	10.8	1.10	mg/l	29
Calcium	13.6	20.9	26.1	3.80	mg/l	23
Magnesium	11.6	12.6	16.4	1.00	mg/l	26
Total Iron	1.40	1.82	2.06	0.015	mg/l	31
Ammonia (NH_4-N)	0.100	0.460	0.490	0.483	mg/l	13
Chloride	29.8	49.6	39.7	6.00	mg/l	24
Sulphate (SO_4)	11.5	26.0	185	7.13	mg/l	19
Phosphate (PO_4-P)	0.514	1.11	0.469	0.303	mg/l	17
Manganese	0.495	0.702	0.793	<0.005	mg/l	26
Nitrite (NO_2-N)	1.43	1.99	1.00	0.033	mg/l	14
Nitrate (NO_3-N)	2.49	3.67	1.77	0.069	mg/l	15
Total Hardness (as $CaC0_3$)	86.0	115	108	13.8	mg/l	25
Total Alkalinity (as $CaC0_3$)	348	413	505	16.8	mg/l	22
Calcium Hardness (as $CaC0_3$)	67.1	34.1	65.1	9.60	mg/l	23
Mg Hardness (as $CaC0_3$)	47.9	42.9	51.9	4.20	mg/l	26
Fluoride	<0.005	<0.005	<0.005	<0.005	mg/l	20
Bicarbonate (as $CaC0_3$)	425	504	616	20.5	mg/l	22
Carbonate	0.00	0.00	0.00	0.00	mg/l	22

5.2.2 Agronomic performance of the aeroponic system

Optimum conditions for fast and vigorous growth of micro-plants as well as for mini-tuber production are also known to differ with genotype (Gopal *et al.*, 1998). The following performance results are depictive of other systems as would be discussed.

5.2.2.1 Rooting characteristics

The mean number of days to root initiation for the one node cuttings was found to be 14 days after planting. The variety with the earliest rooting time was *Mankrong Pona* with mean root initiation of 11.5 d followed by *Pona* with 12.7 d and then *Dente* with 18.3 d (Figure 5-1). Plants on the power-dependent aeroponic units had a mean root initiation period of 10.9 DAP whilst plants on the power-independent units initiated rooting at 17.1 DAP. With the nutrient concentrations, C1 initiated rooting at 13.4 DAP, C2 at 14.1 DAP, C3 at 14.3 DAP with C4 initiating rooting at 14.3 DAP.

Dente propagated with C1, C2, C3 and the C4 on the pressurised aero unit, initiated rooting at 14.7, 15.0, 14.7 and 14.3 DAP respectively (Figure 5-1). *Dente* propagated with C1, C2, C3 and C4 on the gravity fed units however initiated rooting at 21.3, 21.7, 22.7 and 22.3 DAP, again showing significant differences between the Aeroponic units but not the nutrient concentrations. *Mankrong Pona* propagated with C1, C2, C3, and the C4 on the pressurised units initiated rooting at 8.3, 9.0, 8.3 and 9. 3 DAP respectively. However *Mankrong Pona* propagated on the gravity fed units with C1, C2, C3 and the C4 initiated rooting at 13.0, 14.3, 15.0 and 14.7 DAP respectively. *Pona* propagated on the pressurised units using C1, C2, C3 and the C4 initiated rooting at 9.00, 9.0, 9.3, and 9.7 DAP respectively whilst *Pona* propagated with C1, C2, C3 and

C4 on the gravity fed units initiated rooting at 14.0, 15.3, 15.7, and 15.3 DAP respectively. In all these instances, vines propagated using the power dependent aeroponic units initiated rooting significantly earlier than that of the power-independent system (Figure 5-1).

In comparing sole treatment performances mean, the aeroponic units had a least significant difference (LSD) of 7.32, nutrient concentration had 1.24 and variety had 0.72. Interactions between aeroponic units and nutrient concentration, aeroponic units and variety and aeroponic units, nutrient concentration and variety had LSD of 6.213, 1.644 and 5.652 respectively.

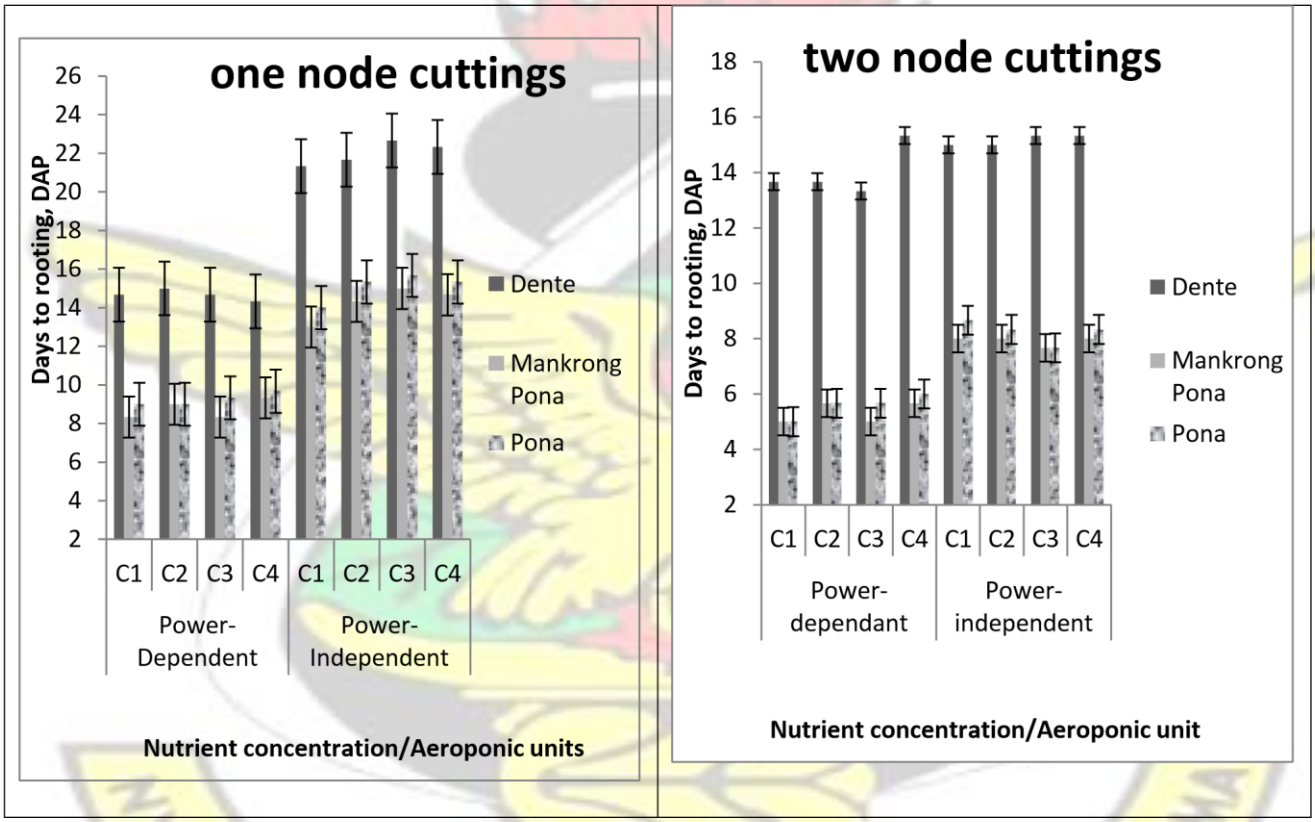


Figure 5- 1 Number of days to rooting for one and two node cuttings

The grand mean for days to rooting for the two node cuttings was 9.4 DAP, rooting 5 days (averagely) earlier than the one node cuttings. Vines on the power-dependent aeroponic units rooted at a mean of 8.3 whereas vines on the power-independent aeroponic units rooted 10.4 days after planting. Vines fertigated with nutrient concentrations C1, C2, C3 and C4 rooted at

9.2, 9.4, 9.1 and 9.8 days after planting respectively. The mean days to rooting for the varieties, *Dente*, *Mankrong Pona* and *Pona* were 14.5, 6.6 and 6.9 DAP respectively.

Interactions between aeroponic units and nutrient concentration gave means of 7.8, 8.3, 8.0 and 9.0 DAP for C1, C2, C3 and C4 under the power-dependent units and means of 10.5, 10.4, 10.2 and 10.6 DAP for C1, C2, C3 and C4 under the power-independent units respectively.

Interactions between aeroponic units and variety gave means of 14.0, 5.3 and 5.6 DAP for *Dente, Mankrong Pona* and *Pona* under the power-dependent aeroponic units and means of 15.7, 7.9 and 8.2 for *Dente*, *Mankrong Pona* and *Pona* under the power-independent unit respectively.

Table 5- 2 Anova for days to rooting of one and two- node cuttings

SOURCE OF VARIATION	One node cuttings					Two node cuttings			
	d.f	s.s	m.s	v.r	Fpr	s.s	m.s	v.r	Fpr
Rep stratum	2	112.333	56.167	1.08		0.58	0.29	0.5	
Rep x Aeroponics unit stratum									
Aeroponics unit	1	696.889	698.889	13.39	0.067	82.35	82.35	160.24	0.006**
Residual	2	104.111	52.056	17.90		1.03	0.51	1.28	
Rep x Aeroponics unit x Nutrient concentration stratum									
Nutrient Concentration	3	9.556	3.185	1.10	0.389	4.59	1.53	3.80	0.040*
Aeroponics Unit x Nutrient Concentration	3	5.556	1.852	0.64	0.605	2.81	0.94	2.33	0.126
Residual	12	34.889	2.907	1.94		4.83	0.40	1.35	
Rep x Aeroponics Unit x Nutrient Co cent ation x Var ety stratum									
Variety	2	681.333	340.667	227.11	<0.001**	977.58	488.79	1636.88	<0.001**
Aeroponics Unit x Variety	2	11.444	5.722	3.81	0.033*	8.52	4.26	14.28	<0.001**
Nutrient Concentration x Variety	6	1.778	0.296	0.20	0.975	1.86	0.31	1.04	0.419
Aeroponics Unit x Nutrient Concentration x Variety	6	2.111	0.352	0.23	0.962	3.1389	0.52	1.75	0.141
Residual	32	48.000	1.500			9.5556	0.29		

Total	71	1708.000	1096.87

** Significant at p<0.01 * Significant at p<0.05

Significant differences ($p<0.05$) existed between the varieties with respect to rooting (Table 5-2). Significant interaction effect existed between the aeroponic units and the varieties (Figure 5-2). However, there were no significant differences between the nutrient concentration and varieties or the nutrient concentrations and aeroponic units.

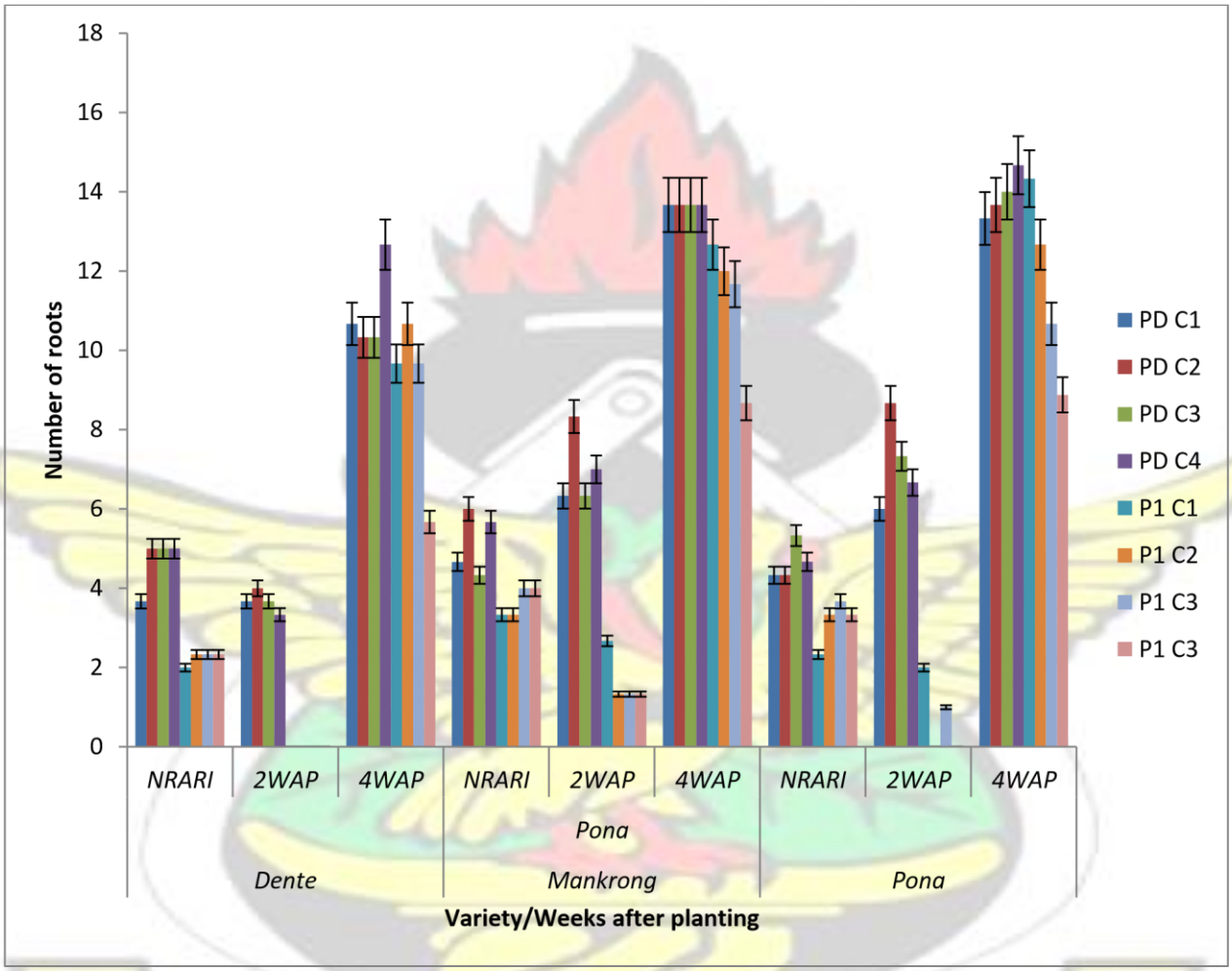


Figure 5- 2 Combined rooting interaction of varieties under both power-dependent and power-independent system for the one node cuttings

The grand mean number of roots at root initiation was 3.9 and 4.3 roots for the one and two-node cuttings respectively. The power-dependent units and power-independent units had means of

4.83 and 3.0 for the one-node cuttings and 5.9 and 2.7 roots for the two-node cutting respectively. Single way interactions of one-node cuttings under the different nutrient concentrations gave means of 3.4, 4.1, 4.1 and 4.2 for C1, C2, C3 and C4 respectively. Same interaction for two-node cuttings gave means of 4.3, 4.2, 4.4 and 4.2 for C1, C2, C3 and C4 respectively. Means for the three way interaction for the number of roots at root initiation and 2 WAP, 4 WAP and 6 WAP for the one and two node cutting is as shown in Figure 5-3

respectively.

Planting with one node cuttings showed significant differences ($p<0.05$) between aeroponic units and variety; and nutrient concentration and variety (Figure 5-2) Significant differences ($p<0.05$) existed between the two aeroponic systems and also the various nutrient concentrations.

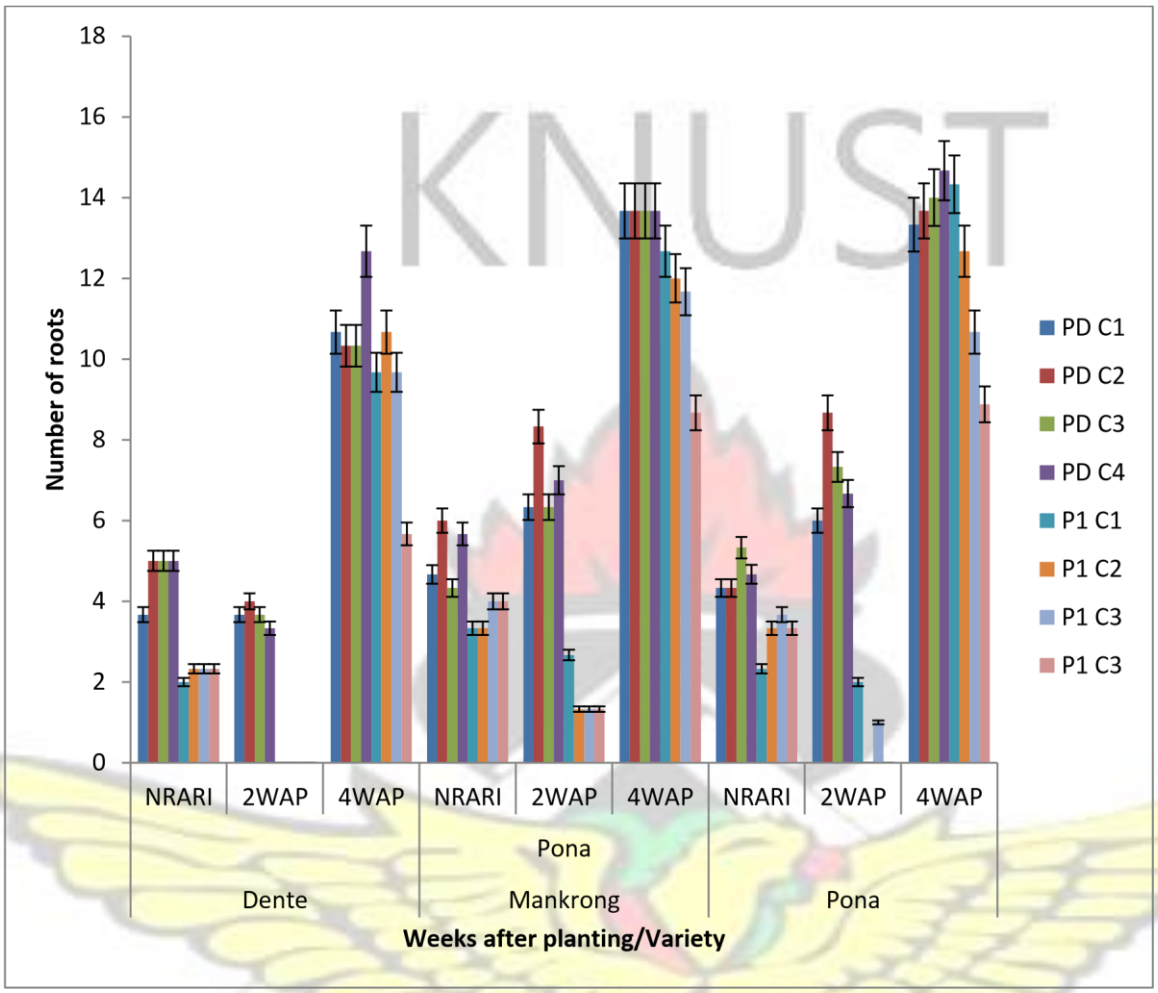

Number of roots
18
16
14
12
10
8
6
4
2
0
PD C1
PD C2
PD C3
PD C4
P1 C1
P1 C2
P1 C3
P1 C3
NRARI
2WAP
4WAP
NRARI
2WAP
4WAP
NRARI
2WAP
4WAP
Dente
Pona
Mankrong
Pona
Weeks after planting/Variety

Figure 5- 3 Number of roots at rooting and subsequent weeks after planting for one node cutting

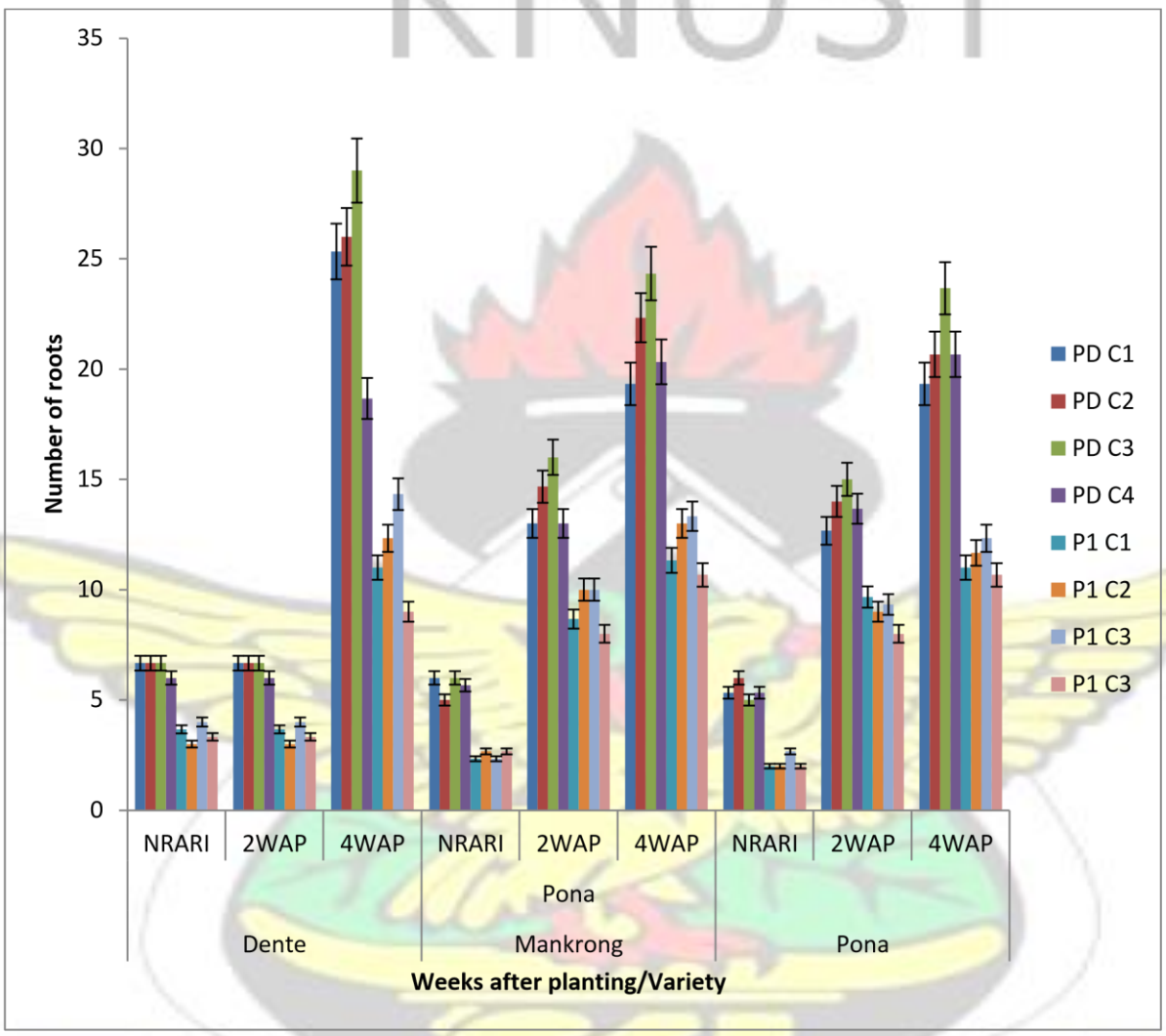


Figure 5- 4 Number of roots at rooting and subsequent weeks after planting for two node cuttings

Significant difference ($p<0.05$) existed between the main treatments (power-dependent and power-independent aeroponic systems) for both the one and two node cuttings. Varieties also showed highly significant differences at $p<0.01$ (Table 5-3) in their response to the number of roots at root

initiation for both the one and two-node cuttings. The number of roots observed was also significant for the one-node cuttings under the two-way interaction between aeroponics unit and variety.

Table 5- 3 Anova for number of roots at root initiation for one and two- node cuttings

SOURCE OF VARIATION		One node cuttings				Two node cuttings			
	d.f	s.s	m.s	v.r	Fpr	s.s	m.s	v.r	Fpr
Rep stratum	2	3.8611	1.9306	0.77		4.33	2.17	0.80	
Rep x Aeroponics unit stratum									
Aeroponics unit	1	58.6806	58.6806	23.34	0.040*	177.35	177.35	65.15	0.015*
Residual	2	5.0278	2.5139	3.57		5.44	2.72	2.41	
Rep x Aeroponics unit x Nutrient concentration stratum									
Nutrient Concentration	3	7.1528	2.3843	3.39	0.054	0.82	0.27	0.24	0.86
Aeroponics Unit x Nutrient Concentration	3	0.8194	0.2731	0.39	0.764	0.70	0.23	0.21	0.87
Residual	12	8.4444	0.7037	1.61		13.55	1.13	2.09	
Rep x Aeroponics Unit x Nutrient C ɔnce ıtration x Variety s ratum									
Variety	2	11.0278	5.5139	12.60	<.001**	19.08	9.54	17.62	<0.001**
Aeroponics Unit x Variety	2	3.3611	1.6806	3.84	0.032*	0.19	0.09	0.18	0.83
Nutrient Concentration x Variety	6	2.97	0.49	1.13	0.36	1.80	0.30	0.56	0.76
Aeroponics Unit x Nutrient Concentration x Variety	6	5.30	0.8843	2.02	0.092	4.25	0.71	1.31	0.28

Residual	32	14.00	0.437		17.33	0.54
Total	71	120.65			244.87	

** Significant at p<0.01 * Significant at p<0.05

5.2.2.2 Mini-tuber characteristics

The grand mean days for mini-tuber initiation were 20.4 DAP for the one node cutting and 14.5 DAP for the two node cutting (Table 5-4). On an average, the two node vine cuttings initiated tuber formation in 5.87 days earlier than the one node cuttings. The power-dependent units had means of 16.97 and 13.5 DAP for the one and two node vine cuttings respectively. The powerindependent units had means of 23.8 and 15.8 DAP for the one and two node vine cuttings respectively. This shows that the two node vine cuttings initiated tuber formation 8 days earlier than the one node vine cuttings. The mean days to micro tuber initiation for the one node cuttings under the various nutrient concentrations were 20.2, 20.0, 20.2 and 21.1 DAP for C1, C2, C3, and the C4 respectively. The mean days to mini-tuber initiation (one node cuttings) for C1, C2, C3, and C4 on the power-dependent units were 17.0, 16.7, 16.6 and 17.7 DAP respectively. For the power-independent units, the mean days to micro tuber initiation for C1, C2, C3 and C4 were 23.4, 23.3, 24.0 and 24.7 DAP respectively.

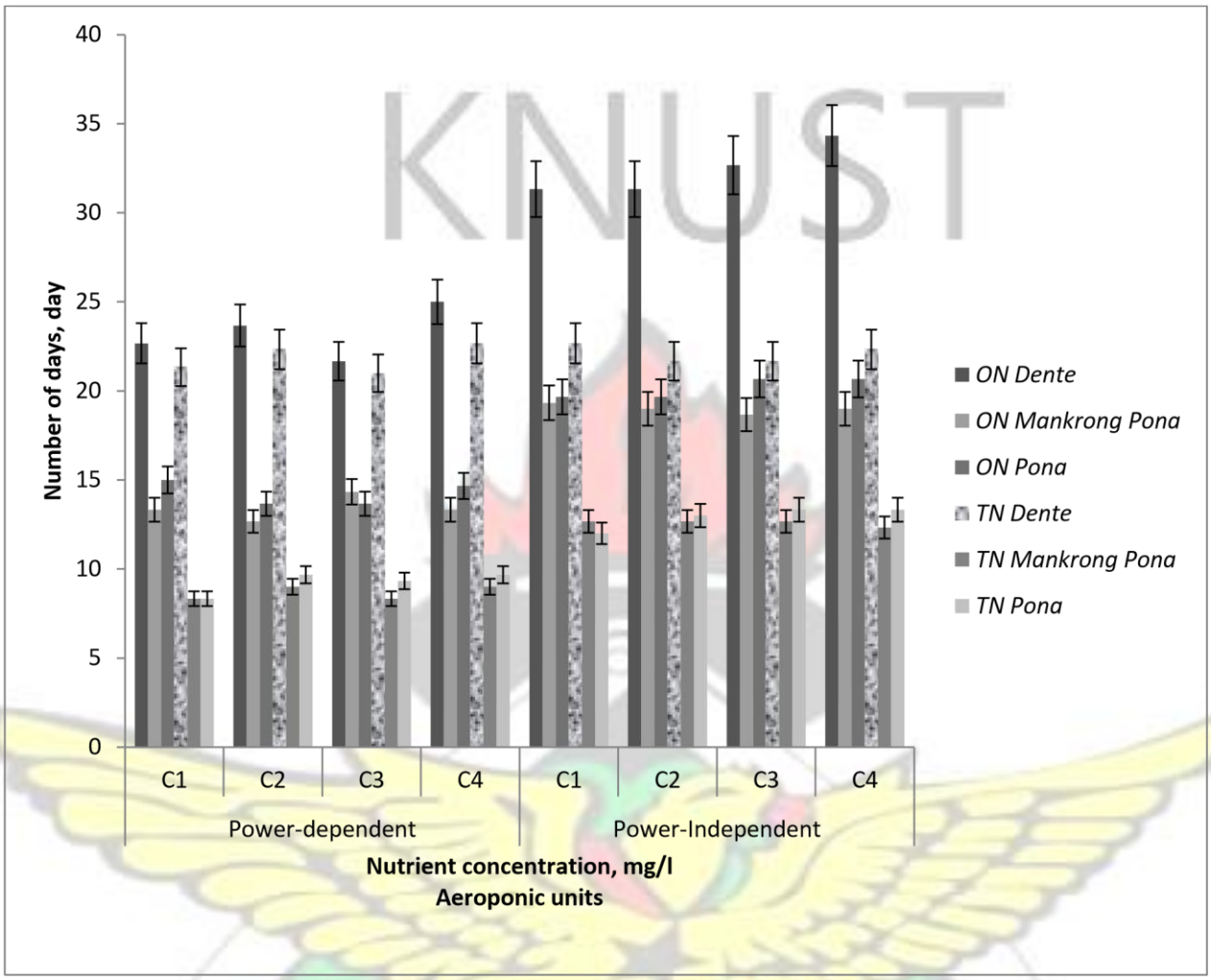
The mean days to mini- tuber initiation for the two node cuttings under the various nutrient concentrations were 14.2, 14.7, 14.3 and 21.9 DAP for C1, C2, C3, and the C4 respectively (Table 5-4). The mean days to mini-tuber initiation (two node cuttings) for C1, C2, C3, and C4 on the power-dependent units were 12.7, 13.7, 12.9 and 13.8 DAP respectively. For the powerindependent units, the mean days to micro tuber initiation for C1, C2, C3 and C4 were 15.7, 15.8, 15.9 and 16.0 respectively. The mean days to tuber initiation for the various varieties on the different aeroponic units for the one node cuttings were as follows, *Dente*, *Mankrong Pona* and *Pona* on the pressurised units had 23.25, 13.42 and 14.25 DAP; *Dente*, *Mankrong Pona* and

Pona on the gravity fed units had 32.42, 19.00 and 20.17 DAP respectively. The mean days to tuber initiation for the various varieties on the different aeroponic units for the two node cuttings were as follows, *Dente*, *Mankrong Pona* and *Pona* on the power-dependent units had 21.83, 8.67 and 9.25 DAP; *Dente*, *Mankrong Pona* and *Pona* on the power-independent units had 22.08, 12.58 and 12.91 DAP respectively.

Table 5- 4 Days to mini-tuber initiation for one and two node vine cuttings

Aeroponic unit	**Nutrient concentration**	**One node cuttings**			**Two node cuttings**		
		Dente	***Mankrong Pona***	***Pona***	***Dente***	***Mankrong Pona***	***Pona***
Power-dependent	C1	22.67	13.33	15.00	21.33	8.33	8.33
	C2	23.67	12.67	13.67	22.33	9.00	9.67
	C3	21.67	14.33	13.67	21.00	8.33	9.33
	C4	25.00	13.33	14.67	22.67	9.00	9.67
Power-independent	C1	31.33	19.33	19.67	22.67	12.67	12.00
	C2	31.33	19.00	19.67	21.67	12.67	13.00
	C3	32.67	18.67	20.67	21.67	12.67	13.33
	C4	34.33	19.00	20.67	22.33	12.33	13.33
s.e.d		1.878	1.878	1.878	0.66	0.66	0.66

Significant differences existed between *Dente* and *Mankrong Pona* and *Dente* and *Pona* but no significant difference was seen between *Mankrong Pona* and *Pona* (Figure 5-5). The interaction between nutrient concentration and variety gave the mean days to micro tuber initiation for *Dente* propagated with C1, C2, C3, and the C4 at 27.0, 27.5, 27.2 and 29.7 DAP respectively; *Mankrong Pona* propagated with C1, C2, C3 and the C4 at 16.3, 15.8, 16.5 and 16.2 DAP respectively; *Pona* propagated with C1, C2, C3 and the C4 at 17.3, 16.7, 17.2 and 17.7 DAP respectively.



ON = One node cuttings TN = Two node cuttings

Figure 5- 5 Days to mini-tuber initiation for one and two node vine cuttings

Similar observations were made for the various interactions in their response to mini-tuber initiation. Significant differences existed between aeroponic units and aeroponic units and varieties as shown in Table 5-5. The varieties again showed highly significant differences. No significant differences existed between the three way interaction between aeroponic units, nutrient concentrations and varieties.

Table 5- 5 Anova for days to mini-tuber initiation for one and two-node cuttings

SOURCE OF VARIATION	One node cuttings					Two node cuttings			
	d.f	s.s	m.s	v.r	Fpr	s.s	m.s	v.r	Fpr
Rep stratum	2	182.250	91.125	2.9		0.0278	0.0139	0.03	
Rep x Aeroponics unit stratum									
Aeroponics unit	1	854.222	854.222	28.07	0.034*	122.72	122.72	285.03	0.03*
Residual	2	60.861	30.431	9.96		0.86	0.43	0.54	
Rep x Aeroponics unit x Nutrient concentration stratum									
Nutrient Concentration	3	14.278	4.759	1.56	0.251	5.00	1.667	2.09	0.15
Aeroponics Unit x Nutrient Concentration	3	2.556	0.852	0.28	0.840	3.61	1.20	1.51	0.26
Residual	12	36.667	3.056	1.02		9.56	0.79	1.26	
Rep x Aeroponics Unit x Nutrient Concentration x Variety stratum									
Variety	2	1992.250	996.125	333.59	<.001**	1975.36	987.68	1567.92	<0.001**
Aeroponics Unit x Variety	2	47.028	23.514	7.87	0.002**	50.36	25.18	39.85	<0.001**
Nutrient Concentration x Variety	6	17.972	2.995	1.00	0.440	6.42	1.06	1.69	0.155
Aeroponics Unit x Nutrient x Concentration x Variety	6	13.861	2.310	0.77	0.596	1.64	0.27	043	0.85
Residual	32	95.556	2.986			20.22	0.27		

Total	71	3317.500	2195.78	0.63

** Significant at p<0.01 * Significant at p<0.05

The grand mean for the number of tubers at tuber initiation was 1.6 mini-tubers. The powerdependent units had 1.6 whilst the power-independent units had a mean of 1.7. The means for the nutrient concentrations C1, C2, C3, and C4 were 1.7, 1.6, 1.7 and 1.7 mini-tubers for the one node cuttings and 1.389, 1.2, 1.8 and 1.1 mini-tubers for the two node cuttings respectively. Varietal means were 1.5, 1.9 and 1.6; 1.0, 1.6 and1.4 mini-tubers for *Dente*, *Mankrong Pona* and *Pona* under one and two node propagation respectively.

The interactions between aeroponic units and nutrient concentrations for the one node cuttings gave the means for C1, C2, C3, and C4 on the power-dependent units as 1.8, 1.6, 1.6 and 1.7 mini-tubers whilst the means for C1, C2, C3, and the C4 for the power-independent units were 1.556, 1.7, 1.8 and 1.7 mini-tubers respectively. The interactions between aeroponic units and nutrient concentrations for the two node cuttings gave the means for C1, C2, C3, and C4 on the power-dependent units as 1.6, 1.2, 2.0 and 1.1 mini-tubers whilst the means for C1, C2, C3, and C4 for the power-independent units were 1.2, 1.1, 1.6 and 1.0 mini-tuber respectively.

Interactions between aeroponic units and variety of the one node cuttings gave means of 1.6, 1.8, and 1.5 mini-tubers for *Dente*, *Mankrong Pona* and *Pona* on the pressurised units whilst the gravity fed units gave means of 1.3, 2 and 1.67 mini-tuber for *Dente*, *Mankrong Pona* and *Pona* respectively. Interactions between aeroponic units and variety of the two node cuttings gave means of 1.58, 1.83, and 1.50 mini-tubers for *Dente*, *Mankrong Pona* and *Pona* on the pressurised units whilst the gravity fed units gave means of 1.3, 2 and 1.67 mini-tubers for *Dente*, *Mankrong Pona* and *Pona* respectively. The three way interaction between aeroponic units, nutrient concentration and variety is as shown in Table 5-6.

The ANOVA table for number of mini-tuber(s) at tuber initiation is as shown in Table 5-6. No significant differences existed in the interaction between aeroponic units, nutrient concentration

and variety. However, significant differences existed between the various varieties and their number of mini-tubers at the tuber initiation.

Table 5- 6

Anova for number of mini-tubers at mini-tuber initiation for one and two node cuttings

SOURCE OF VARIATION	One node cuttings					Two node cuttings			
	d.f	s.s	m.s	v.r	Fpr	s.s	m.s	v.r	Fpr
Rep stratum	2	2.1111	1.0556	1.46		0.0278	0.0139	0.11	
Rep x Aeroponics unit stratum									
Aeroponics unit	1	0.0139	0.0139	0.02	0.902	1.1250	1.1250	9.00	0.095
Residual	2	1.4444	0.7222	3.90		0.2500	0.1250	0.87	
Rep x Aeroponics unit x Nutrient concentration stratum									
Nutrient Concentration	3	0.0417	0.0139	0.08	0.972	5.4861	1.8287	12.74	<.001**
Aeroponics Unit x Nutrient Concentration	3	0.4861	0.1620	0.88	0.481	0.3750	0.1250	0.87	0.483
Residual	12	2.2222	0.1852	0.72		1.7222	0.1435	1.15	
Rep x Aeroponics Unit x Nutrient Conce ntration x Variet / stratum									
Variety	2	2.6944	1.3472	5.24	0.011**	3.0278	1.5139	12.11	<.001**
Aeroponics Unit x Variety	2	0.6944	0.3472	1.35	0.273	0.0833	0.0417	0.33	0.719
Nutrient Concentration x Variety	6	1.4167	0.2361	0.92	0.494	1.6389	0.2731	2.19	0.070
Aeroponics Unit x Nutrient Concentration x Variety	6	0.9722	0.1620	0.63	0.705	0.5833	0.09	0.78	0.593

Table 5- 7

Residual	32	8.2222	0.2569		4.0000	0.1250
Total	71	20.3194			18.3194	

**Significant at p<0.01

Number of mini-tubers at mini-tuber initiation and subsequent weeks after planting for one-node cuttings

Aeroponic unit	**Nutrient concentration**	**Variety**								
		Dente			***Mankrong Pona***			***Pona***		
		NMATI	**2WAP**	**4WAP**	**NMATI**	**2WAP**	**4WAP**	**NMTATI**	**2WAP**	**4WAP**
Powerdependent	C1	1.67	2.33	2.33	2.33	2.67	2.67	1.33	2.00	2.00
	C2	1.33	2.00	2.33	1.67	2.00	2.00	1.67	2.33	2.33
	C3	1.67	2.33	2.33	1.33	2.67	2.67	1.67	2.33	2.33
	C4	1.67	1.67	1.67	2.00	2.33	2.33	1.33	1.67	1.67
Powerindependent	C1	1.00	1.67	1.67	2.00	2.00	2.00	1.67	2.33	2.33
	C2	1.33	1.67	2.33	2.00	2.33	2.33	1.67	2.00	2.00
	C3	1.67	1.67	2.00	2.00	2.33	3.00	1.67	1.67	2.33

Table 5- 8

	C4	1.33	2.00	2.00	2.00	2.00	2.33	1.67	2.00	2.00
s.e.d		0.43	0.47	0.44	0.43	0.47	0.44	0.43	0.47	0.44

96

Number of mini-tubers at mini-tuber initiation and subsequent weeks after planting for two-node cuttings

Aeroponic unit	**Nutrient concentration**	**Variety**								
		Dente			***Mankrong Pona***			***Pona***		
		NMATI	**2WAP**	**4WAP**	**NMATI**	**2WAP**	**4WAP**	**NMTATI**	**2WAP**	**4WAP**
Powerdependent	C1	1.00	0.00	1.00	2.00	2.67	2.67	1.67	2.00	2.00
	C2	1.00	0.00	1.33	1.33	2.00	2.33	1.33	2.00	2.00
	C3	1.67	0.00	1.67	2.33	3.00	3.67	2.00	2.33	3.00
	C4	1.00	0.00	1.00	1.33	2.00	2.00	1.00	2.00	2.33
Powerindependent	C1	1.00	0.00	1.00	1.67	1.67	1.67	1.00	1.00	1.33
	C2	1.00	0.00	1.00	1.00	1.00	1.33	1.33	1.33	1.33
	C3	1.00	0.33	1.00	2.00	2.00	2.00	1.67	1.67	2.00
	C4	1.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00
s.e.d		0.29	0.30	0.35	0.29	0.30	0.35	0.29	0.30	0.35

97

Anova for number of mini-tubers at two weeks after planting for one and two-node cuttings

Table 5- 9

SOURCE OF VA RIATION		One node cuttings				Two node cuttings		
	d.f	s.s	m.s	v.r	Fpr	s.s	m.s	v.r	Fpr
Rep stratum	2	0.58	0.29	0.31		0.53	0.26	2.71	
Rep x Aeroponics unit stratum									
Aeroponics unit	1	0.89	0.89	0.96	0.43	5.55	5.55	57.14	0.017*
Residual	2	1.86	0.93	3.59		0.19	0.09	0.49	
Rep x Aeroponics unit x Nutrient concentration stratum			0.20			3.00			
Nutrient Concentration	3	0.61		0.79	0.52		1.00	5.02	0.018*
Aeroponics Unit x Nutrient Concentration	3	1.11	0.37	1.43	0.28	0.11	0.04	0.19	0.904
Residual	12	3.11	0.26	0.91		2.39	0.19	1.79	
Rep x Aeroponics Unit x Nutrient Conc ntration x Variety strat ım									
Variety	2	1.75	0.87	3.07	0.06	47.44	23.72	213.50	<.001**
Aeroponics Unit x Variety	2	0.19	0.09	0.34	0.71	4.78	2.39	21.50	<.001**
Nutrient Concentration x Variety	6	0.47	0.08	0.28	0.94	2.67	0.44	4.00	0.004**
Aeroponics Unit x Nutrient Concentration x Variety	6	1.80	0.30	1.06	0.408	0.22	0.04	0.33	0.914
Residual	32	9.11	0.28			3.55	0.11		

Table 5- 10

Total	71	21.50	70.44

** Significant at p<0.01 *Significant at p<0.05

No significant differences were seen in the number of mini-tubers for any of the treatment interaction at two weeks after planting (Table 5-9) for the one node planting. However, with the two-node cuttings, significant differences were seen in the main treatment (aeroponic units), sub plot (nutrient concentration) and sub-sub plot (variety). Significant differences also existed between the two way interactions aeroponic units x variety and nutrient concentration x variety for the two node cutting but not the one node cuttings. At four weeks after planting significant differences ($p<0.05$) are seen in the nutrient concentration treatments (Table 5-8) for both the one and two node cuttings. Plate 5-1 shows rooting of and mini-tuber ignition of the one and two node cuttings.

Plate 5- 1 Rooting and mini-tuber initiation at vine nodes

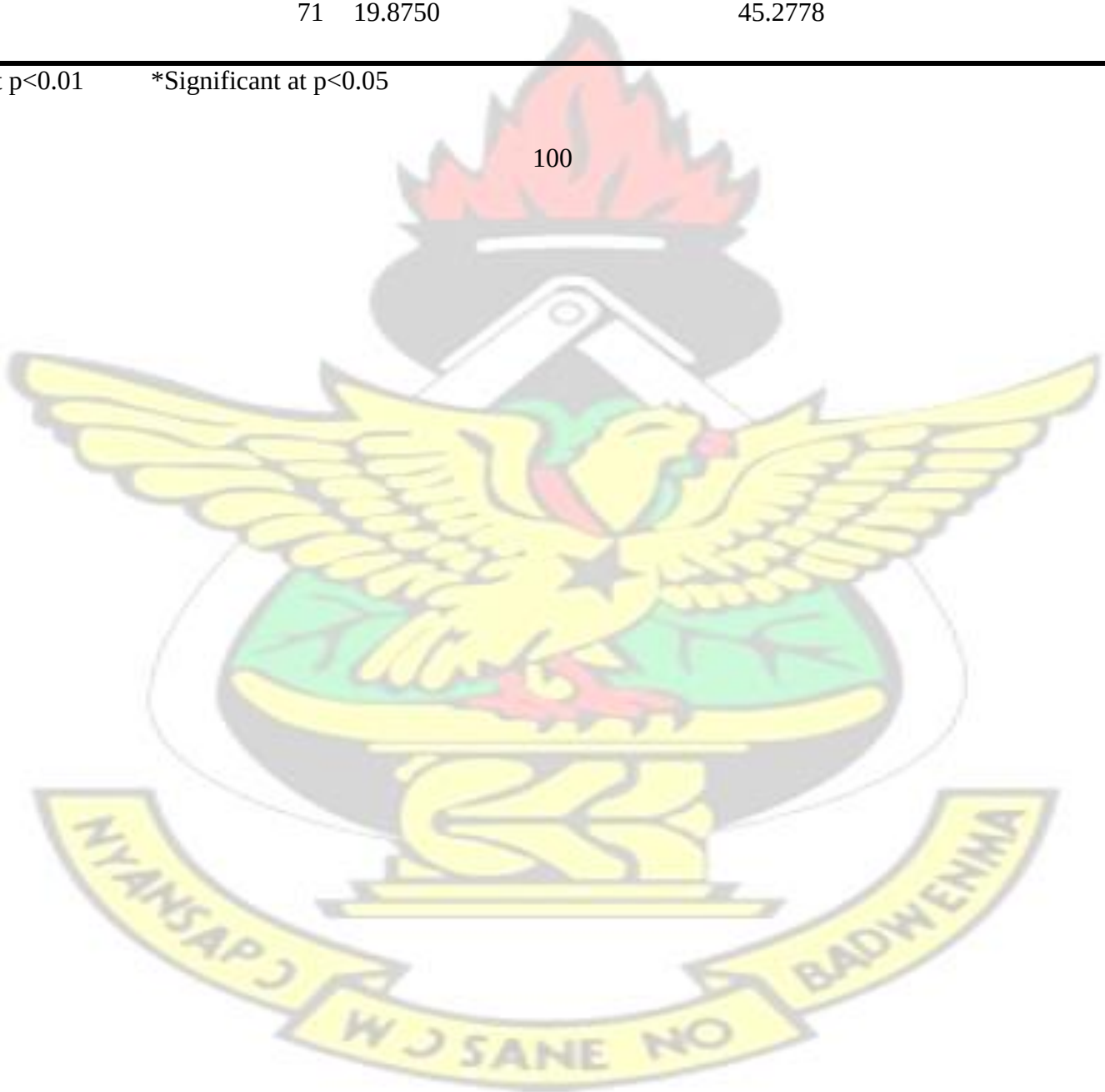
Table 5-10 Anova for number of mini-tubers at four weeks after planting

		One node cuttings				Two node cuttings			
	d.f	s.s	m.s	v.r	Fpr	s.s	m.s	v.r	Fpr
Rep stratum	2	0.5833	0.2917	0.29		0.194	1.00	0.0972	
Rep x Aeroponics unit stratum									
Aeroponics unit	1	0.0139	0.0139	0.10	0.918	10.8889	10.8889	112.00	0.009**
Residual	2	2.0278	1.0139	5.92		0.1944	0.0972	0.29	
Rep x Aeroponics unit x Nutrient concentration stratum									
Nutrient Concentration	3	1.8194	0.6065	3.54	0.048*	7.1667	2.3889	7.07	0.005**
Aeroponics Unit x Nutrient Concentration	3	0.7083	0.2361	1.38	0.297	0.7778	0.2593	0.77	0.534
Residual	12	2.0556	0.1713	0.69					
Rep x Aeroponics Unit x Nutrient Concentration x Variety stratum									
Variety	2	1.5833	0.7917	3.17	0.056*	12.1944	6.0972	46.21	<.001**
Aeroponics x Unit x Variety	2	0.1944	0.0972	0.39	0.681	2.6944	1.3472	10.21	<.001**
Nutrient Concentration x Variety	6	1.3056	0.2176	0.87	0.527	2.2500	0.3750	2.84	0.025*
Aeroponics Unit x Nutrient Concentration Variety	6	1.5833	0.2639	1.06	0.409	0.6389	0.1065	0.81	0.572

Table 5-

Residual	32	8.0000	0.2500	4.2222	0.1319
Total	71	19.8750		45.2778	

**Significant at p<0.01 *Significant at p<0.05



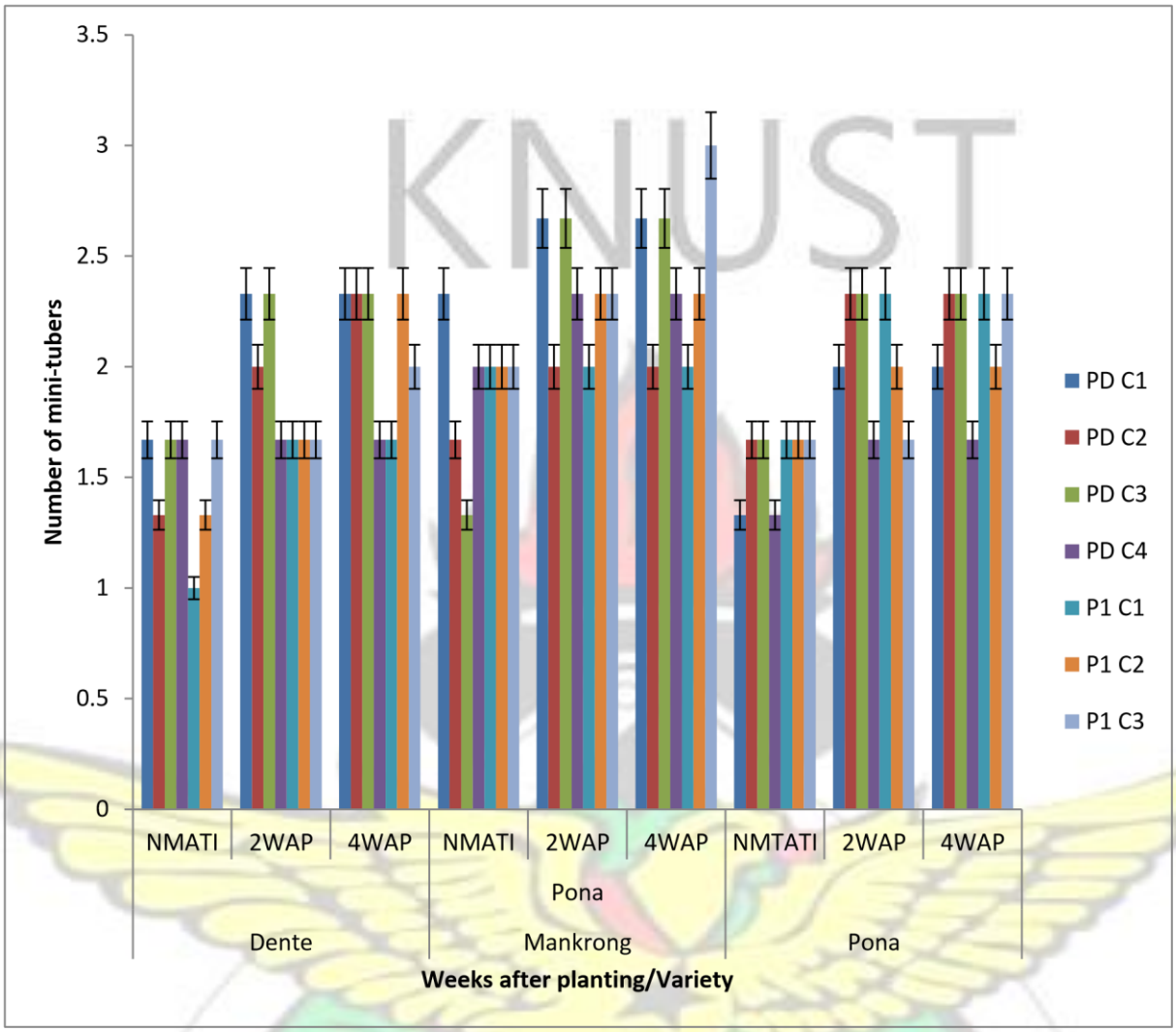


Figure 5- 6 Chart showing significant difference between nutrient concentrations for the various treatments

Table 5-11 Growth performance under the various treatments

Aeroponic unit	Nutrient concentration	Variety								
		Dente			***Mankrong Pona***			***Pona***		
		NMTATI	**2WAP**	**4WAP**	**NMTATI**	**2WAP**	**4WAP**	**NMTATI**	**2WAP**	4WAP
Powerdependent	C1	1.67	2.33	2.33	2.33	2.67	2.67	1.33	2.00	2.00
	C2	1.33	2.00	2.33	1.67	2.00	2.00	1.67	2.33	2.33
	C3	1.67	2.33	2.33	1.33	2.67	2.67	1.67	2.33	2.33
	C4	1.67	1.67	1.67	2.00	2.33	2.33	1.33	1.67	1.67
Powerindependent	C1	1.00	1.67	1.67	2.00	2.00	2.00	1.67	2.33	2.33
	C2	1.33	1.67	2.33	2.00	2.33	2.33	1.67	2.00	2.00
	C3	1.67	1.67	2.00	2.00	2.33	3.0	1.67	1.67	2.33
	C3	1.33	2.00	2.00	2.00	2.00	2.33	1.67	2.00	2.00
s.e.d		0.43	0.47	0.44	0.43	0.47	0.44	0.43	0.47	0.44

In comparing means of number of days to micro tuber initiation, the aeroponic units had a 7.8 % coefficient of variation, the interaction between the aeroponic units and the nutrient concentration had a coefficient of variation of 4.9 % whilst the interaction between the aeroponic units, nutrient concentration and variety had 8.5 %

5.2.2.3 Mini-tuber yields

The grand mean for the number of mini-tubers harvested at the first harvest for all the varieties under the two systems was 1.54 mini-tubers. The power-dependent system had a higher mean of 1.69 mini-tubers whereas the power-independent system had a mean of 1.31 mini-tubers. Means were same for C1 and C2. C3 and C4 had means of 1.72 and 1.28 respectively. The numbers of mini-tubers at first harvest for the various varieties were 0.00, 2.33 and 2.17 for *Dente*, *Mankrong Pona* and *Pona* respectively (Figure 5-7). *Dente* had no harvesy4ted mini-tubers at first harvest because of its late maturing nature.

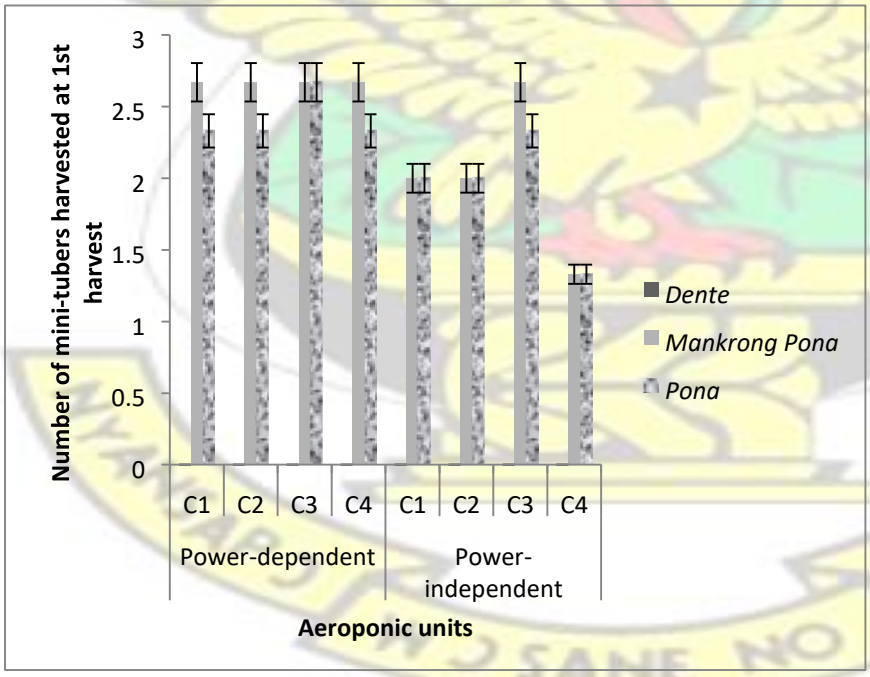


Figure 5- 7 Number of mini-tubers harvested at first harvest

There was no significant difference in the total number of mini-tubers harvested at the first harvest for the aeroponic systems. Again, no significant difference was observed in the threeway interaction between aeroponic systems, nutrient concentration and variety (Table 5-12). However, significant differences were observed between the two-way interaction between aeroponic systems and variety. Highly significant difference ($p<0.01$) was observed between the varieties once again showing its phenotypic response to the various concentrations and aeroponic systems.

Table 5- 12 Anova for number of mini-tubers harvested at first harvest

SOURCE OF VARIATION	Two node cuttings				
	d.f	s.s	m.s	v.r	Fpr
Rep stratum	2	0.33	0.167	0.12	
Rep x Aeroponics unit stratum					
Aeroponics unit	1	2.72	2.72	1.96	0.29
Residual	2	2.78	1.39	12.50	
Rep x Aeroponics unit x Nutrient concentration stratum					
Nutrient Concentration	3	1.78	0.59	5.33	0.014*
Aeroponics Unit x Nutrient Concentration	3	1.06	0.35	3.17	0.064*
Residual	12	1.33	0.11	0.64	
Rep x Aeroponics Unit x Nutrient Concentration x Variety stratum					
Variety	2	81.33	40.67	234.24	< 0.001**
Aeroponics Unit x Variety	2	1.44	0.72	4.16	0.025*
Nutrient Concentration x Variety	6	0.89	0.15	0.85	0.539
Aeroponics Unit x Nutrient Concentration x Variety	6	0.78	0.12	0.75	0.616
Residual	32	0.78	0.17		
Total	71	100.00			

** Significant at p <0.01 * Significant at p < 0.05

At the second harvest, the grand mean for the number of mini-tubers harvested was 1.48. The power-dependent and power-independent systems had means of 1.67 and 1.31 respectively. The nutrient concentrations, C1, C2, C3 and C4 had means of 1.56, 1.39, 1.67 and 1.33 respectively. *Dente, Mankrong Pona* and *Pona* had means of 2.21, 1.25 and 1.00 respectively (Figure 5-8).

Plate 5-2 shows samples of harvested mini-tubers.

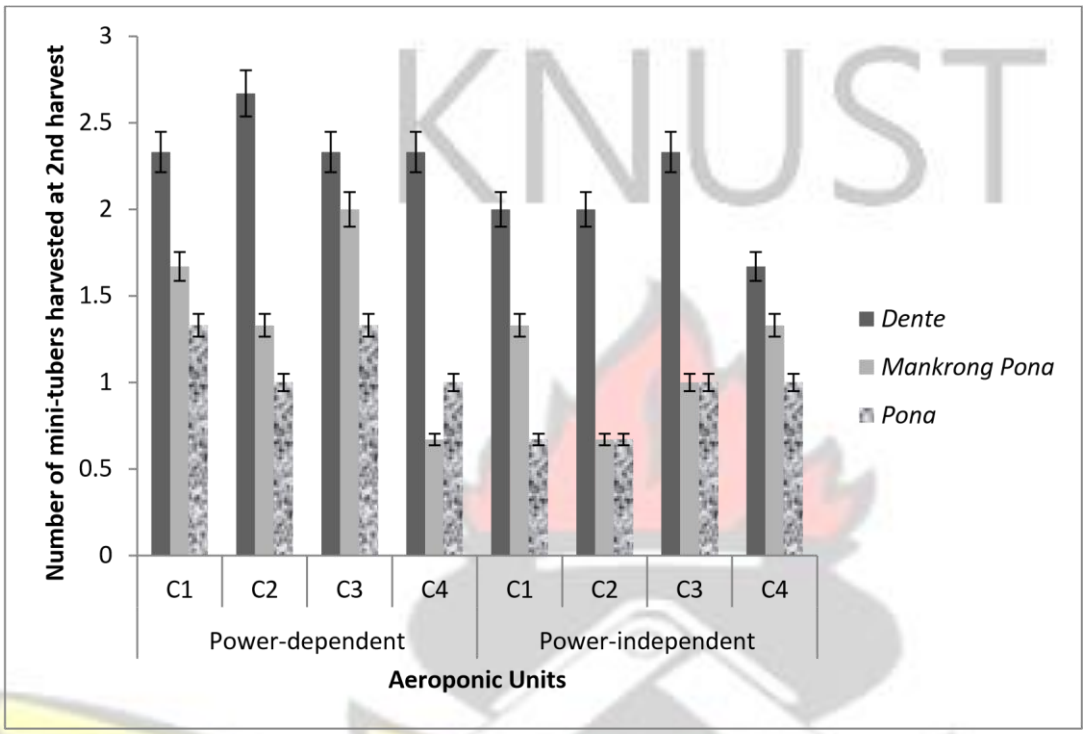


Figure 5- 8 Number of mini-tubers harvested at second harvest

Plate 5- 2 Harvested mini-tubers samples

Table 5- 13 Anova for number of mini-tubers at second harvest

SOURCE OF VARIATION	Two node cuttings				
	d.f	s.s	m.s	v.r	Fpr
Rep stratum	2	1.44	0.72	1.86	
Rep x Aeroponics unit stratum					
Aeroponics unit	1	2.35	2.35	6.04	0.133
Residual	2	0.78	0.39	3.50	
Rep x Aeroponics unit x Nutrient concentration stratum					
Nutrient Concentration	3	1.26	0.42	3.79	0.040*
Aeroponics Unit x Nutrient Concentration	3	0.82	0.27	2.446	0.113
Residual	12	1.33	0.11	0.32	
Rep x Aeroponics Unit x Nutrient Concentration x Variety stratum			9.76		
Variety	2	19.53		28.12	<0.001**
Aeroponics Unit x Variety	2	0.03	0.01	0.04	0.961
Nutrient Concentration x Variety	6	1.03	0.17	0.49	0.808
Aeroponics Unit x Nutrient Concentration x Variety	6	2.31	0.38	1.11	0.380
Residual	32	11.11	0.34		
Total	71	41.99			

** Significant at p<0.01 *Significant at p<0.05

There were no significant differences in the three-way interaction between aeroponic system, nutrient concentration and variety (Table 5-13). Significant differences were seen in the various nutrient concentrations used. There was a highly significant difference ($p < 0.01$) between the varieties.

The grand mean for the total number of mini-tubers harvested per plant (from both the first and second harvest) was 2.38. The aeroponic systems had means of 2.89 and 1.89 for the powerdependent and power-independent systems respectively (Figure 5-9).

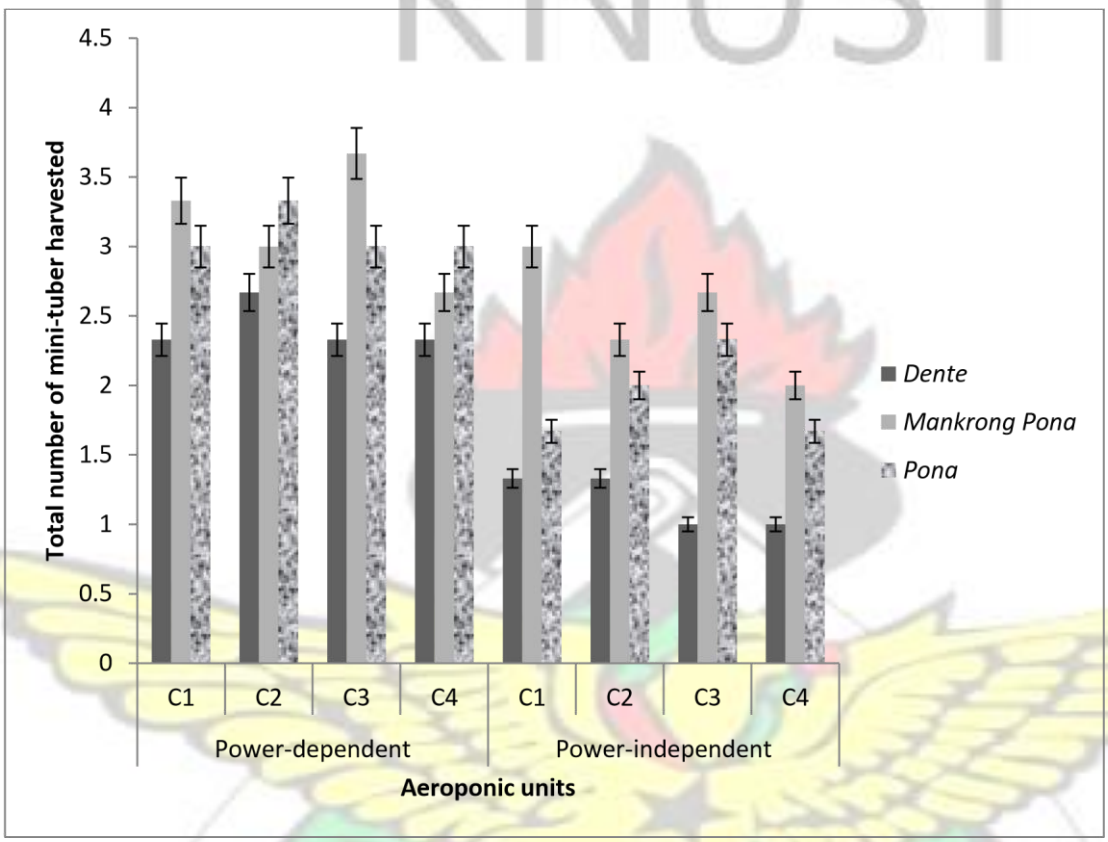


Figure 5- 9 Total number of mini-tubers harvested after two harvests

There were no significant differences between any of the three or two way interactions after the second harvest. However, there were significant differences between aeroponic systems (powerdependent and power-independent systems) (Table 5-14).

Table 5- 14 Anova for total number of mini-tubers harvest after two harvests

Source of Variation	d.f	s.s	m.s	v.r	Fpr
Rep stratum	2	3.08	1.54	5.84	
Rep x Aeroponics unit stratum					
Aeroponics unit	1	19.01	19.01	72.05	0.014*

Residual	2	0.52	0.26	0.72	
Rep x Aeroponics unit x Nutrient concentration stratum					
Nutrient Concentration	3	1.71	0.51	1.56	0.25
Aeroponics Unit x Nutrient Concentration	3	0.15	0.05	0.14	0.93
Residual	12	4.39	0.37	0.73	
Rep x Aeroponics Unit x Nutrient Concentration x Variety stratum			6.79		
Variety	2	13.58		13.58	<0.001**
Aeroponics Unit x Variety	2	1.19	0.59	1.19	0.312
Nutrient Concentration x Variety	6	2.42	0.40	0.81	0.57
Aeroponics Unit x Nutrient Concentration x Variety	6	0.81	0.13	0.27	0.95
Residual	32	16.00	0.50		
Total	71	62.87			

** Significant at p<0.01 *Significant at p<0.05

The grand mean for the weight of mini-tubers harvested was 6.22 g. The power dependent aeroponic systems had a higher mean of 7.07 whereas the power-independent aeroponic system had a mean of 5.36. The nutrient concentrations C1, C2, C3 and C4 had means of 3.57, 7.22, 10.58 and 3.5 g respectively (Figure 5-10). The varieties had means of 6.35, 6.26 and 6.02 g for *Dente*, *Mankrong Pona* and *Pona* respectively. There were significant differences in weight of mini-tubers produced using the various nutrient concentrations.

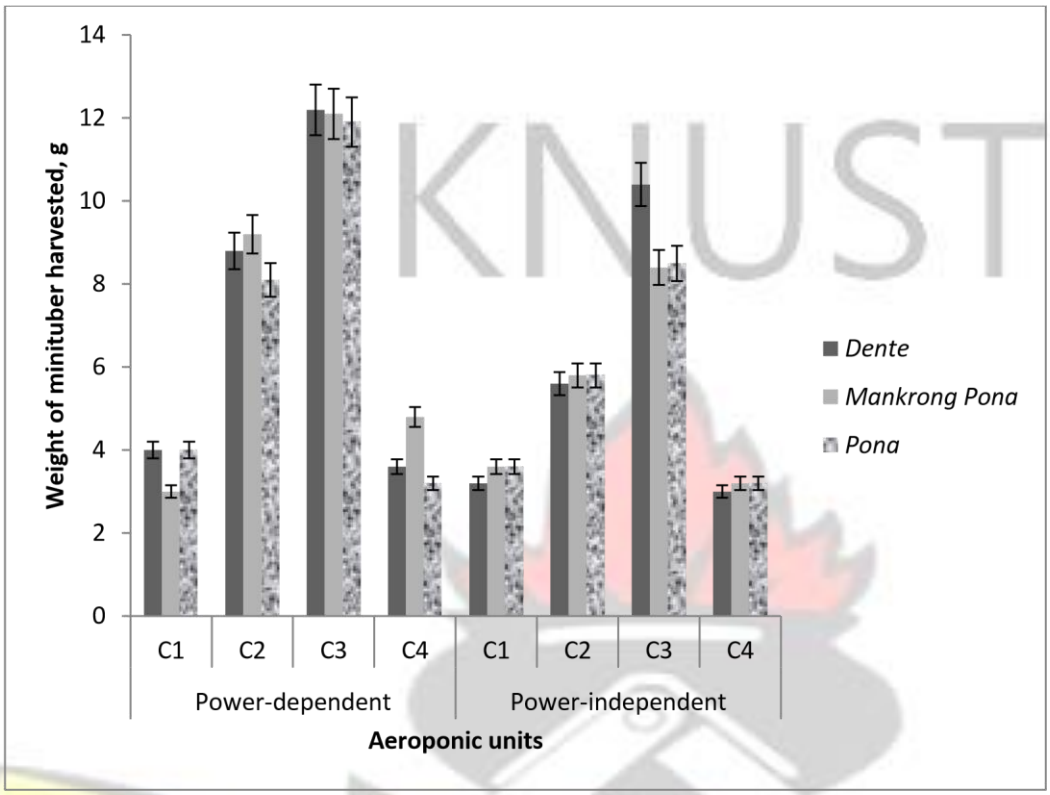


Figure 5- 10 Weight of mini-tuber harvested

5.2.2.4 Vine and leaves characteristics

A regression analysis using MSTAT 5.4 data analysis software showed a positive correlation between number of vines and mini-tuber size/weight. The more the number of vines, the bigger the mini-tubers harvested as shown in Figure 5-11. Kempen (2012) agrees that for optimal tuber formation and high yields a productive canopy is required. If crop growth rate is assumed to be proportional to the rate of photosynthesis and thus net assimilation, then maximum radiation interception is needed for as much of the growing season as possible. A positive correlation between leaf area and tuber number has also been established by Kahn *et al.,* (1983).

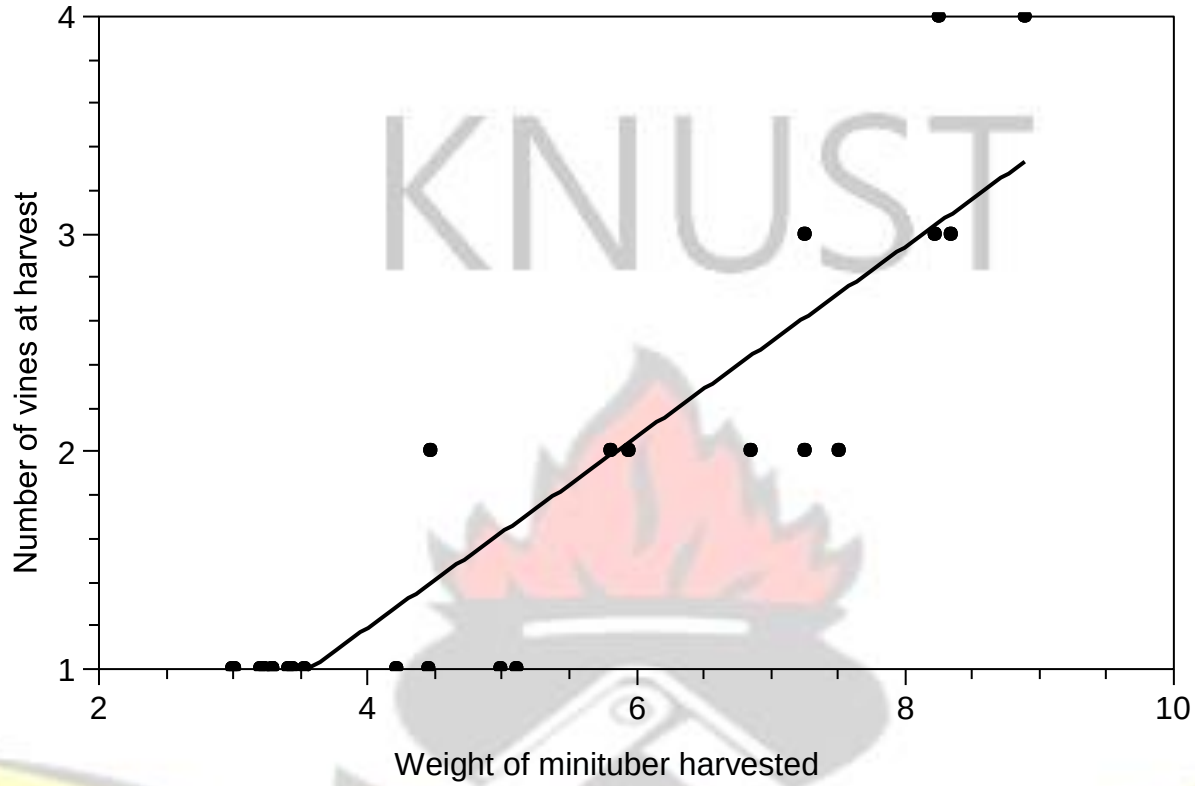


Figure 5- 11 Linear correlation between number of vines and weight of mini-tubers

5.2.2.5 Vine multiplication ratio for mini-tuber generation

Using the two-node cuttings, a mean of 130 vines were cut per explant for transplanting onto the aeroponic units. The maximum mean number of mini-tubers harvested for dente was attained using nutrient concentration C2 whereas the maximum number of mini-tubers for pona and *Mankrong Pona* were attained using nutrient concentration C3.

Table 5- 15 Mean mini-tuber yields and multiplication ratio of the yam varieties under the two aeroponic systems

Aeroponic unit	Vine cuttings per plant	Mean yield per cutting			Multiplication ratio/explant			
		Dente	*Mankrong Pona*	*Pona*	*Dente*	*Mankrong Pona*	*Pona*	*Mean*

Power-Dependent	130	2.67	3.67	3.00	347.10	477.10	390.00	404.70
Power-Independent	130	1.33	2.67	2.33	172.90	347.10	302.90	274.30

Propagation using the power-dependent aeroponic system gave a mean multiplication ratio of 404 mini-tubers per explant (Table 5-15). Using the power-dependent system, *Mankrong Pona* had the highest multiplication of 477 mini-tubers/explant followed by *Pona* and *Dente* with 390 and 347 mini-tubers/explant respectively.

Propagation using the power-independent aeroponic system again showed *Mankrong Pona* having the highest multiplication ratio of 347 mini-tubers/explant followed by *Pona* and *Dente* with 302 and 173 mini-tubers/explant respectively (Table 5-15). The mean multiplication ratio of the power-independent system was 274 mini-tubers per explants.

5.2.2.6 Dormancy and breaking dormancy characteristics of mini-tubers

The physical characteristic of the tubers at the initial stages of breaking dormancy is as shown in Plate 5-3 with yam mini-tubers samples showing the foliar primordium on the surface of the tuber. The grand mean time for breaking dormancy was 63.12 days after harvest (DAH). Minitubers from the power-dependent and power-independent aeroponic systems broke dormancy at

63.17 and 63.08 DAH respectively. Mini-tubers propagated using C1, C2, C3 and C4 had a mean dormancy breaking time of 62.83, 62.72, 63.28 and 63.67 DAH respectively (Figure 5-12). The varieties, *Dente*, *Mankrong Pona* and *Pona* had mean dormancy breaking times of 89.92, 43.25 and 56.21 DAH respectively.

Plate 5- 3 Yam mini-tubers samples in phase three depicting the foliar primordium to appearance of the shoot bud on the surface of the tuber

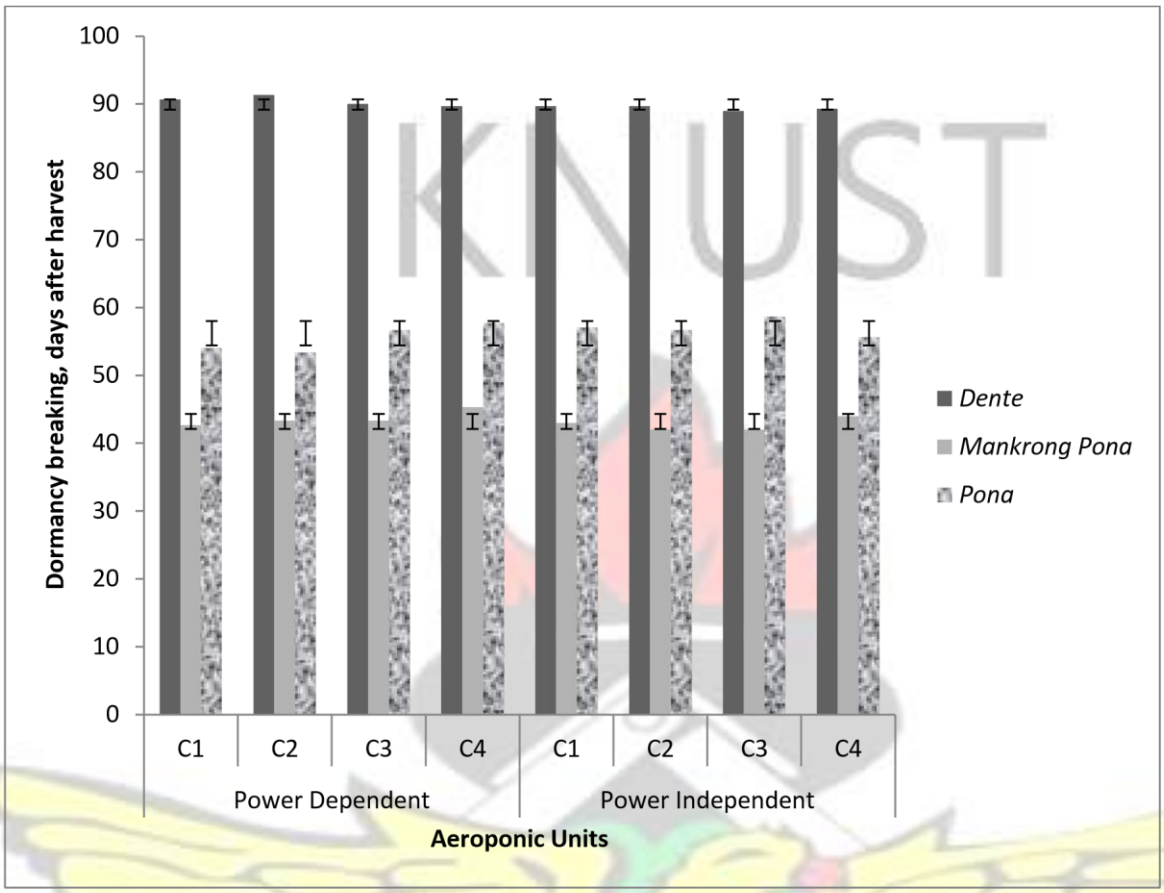


Figure 5- 12 Days to breaking dormancy for the various treatments

Significant differences were observed among the two-way interactions between aeroponic units and variety as well as nutrient concentration and variety (Table 5-15). However, no significant differences were observed for the three-way interaction between aeroponic units, nutrient concentration and variety. Very significant differences ($p<0.01$) were observed for the varieties in their response to breaking dormancy.

Table 5- 16 Anova for days to breaking dormancy

SOURCE OF VARIATION	d.f	s.s	m.s	v.r	Fpr
Rep stratum	2	1.583	0.792	0.14	

Rep x Aeroponics unit stratum					
Aeroponics unit	1	0.125	0.125	0.02	0.89
Residual	2	11.08	5.54	1.12	
Rep x Aeroponics unit x Nutrient concentration stratum					
Nutrient Concentration	3	10.15	3.38	0.68	0.58
Aeroponics Unit x Nutrient Concentration	3	8.26	2.75	0.56	0.65
Residual	12	59.33	4.94	2.22	
Rep x Aeroponics Unit x Nutrient Concentration x Variety stratum					
Variety	2	27855.58	13927.79	6247.98	<0.001**
Aeroponics Unit x Variety	2	25.08	12.542	5.63	0.008**
Nutrient Concentration x Variety	6	40.30	6.72	3.01	0.019*
Aeroponics Unit x Nutrient Concn x Variety	6	23.02	3.83	1.72	0.148
Residual	32	71.33	2.22		
Total	71	28105.87			

** Significant at p<0.01 *Significant at p<0.05

After reaching physiological maturity, seeds may enter a state of deep dormancy. Dormancy is the physiological state of the tuber in which tubers do not sprout even when placed in ideal germination conditions (Reust, 2002; Sonnewald and Sonnewald, 2014). Mini-tubers used for the direct seeding evaluation in the screenhouse were not allowed to break dormancy before planting. They were planted two days after harvest and thus none of the following characteristics were observed with this treatment. However the number of days to emergence was suggestive of the fact that it underwent dormancy in the soil after planting. Craufurd *et al*. (2001) express that the mechanism of dormancy in yam tubers is not fully understood although various changes in hormonal composition during the dormant period are known. Ile *et al*. (2006) identify three phases of tuber dormancy for white yam and these are: “phase one: the tuber initiation to the appearance of the

tuber germinating meristem; phase two: the tuber germinating meristem to initiation of foliar primordium; and phase three: the foliar primordium to appearance of the shoot bud on the surface of the tuber" (Ile *et al.*, 2006).

According to Craufurd *et al*. (2001), dormancy ends when tubers germinate and the growing shoot(s) or vines emerge. In this research, phase three of the dormancy stages as defined by Ile *et al.* (2006) was observed and reported as the dormancy breaking stage.

5.3 General Discussion of Results from Agronomic Evaluation of Aeroponic systems

In yams, mini-tuber production is affected by genotype, as has been seen by Powell *et al.* (1989) for potato. This research confirms the assertion that genotypes differ widely in their capacity to produce mini-tubers, some being more prolific than others (Venkatasalam *et al.*, 2011). The prolific nature of these genotypes established a positive correlation between days to rooting and days to mini-tuber initiation (Figure 5-13).

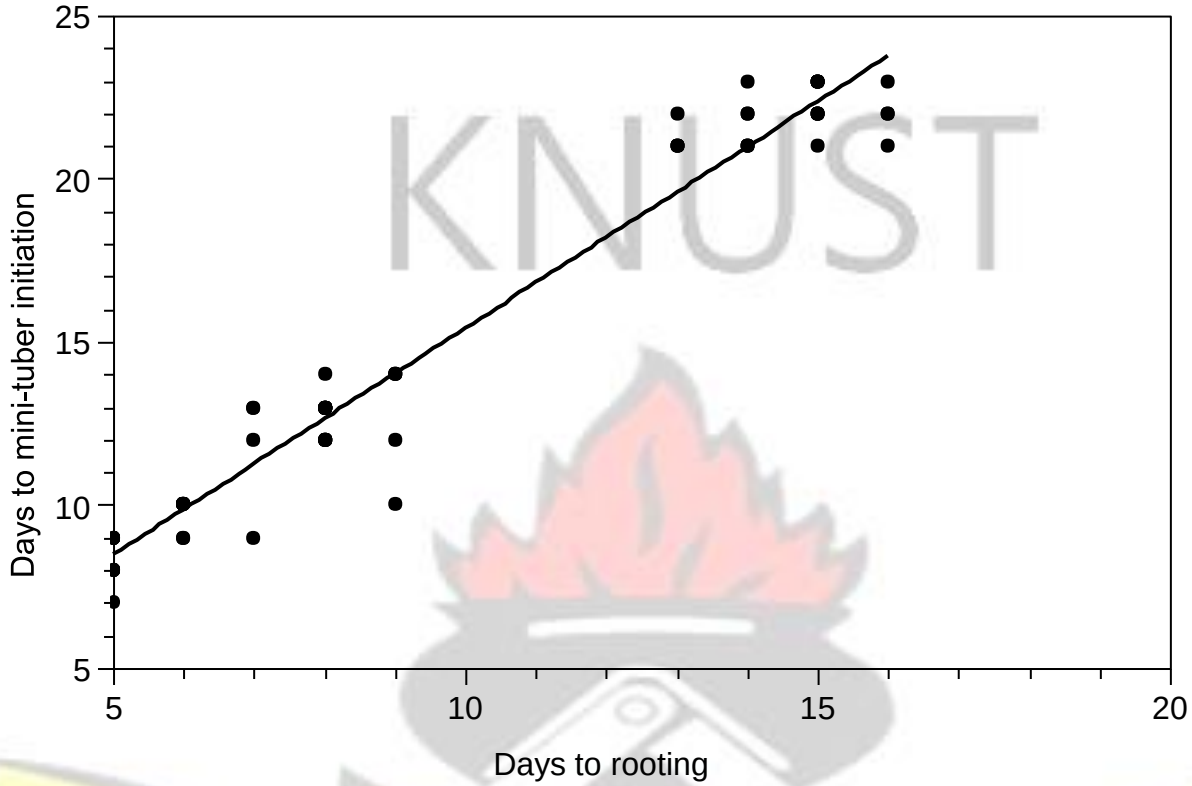


Figure 5- 13 Correlation between days to rooting and days to mini-tuber initiation

Even though no correlation was observed for days to root initiation and number of roots at root initiation, the same was not the case for days to mini-tuber initiation and number of mini-tubers at mini-tuber initiation. A negative correlation ($R^2 = 0.196$) was observed between the number of days to mini-tuber formation and the number of mini-tubers at tuber initiation establishing that early tuberisation does not have any effect on the number of mini-tubers as shown in Figure 5-14. This can also be attributed to the genotypic differences between the yam varieties used.

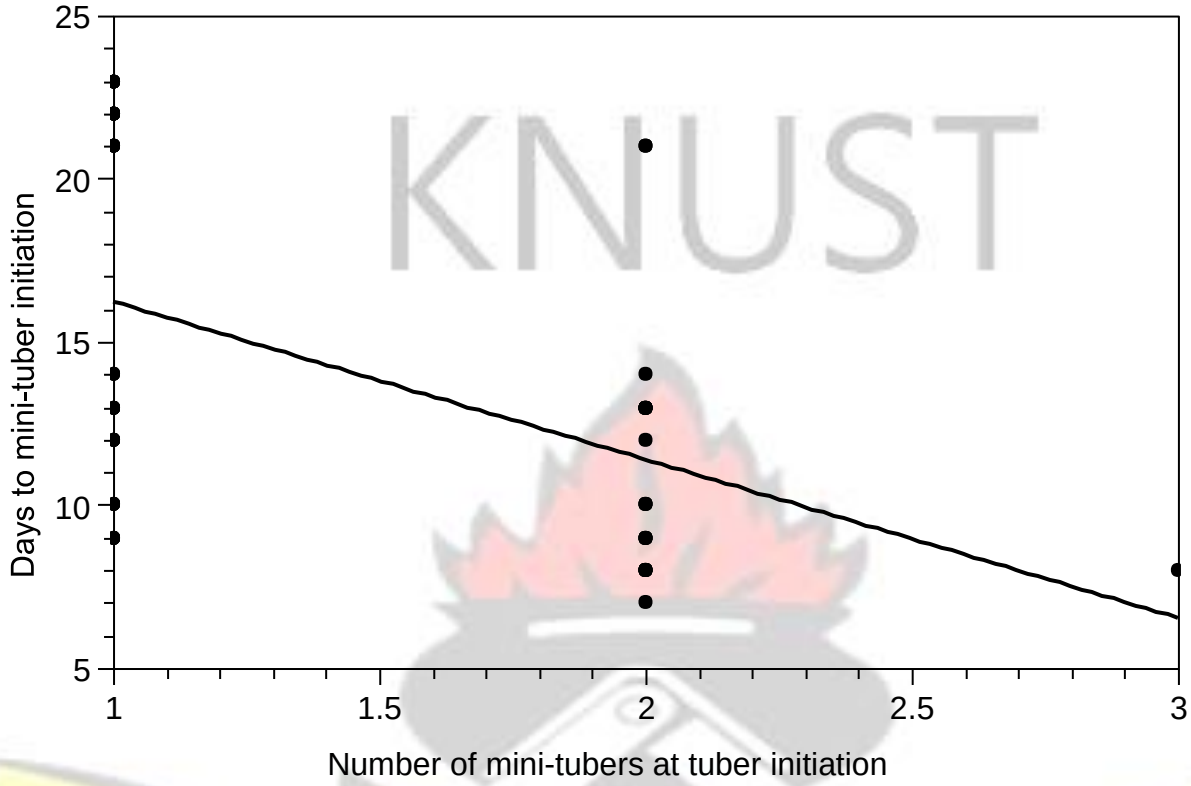


Figure 5- 14 Correlation between days to mini-tuber initiation and number of mini-tubers at tuber initiation

As has been reported by Soffer and Burger (1988), aeroponics optimizes root aeration resulting in more yields than classical hydroponics. A positive correlation ($R^2 = 0.1274$), though not very strong was observed between number of roots and number of mini-tubers. From Figure 5-15 varieties with the most prolific rooting system also yielded more mini-tubers, thus confirming the report by Soffer and Burger (1988).

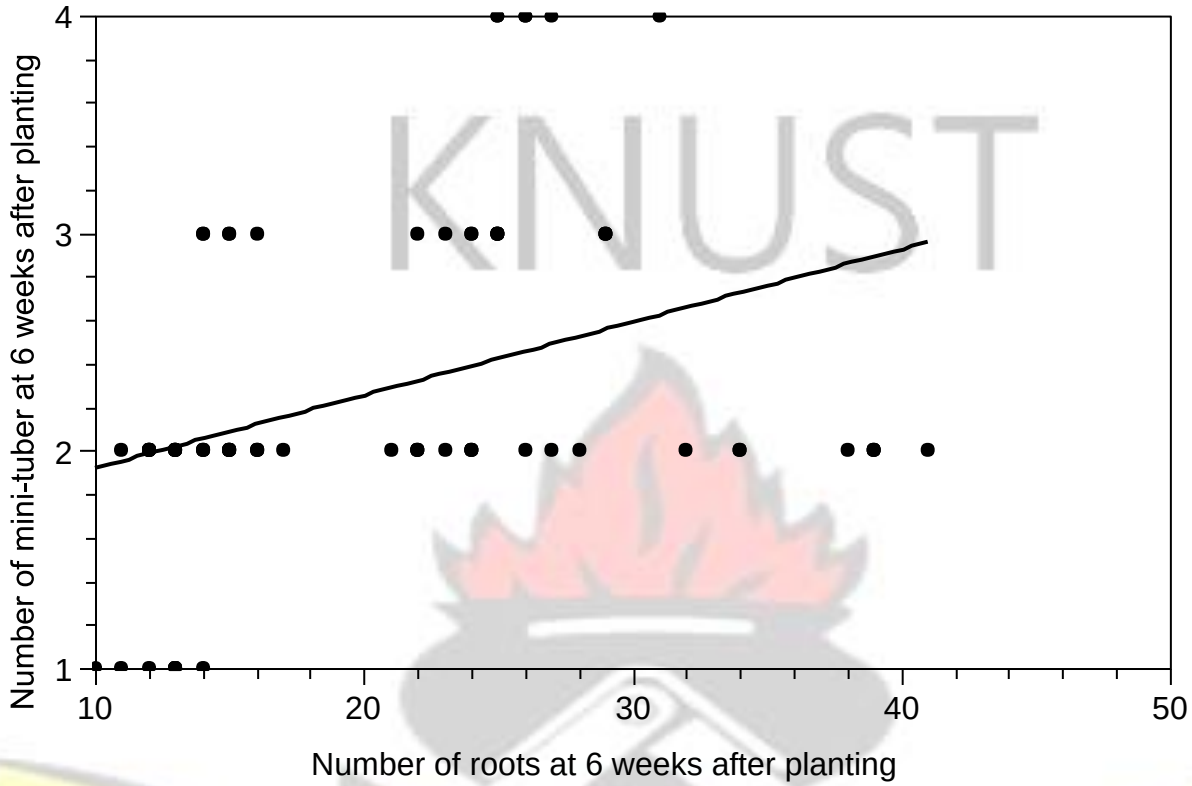


Figure 5- 15 Correlation between number of roots and number of mini-tubers at six weeks after planting

There was also a positive correlation ($R^2 = 0.344$) between days to rooting and days to new leaf (Figure 5-16). Early rooted varieties also had early new leaves.

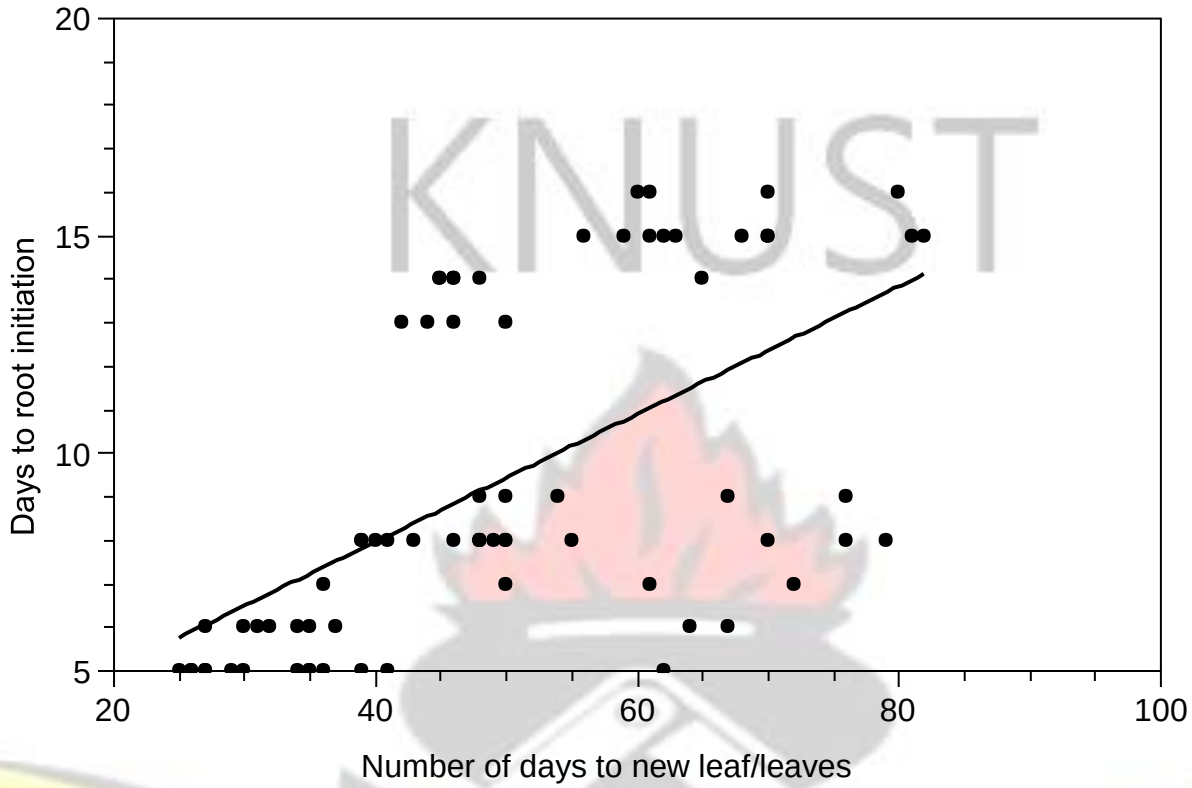


Figure 5- 16 Correlation between days to root initiation and number of days to new leaf

Although the early rooting may have played some role in vine cuttings expressing new leaf/leaves, one remains free to speculate that the quantitative genotypic reflect the physiological differences in the cultivars used. Thus, the correlations between the number of days to root initiation and new leaf/leaves formation may depend on the physiological conditions of the cultivars used and not necessarily on the nutrient concentration used.

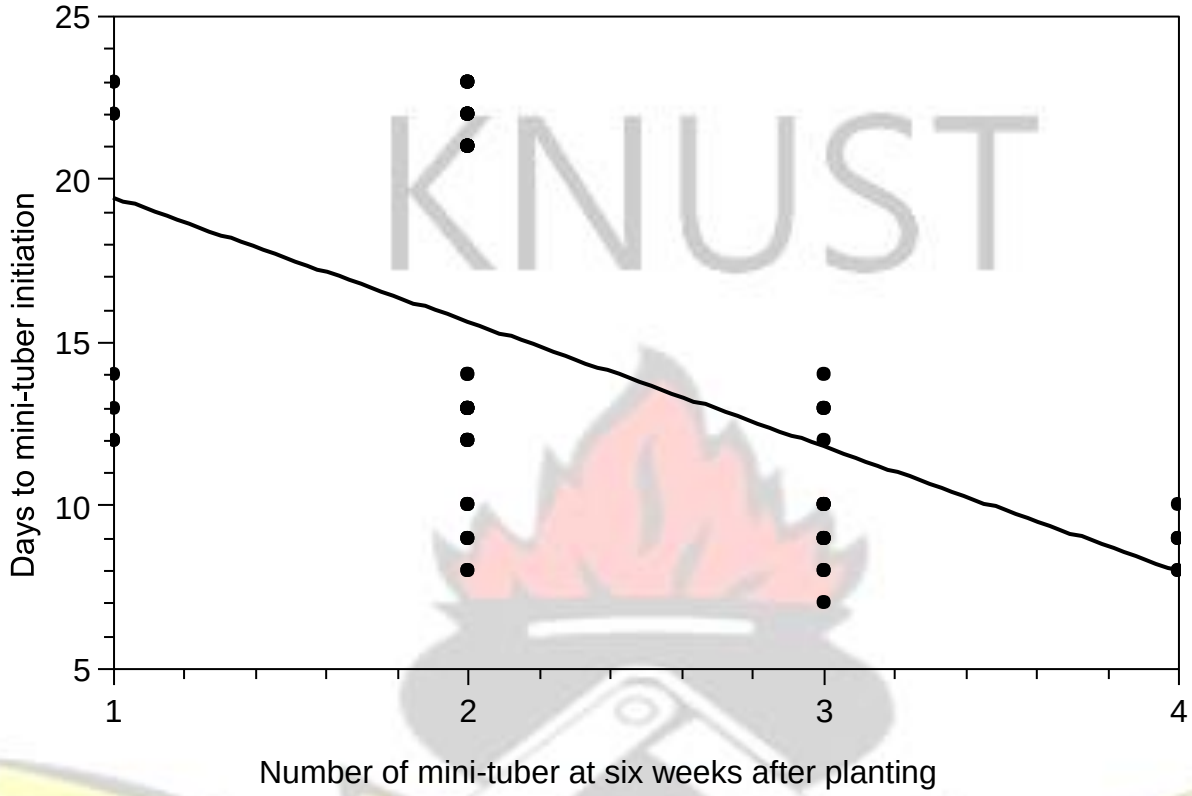


Figure 5- 17 Correlation between days to mini-tuber initiation and number of mini-tubers at six weeks after planting

The negative correlation (R^2 = 0.28) between days to mini-tuber initiation and number of minitubers at six weeks after planting (Figure 5-17), though weak, is suggestive of the fact that initiating early tuberisation does not affect final yield or number of mini-tubers that would be produced per plant. This is because many factors have been reported to affect tuber formation (Kempen, 2012: Menzel, 1980: Sattelmacher and Marschner, 1978). According to Kempen (2012), even the bacteria living in the root zone are reported to have an influence; however, nitrogen levels, temperature and light have the greatest effect. Reports show that short days and cool night temperatures also promote tuberization whereas long days, high night temperatures, and high nitrogen fertilisation inhibit or delay the process (Sattelmacher and Marschner, 1978).

This research did not go further to corroborate these assertions, however, it was realized that reducing light and shade by 40 % in the screenhouse prevented loss of materials (vine cuttings) planted on the aeroponic units. This could be an area for further research.

Absolute darkness is necessary for tuber formation, otherwise with a minimum of light, stolon tips develop small bleached leaves and no tuber formation will occur (Ritter *et al.,* 2001). Minitubers were observed to be growing on other parts of the plant above the root chamber from axillary nodes on the stem as has been reported by Ewing and Struik (1992). Even though, this was not the focus of this research, ways to maximize the production of such above ground minitubers could yield an added advantage and should be researched into.

The planting density, number and timing of harvests are key factors in optimizing mini-tuber production. The planting density used resulted in optimized resource use efficiency. Maroya *et al*. (2014) reported using a planting density of 400 and 100 cm^2/plant which resulted in minituber every three to five months whereas this research used a planting density of 36 cm^2/plant and reports mini-tuber yields from 4 months onwards and subsequently every two weeks.

There were also highly significant differences ($p<0.05$) between the multiplication ratio of the varieties propagated using the two different aeroponic systems (Figure 5-18) The performance of Dente, though the lowest amongst the three varieties used performed favourably with results achieved.

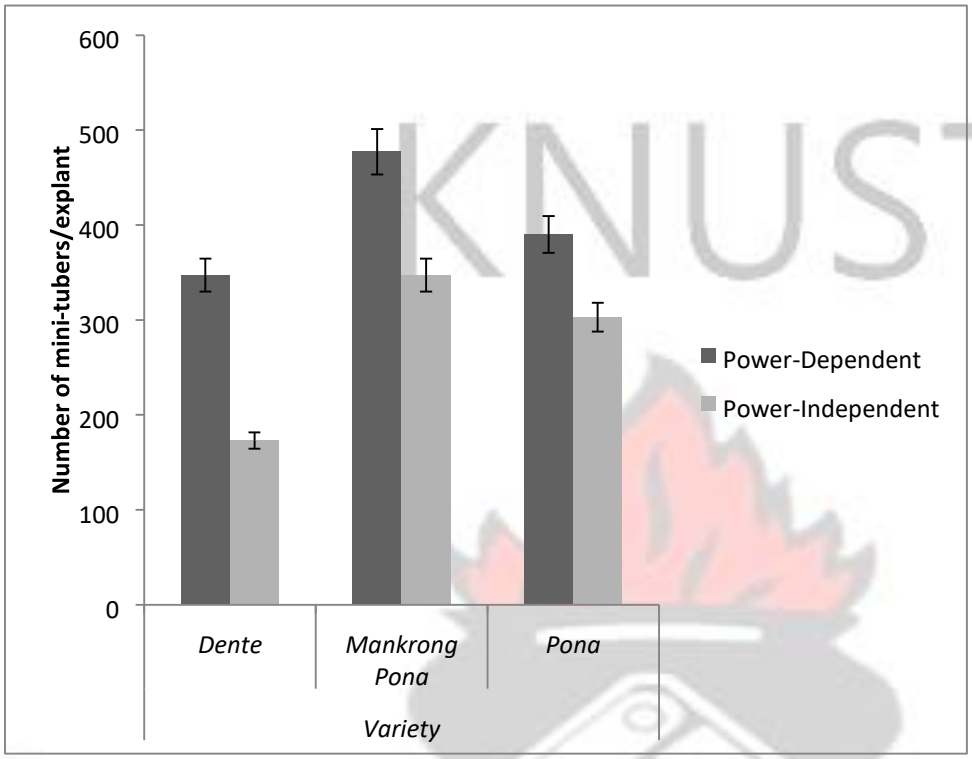


Figure 5- 18 Multiplication ratio of the various varieties using the two aeroponic systems

5.4 Results from Agronomic Evaluation of resulting mini-tubers

Planting whole tubers rather than setts has been proven to provide benefits in terms of survivability once planted (McNamara and Morse, 2014). The small, whole tuber setts have a head, which means that sprouting is early, strong and uniform. Also, these small, whole tuber setts have no cut surfaces and therefore rot less easily than cut pieces (Wilson, 1989). The following discussion reports on the results from the agronomic evaluation of the mini-tubers that were harvested from the two aeroponic systems.

5.4.1 Direct planting of non-dormant seeds in the field

The grand mean for emergence under this treatment was 5.36 days after planting. Mean emergence for both the power-dependent and power-independent aeroponic systems was 5.36 days after

planting. There were no significant differences between any interactions under this treatment (Figure 5-19).

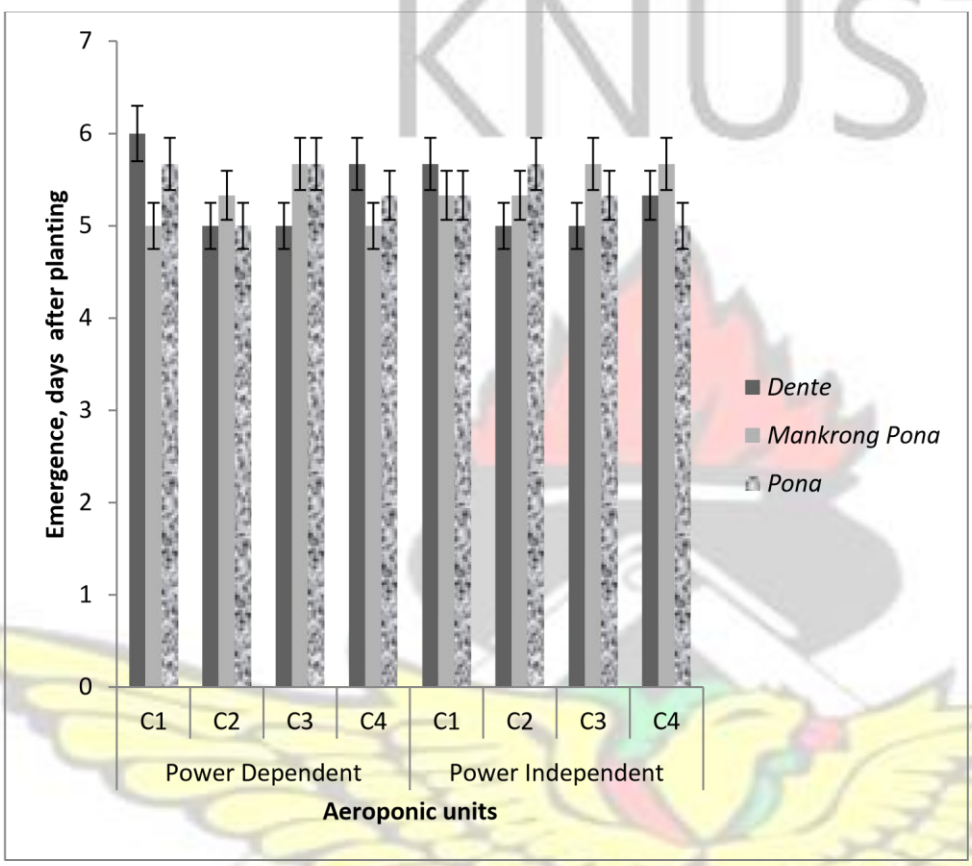


Figure 5- 19 Emergence characteristics of directly planted non-dormant seeds in the field

5.4.2 Direct planting of dormant seeds

The mean emergence for all varieties planted under this treatment was 60.21 days after planting (DAP). Mean emergence for mini-tubers derived from the power-dependent and powerindependent aeroponic systems were 60.56 and 59.86 days after planting. The mean emergence for C1, C2, C3 and C4 were 60.17, 58.00, 60.39 and 62.28 DAP respectively. Varietal means were 81.25, 56.08 and 43.29 for *Dente*, *Mankrong Pona* and *Pona* respectively. The emergence characteristics showing roots and shoots are as shown in Plate 5-4.

Plate 5- 4 Mini-tuber showing germination at the apical meristem

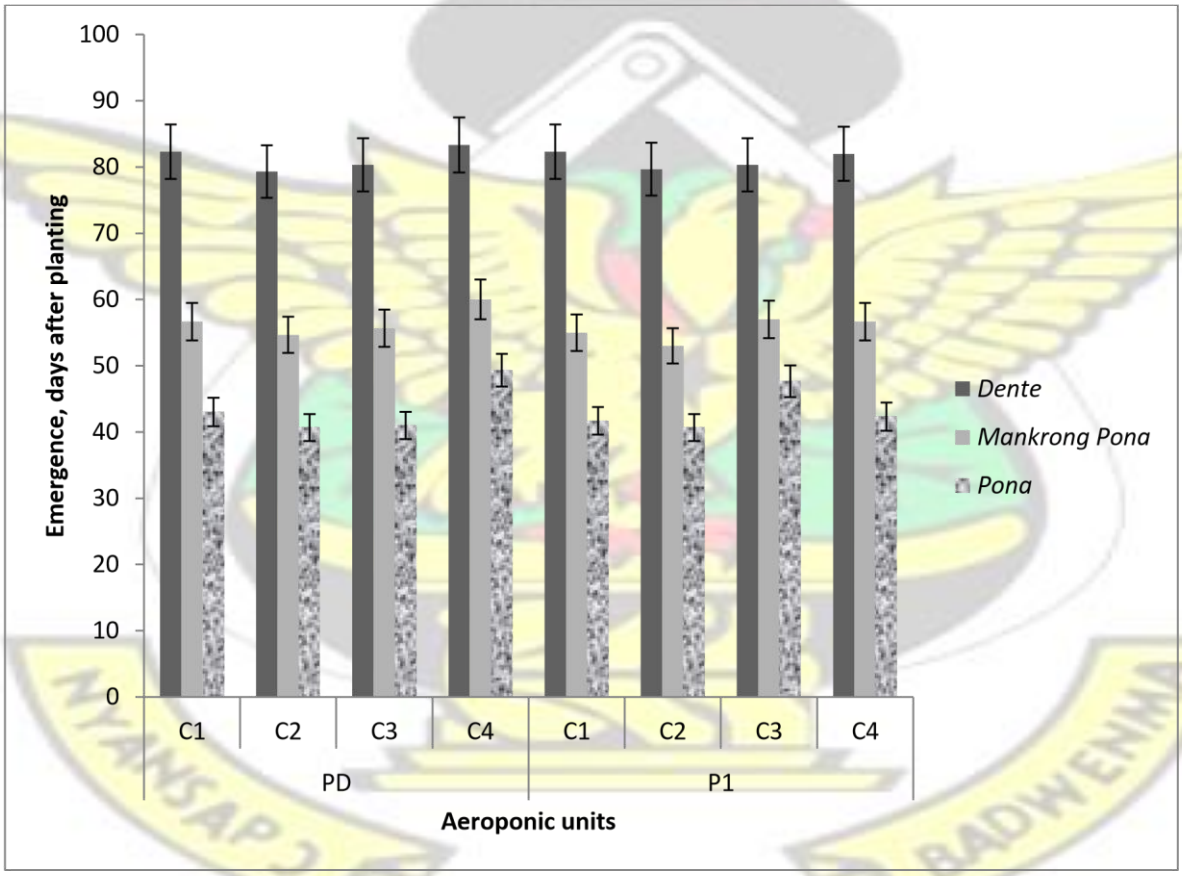


Figure 5- 20 Days to emergence for directly planted dormant mini-tubers

There were no significant differences ($p<0.05$) between either of the two or three-way interactions (aeroponic units and nutrient concentrations; nutrient concentration and variety; aeroponic units, nutrient concentration and variety). There was, however, very significant differences ($p<0.01$) in varietal performance with regards to emergence (Table 5-17).

Table 5- 17 Anova for emergence of directly planted dormant seeds

SOURCE OF VARIATION	d.f	s.s	m.s	v.r	Fpr
Rep stratum	2	42.25	21.12	0.73	
Rep x Aeroponics unit stratum					
Aeroponics unit	1	8.68	8.68	0.3	0.638
Residual	2	57.52	28.76	0.70	
Rep x Aeroponics unit x Nutrient concentration stratum					
Nutrient Concentration	3	165.48	55.16	1.34	0.30
Aeroponics Unit x Nutrient Concentration	3	94.15	31.38	0.76	0.53
Residual	12	492.44	41.03	4.74	
Rep x Aeroponics Unit x Nutrient Concentration x Variety stratum					
Variety	2	17902.58	8951.29	1033.67	<0.001**
Aeroponics Unit x Variety	2	3.69	1.84	0.21	0.81
Nutrient Concentration x Variety	6	28.97	4.82	0.56	0.76
Aeroponics Unit x Nutrient Concentration x Variety	6	66.97	11.16	1.29	0.29
Residual	32	277.11	8.660		
Total	71	19139.87			

** Significant at $p<0.01$

5.4.3 Pre-germination of non-dormant seeds

The mean emergence for this treatment was 5.6 days after planting (Figure 5-21). Mean emergence for the aeroponic systems were 5.7 DAP (power-dependent) and 5.50 DAP (powerindependent). Nutrient concentrations C1, C2, C3 and C4 has mean emergence of 5.6, 5.4, 5.4 and 5.9 DAP respectively. The varieties *Dente*, *Mankrong Pona* and *Pona* had mean emergence of 5.71, 5.46 and 5.6 DAP respectively. There were no significant differences among the interactions under this treatment.

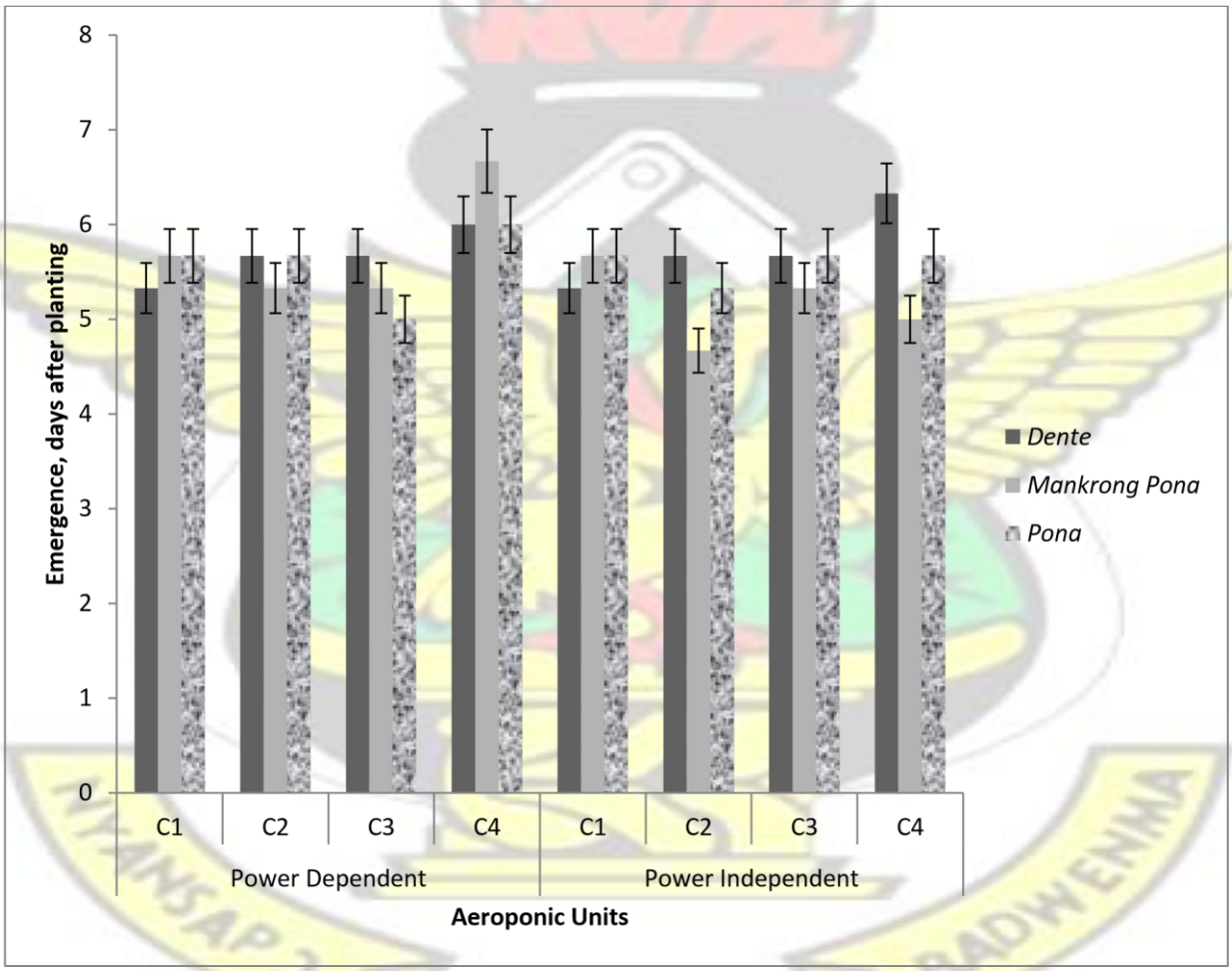


Figure 5- 21 Emergence of nursed seeds in the screenhouse

5.4.4 Seed yam yields

The mean number of tubers per plant for the power-dependent aeroponics was 2.58, 2.92 and 2.10 tubers for *Dente*, *Mankrong Pona* and *Pona* respectively propagated using mini-tubers from C3. Mean number of tubers for the power-independent system was 2.01, 2.23 and 2.12 for *Dente*, *Mankrong Pona* and *Pona* respectively, again using C3.

There were significant differences between C1, C2 and C3 in the numbers of mini-tuber/plant under the power-dependent system (Figure 5-22). Under the power-independent system, the only significant difference was seen between C3 and the other nutrient concentration. Significant differences were not seen among the various varieties with respect to the individual nutrient concentration used. However, significant differences were seen in the number of mini-tubers of two varieties, *Dente* and *Mankrong Pona* propagated under the two aeroponic system using nutrient concentration C3. In all treatments, seed yam propagated from C3 lines performed better in terms of number of tubers per plant.

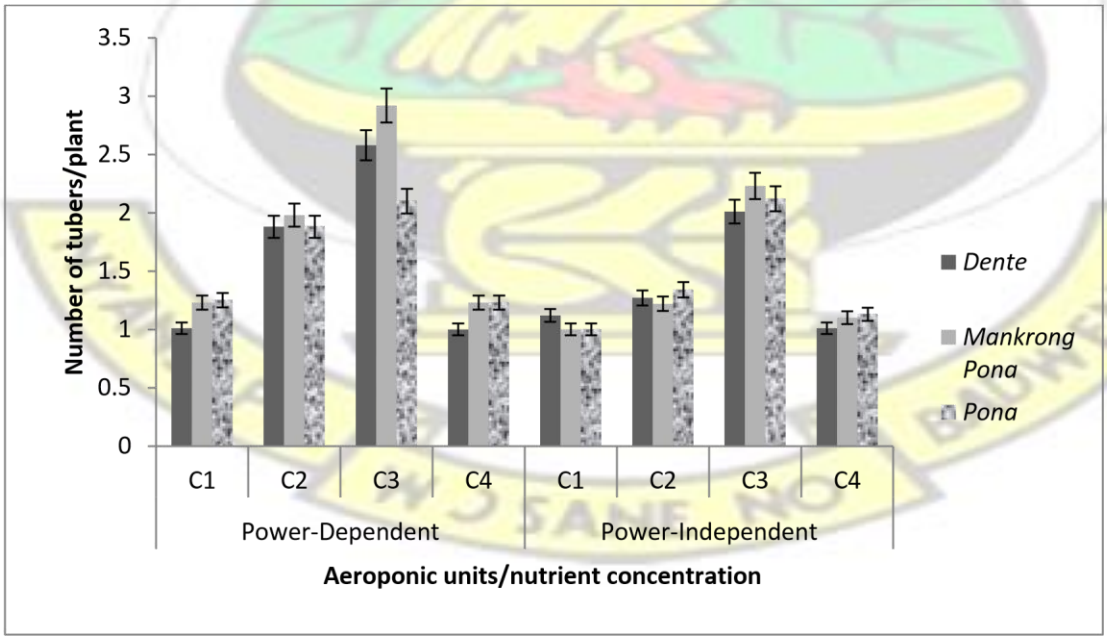


Figure 5- 22 Chart showing number of tubers per plant

The mean tuber weight for seed yam propagated with C3 mini-tubers under the power-dependent system was 560 g, 560 g and 543.28 g for *Dente*, *Mankrong Pona* and *Pona* respectively. Under the same treatment, the power-independent system also gave 521.22 g, 501.11 g and 510 g for *Dente*, *Mankrong Pona* and *Pona* respectively.

There was no significant difference in weight between seed yams propagated from C3 minitubers under the two aeroponic systems. With the exception of *Dente* propagated from C2 minitubers under the power-dependent system, no significant differences were seen in any of the varieties under the various treatments.

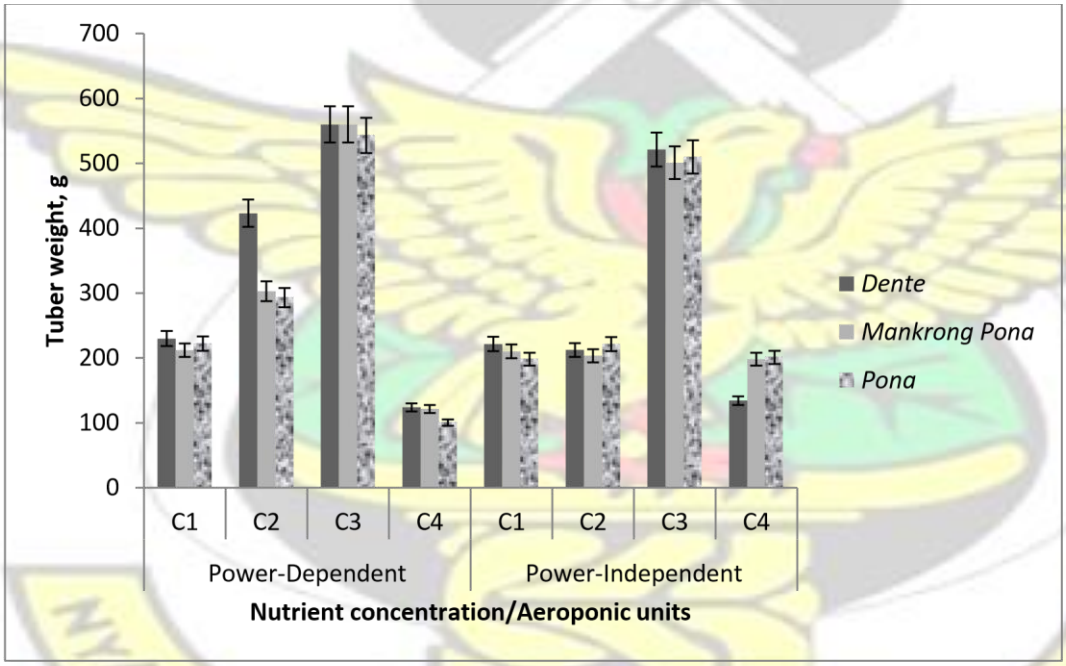


Figure 5- 23 Seed yam weight

5.4.5 Vine multiplication ratio for seed yam generation

Mean seed yam multiplication ratio of the power-dependent aeroponic system for all the varieties was 1035 mini-tubers/explant. *Mankrong Pona* had the highest multiplication ratio of 1393 seed yams/explant followed by *Dente* and Pona with 895 and 819 seed yams/explant respectively.

The highest multiplication ratio using the power-independent aeroponic system was 774 seed yams /explant for *Mankrong Pona* whilst *Pona* and *Dente* had 642 and 347 seed yams/explant respectively. The mean seed yam propagation ratio using the power-independent system was 587 seed yams/explant. Table 5-18 presents the mean seed yam yield and multiplication ratio of the yam varieties under the two aeroponic systems.

Table 5- 18 Mean seed yam yields and multiplication ratio of the yam varieties under the two aeroponic systems

Aeroponic unit	Mean yield per mini-tuber			Multiplication ratio/explant (mini-tuber)			Multiplication ratio/explant (seed yam)			
	Dente	***Mankrong Pona***	***Pona***	***Dente***	***Mankrong Pona***	***Pona***	***Dente***	***Mankrong Pona***	***Pona***	***Mean***
PowerDependent	2.58	2.92	2.10	347.10	477.10	390.00	895.52	1393.13	819.00	1035.88
Power-Independent	2.01	2.23	2.12	172.90	347.10	302.90	347.53	774.03	642.15	587.90

5.5 General Discussion of Results from Agronomic Evaluation of Resulting Mini-tubers

Propagated plants from mini-tubers nursed in the screenhouse had rudimentary leaves before transfer to the experimental field 14 days after emergence whilst compound leaves were formed after transplanting. According to Lommen (1995), glasshouse raised transplants from very early cultivars sometimes show a poor performance after transplanting into the field. This has been attributed to the fact that immediately after transplanting, a major part of the daily dry matter production is invested in tuber growth (Lommen, 1995). This high degree of partitioning to tubers leads to a limited growth of the haulm and thereby limits the biomass production and final tuber yield (Lommen, 1995).

From Table 5-19, nutrient concentration did not have any significance on the number of tubers harvested. However, significant differences were seen in the mini-tuber weight of the various varieties produced using the various nutrient concentrations. The mean number of tubers produced was significant ($p<0.01$) for all varieties propagated using C3 (Table 5-19). Even though the nutrient effects were not so significant in any of the previous discussions, it stands to be argued that the nutrient concentration used in propagating the mini-tubers, whether by the power-dependent or power-independent aeroponic systems has significant impact on the final yield of the second generation seed.

Table 5- 19 Anova for number of tubers harvested under direct planting of non-dormant seeds in the field

SOURCE OF VARIATION	d.f	s.s	m.s	v.r	Fpr
Rep stratum	2	1.69	0.85	0.97	

Rep x Aeroponics unit stratum					
Aeroponics unit	1	0.50	0.50	0.57	0.52
Residual	2	1.75	0.87	7.27	
Rep x Aeroponics unit x Nutrient concentration stratum					
Nutrient Concentration	3	15.33	5.11	42.46	<0.001**
Aeroponics Unit x Nutrient Concentration	3	1.05	0.35	2.92	0.07
Residual	12	1.44	0.12	0.60	
Rep x Aeroponics Unit x Nutrient Concentration x Variety stratum					
Variety	2	0.11	0.55	0.28	0.76
Aeroponics Unit x Variety	2	0.33	0.16	0.83	0.45
Nutrient Concentration x Variety	6	0.33	0.55	0.28	0.94
Aeroponics Unit x Nutrient Concentration x Variety	6	0.78	0.13	0.64	0.69
Residual	32	6.44	0.20		
Total	71	29.78			

** Significant at $p < 0.01$

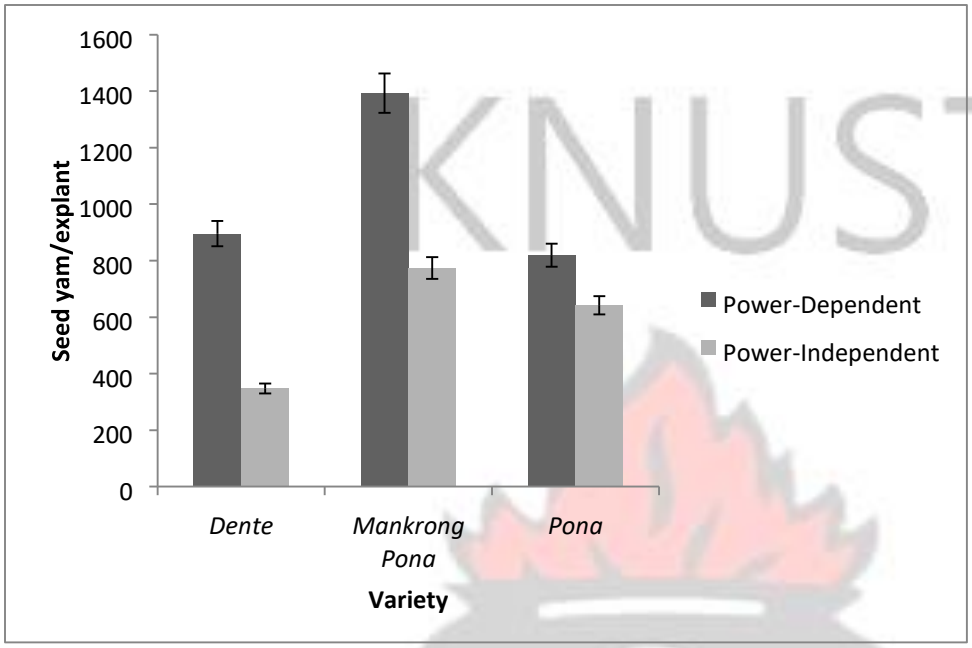


Figure 5- 24 Multiplication ratio of the various varieties using the two aeroponic systems

Significant differences were seen between seed yams propagated from mini-tubers generated using the power-dependent and power-independent systems (Figure 5-24).

5.6 Results from Economic analysis

A market for mini-tubers is almost non-existent in Ghana. The size of operations and consequent economies of scale of mini-tuber production as well as the efficiency of open field production of mini-tubers and first-to-second generation seed tubers are factors that directly impact on the final price for end-users (Mateus-Rodrigues, 2013).

5.6.1 Benefit-Cost analysis for seed yam production under the power-dependent and power-independent aeroponic system

Total fixed costs for the installation of the power-dependent system was GHC 52200.00 (Table 5-20) whereas that of the power-independent system was 44.44% lower in total fixed cost (Table 5-23). A sum of years depreciation of assets of the power-dependent and power-independent system is as shown in Tables 5-21 and 5-24.

Total variable cost for seed yam production using the power-independent system was 25.29 % lower than that of the power-dependent system. Net benefit accrued over an active production period of five years was GHC 130768.00 and GHC 101927 for the power-dependent and powerindependent aeroponic systems respectively (Tables 5-22 and 5-25). This showed a percentage difference of 28.29 % in favour of the power-dependent system underscoring the fact that though the power-independent system has a lower investment cost, the power-dependent system has a higher benefit margin.

Two economic variables: benefit-cost ratio (BCR) and the return on investment (ROI) were used to calculate the financial viability of the two systems over an active production period of five years. BCRs for the power-dependent system was 0.11, 0.33, 0.65, 0.88 and 1.22 from year one through to year five (Table 5-22). The power-independent system had BCRs of 0.21, 0.45, 0.72, 1.03 and 1.36 for years one to five respectively (Table 5-25). According to Holland (2012) a benefit-cost ratio (or cost-benefit ratio) of (example) 1.21 implies that for every one unit that is invested in the system, the investment generates a net benefit that is 1.21 times (or 121 %) the invested amount.

All BCRs from both the power-dependent and power-independent system are said to be good with each performing well above the breakeven ratio of 1:1.

Return on investment over a five year period for the power-dependent and power-independent system were 211.60 % and 282.00 % respectively Tables 5-22 and 5-25.

Table 5-

20 Installation and seed yam production cost under the power-dependent (pressurised) aeroponic system

Item Description	Production Years/ costs									
	Year 1		**Year 2**		**Year 3**		**Year 4**		**Year 5**	
	Amount GHC	Percentage %	Amount GHC	Percentage %	Amount GHC	Percentage %	Amount GHC	Percentage %	Amount GHC	Percentage %
Fixed cost: Aeroponic system										
Screenhouse	18000.00	34.48	0	0	0	0	0	0	0	0
Pump house	15000.00	28.74	0	0	0	0	0	0	0	0
Fertigation	5000.00	9.58	0	0	0	0	0	0	0	0
Electrical system	6200.00	11.88								
Growth chambers	8000.00	15.32	0	0	0	0	0	0	0	0
Total	**52200.00**	**100.00**	0	0	0	0	0	0	0	0
Variable Cost 1: Mini-tuber production			0	0	0	0	0	0	0	0
Electricity costs	600.00	9.45								
Soluble nutrients	500.00	7.87	712.2	9.20	845.38	9.20	1003.47	9.20	1191.12	9.20
Planting materials	400.00	6.3	593.50	7.66	704.48	7.66	836.22	7.66	992.59 0	7.66
Water and water analysis	550.00	8.66	0	0	0	0	0	0		0
Personnel cost	2500.00	39.37							1091.85	
			652.85	8.43	774.93	8.43	919.84	8.43		8.43
									4962.98	
			2967.50	38.31	3522.42	38.31	4181.11	38.31		38.31

Maintenance	800.00	12.6	949.60	12.26	1127.17	12.26	1338.40	12.26	1588.68	12.26
Logistics	1000.00	15.75	1870.00	24.14	2219.69	24.14	2634.77	24.14	3127.47	24.14
Sub-total	**6350.00**	**100.00**	**7745.65**	**100.00**	**9194.34**	**100.00**	**10913.81**	**100.00**	**12684.69**	**100.00**
Variable Cost 2: Seed yam production										
Land (Rent)	100.00	3.07	118.70	3.07	209.90	3.07	249.15	3.07	295.74	3.07
Fertilizer	750.00	23.08	890.25	23.08	1056.73	23.08	1254.34	23.08	1488.15	23.08
Land preparation	400.00	12.3	474.80	12.3	563.59	12.3	668.98	12.3	794.08	12.3
Labour (field establishment)	1050.00	32.31	1246.35	32.31	1479.42	32.31	1756.07	32.31	2084.45	32.31
Stakes and staking	750.00	23.1	890.25	23.1	1056.73	23.1	1254.34	23.1	1488.90	23.1
Storage (rent)	200.00	6.13	234.40	6.13	278.79	6.13	330.92	6.13	392.80	6.13
Sub-total	**3250.00**	**100.00**	**3854.75**	**100.00**	**4645.19**	**100.00**	**5513.80**	**100.00**	**6544.12**	**100.00**
Total variable costs GHC	**9600.00**		**11600.40**		**12390.00**		**16427.61**		**19228.81**	

Table 5-

Table 5- 21

Sum of years depreciation for the power-dependent aeroponic system

Year	Beginning book value	Total depreciable costs	Depreciable rate	Depreciation expense	Accumulated depreciation	Ending book value
1	52200	37200	0.33	12400	12400	39800
2	39800	37200	0.267	9920	22320	29880
3	29880	37200	0.20	7440	29760	22440
4	22440	37200	0.13	4960	34720	17480
5	17480	37200	0.07	2480	37200	15000

Table 5- 22

Benefit-cost ratio and return on investment for five years of production using the power-dependent aeroponic system

Economic metric	Economic year/Value				
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Total fixed costs (A) GH¢	52200.00	0	0	0	0
Fixed cost depreciation (B) GH¢	12400.00	9920.00	7440.00	4960.00	2480.00
Total variable costs (C) GH¢	9600.00	11600.40	12390.00	16427.61	19228.10
Total investment/production costs (D = A + C) GH¢	61800.00	11600.00	12390.00	16427.1	19228.10
Total amortised cost (E) GH¢	19716.89	19716.89	19716.89	19716.89	19716.89
Total projected costs (F = B + D + E) GH¢	41716.89	41237.29	39546.89	41104.50	41424.99
Marketable seed yam produced (G)	23147.00	23147.00	23147.00	23147.00	23147.00
Price per seed (GH¢) (H)	2.00	2.37	2.82	3.34	3.97
Total benefit from sale of seed yam (I = G * H) GH¢	46294.00	54950.96	65224.81	77424.22	91902.55
Net benefit (J = I - F) GH¢	4577.11	13713.69	25676.92	36319.72	50477.56
Benefit-cost ratio (BCR) (K = J/F)	0.11	0.33	0.65	0.88	1.22

Table 5- 23

Return on investment (L = J/D) Net benefit/investment) %	7.40	22.19	41.55	58.77	81.68

Installation and seed yam production cost under the power-independent (gravity-fed) aeroponic system

Item Description	Production Years/ costs									
	Year 1		**Year 2**		**Year 3**		**Year 4**		**Year 5**	
	Amount GHC	Percentage %	Amount GHC	Percentage %	Amount GHC	Percentage %	Amount GHC	Percentage %	Amount GHC	Percentage %
Fixed Costs: Aeroponic system										
Screenhouse	18000.000	62.07	0	0	0	0	0	0	0	0
Fertigation	3000.00	10.34	**system** 0	0	0	0	0	0	0	0
Growth chambers	8000.00	27.59								
Total	**29000.00**	**100.00**	0	0	0	0	0	0	0	0
Variable Cost 1: Mini-tuber production			0	0	0	0	0	0	0	0
Soluble nutrients	500.00	12.99	593.50	12.98	704.48	12.99	836.22	12.99	992.59	12.99
Planting materials	400.00	10.39	474.80	10.39	563.59	10.39	668.98	10.39	794.08	10.39
Water and water analysis Personnel	550.00	14.285	652.85	14.28	774.93	14.28	919.84	14.28	1091.85	14.28
cost	1500.00	38.96	1780.50	38.96	2113.45	38.96	2508.66	38.96	2977.78	38.96
Maintenance	400.00	10.39	474.80	10.39	563.59	10.389	668.98	10.39	794.08	10.39
Logistics	500.00	12.99	593.50	12.99	704.48	12.99	836.22	12.99	992.59	12.99
Sub-total	**3850.00**	**100.00**	**4569.95**	**100.00**	**5424.52**	**100.00**	**6438.90**	**100.00**	**7642.97**	**100.00**

Table 5- 25

Variable Cost 2: Seed yam production										
Land (Rent)	100.00	3.07	118.70	3.07	209.90	3.07	249.15	3.07	295.74	3.07
Fertilizer	750.00	23.08	890.25	23.08	1056.73	23.08	1254.34	23.08	1488.15	23.08
Land preparation	400.00	12.3	474.80	12.3	563.59	12.3	668.98	12.3	794.08	12.3
Labour (planting, weeding, fertilizer application harvesting)	1050.00	32.31	1246.35	32.31	1479.42	32.31	1756.07	32.31	2084.45	32.31
Stakes and staking	750.00	23.1	890.25	23.1	1056.73	23.1	1254.34	23.1	1488.90	23.1
Storage (rent)	200.00	6.13	234.40	6.13	278.79	6.13	330.92	6.13	392.80	6.13
Sub-total	**3250.00**	**100.00**	**3854.75**	**100.00**	**4645.19**	**100.00**	**5513.80**	**100.00**	**6544.12**	**100.00**
Total variable costs	**7100.00**		**8424.70**		**10069.71**		**11952.70**		**14187.09**	

Table 5-

24 Sum of years depreciation for the power-dependent aeroponic system

Year	Beginning book value	Total depreciable costs	Depreciable rate	Depreciation expense	Accumulated depreciation	Ending book value
1	29000.00	25000.00	0.33	8333.33	8333.33	20666.67
2	20666.67	25000.00	0.27	6666.67	15000.00	14000.00
3	14000.00	25000.00	0.20	5000.00	20000.00	9000.00
4	9000.00	25000.00	0.13	3333.33	23333.33	5666.67
5	5666.67	25000.00	0.07	1666.67	25000.00	4000.00

Table 5- 25 Benefit-cost ratio and return on investment for five years of production for the power-independent aeroponic system

Economic metric	Economic year/Value				
	Year 1	Year 2	Year 3	Year 4	Year 5
Total fixed costs (A) GH¢	29000.00	0	0	0	0
Fixed cost depreciation (B) GH¢	8333.33	6666.67	5000.00	3333.33	1666.67
Total variable costs (C) GH¢	7100.00	8424.70	10069.71	11952.70	14187.09
Total investment/production costs (D = A + C) GH¢	36100	8424.70	10068.71	11952.70	14187.09
Total amortised cost (E) GH¢	11532.12	11532.12	11532.12	11532.12	11532.12
Total projected costs (F = B + D + E) GH¢	26965.45	26623.49	26601.83	26818.15	27385.88
Marketable seed yam produced (G)	16290.00	16290.00	16290.00	16290.00	16290.00
Price per seed (H) GH¢	2	2.37	2.82	3.34	3.97
Total benefit from sale of seed yam (I = G * H) GH¢	32580.00	38672.47	45904.21	54488.3	64677.61
Net benefit (J = I - F)	5614.33	12048.97	19302.38	27670.15	37291.33
Benefit-cost ratio (BCR) (K = J/F)	0.21	0.45	0.72	1.03	1.36
Return on investment (L = J/D) (Net benefit/ first year investment) %	15.55	33.38	53.47	76.64	103.30

5.6.2 Scenario analysis for seed yam production

From Tables 5-20 and 5-23 the major cost encountered for both the power-dependent and powerindependent aeroponic systems was in the construction of screenhouse (34.48 %m and 62.07 % respectively) and pump house (28.74 %,) for the power-dependent aeroponic system in fixed

costs and personnel (39.37 % and 38.96 % respectively) in variable costs. If such cost can be reduced, the cost of production would be reduced and thus BCR and ROI increased.

From Table 5-26, scenario one gave a BCR of 0.29 whilst scenario two also gave a BCR of 0.50. Since the power-independent system had no use of a pump house, scenario two analyses was omitted for this system. Scenario one thus gave a BCR of 0.57 also showing an increase in the scenario-free case.

Table 5- 26 Scenario analysis for first year of production using amortized cost

Economic metric	**Aeroponic systems/Scenario**		
	Power-dependent		**Powerindependent**
	Scenario 1	**Scenario 2**	**Scenario 1**
Total fixed costs (A) GH¢	43000.00	35500.00	20000.00
Fixed cost depreciation (B) GH¢	9333.33	6833.33	5000.00
Total variable costs (C) GH¢	9600.00	9600.00	7100.00
Total investment/production costs (D = A + C) GH¢	52600.00	45100.00	27100.00
Total amortised cost (E) GH¢	16789.92	14395.92	8650.32
Total projected costs (F = B + C + E) GH¢	35723.25	30829.25	20.750.32
Marketable seed yam produced (G)	23147	23147	16290
Price per seed (H) GH¢	2.00	2.00	2.00
Total benefit from sale of seed yam (I = G * H) GH¢	46294.00	46294.00	32580.00
Net benefit (J = I/F) GH¢	**10570.75**	**15465.00**	**11830.00**
Benefit-cost ratio (BCR) (K = J/F)	**0.29**	**0.50**	**0.57**

Return on investment (L = J/D) %	**20.00**	**34.00**	**44.00**

5.7 General Discussions from Economic Analysis

Highly significant differences were observed in the benefit-cost ratio between the powerdependent and power-independent aeroponic systems (Figure 5-25) with the power-independent system performing better in terms of BCR. BCR increased linearly for both aeroponic systems from year one through to year five as shown in Figure 5-25.

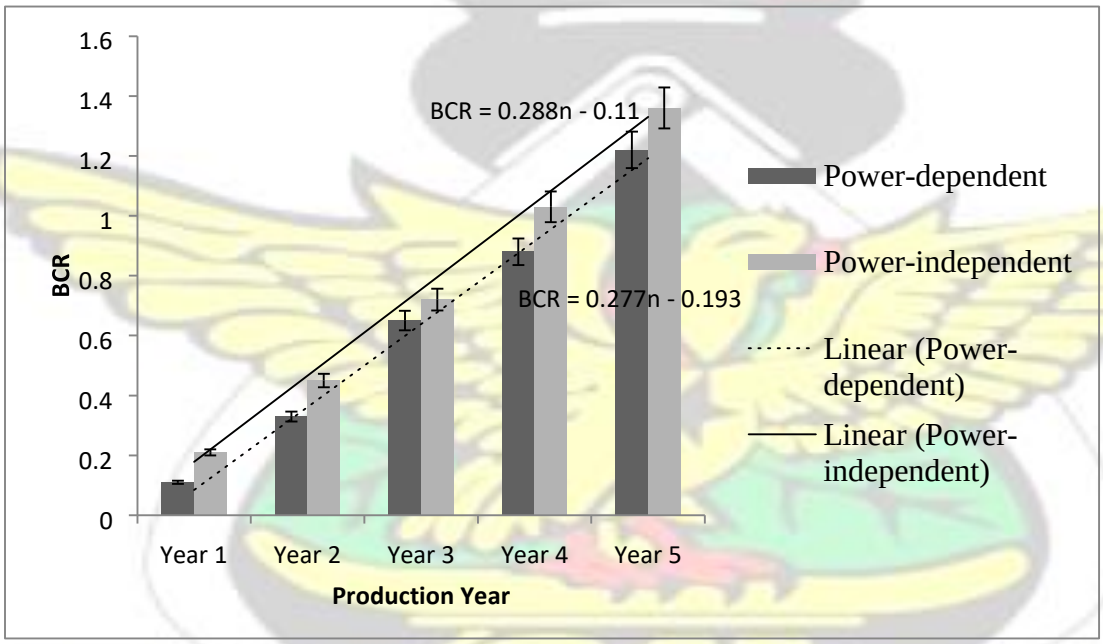


Figure 5- 25 Chart showing benefit-cost ratio of the two aeroponic systems for five production years

Significant increases were seen in all the scenario analysis undertaken. Comparing the base scenario (scenario-free) with both scenario one and two for the power-dependent system saw significant increases in BCR between the base year and the two scenarios (Figure 5-26). There was

also significant differences between scenario one and scenario two for the power-dependent system. In all cases under the power-dependent system, BCR favoured scenario two. The powerindependent system showed a highly significant difference between the base scenario and scenario one.

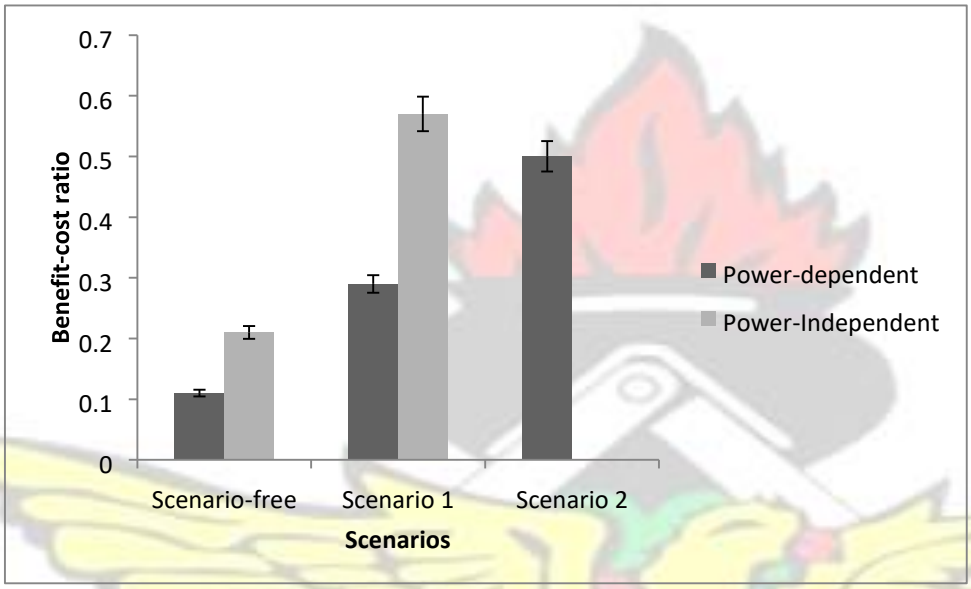


Figure 5- 26 BCR scenario analysis for the two aeroponic systems

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Introduction

This chapter discusses the conclusions of this study and proposes recommendations for policy and areas of further research.

6.2 Conclusion

The conclusion of this study would stand on the objectives, answer the research questions and approve or disapprove the hypothesis guiding the conduct of this research to ascertain gains and advances made to the science field with this work.

The study here reported gives evidence that power-dependent and power-independent aeroponic systems could become be an effective option for propagating seed yams. It has also proven that aeroponics makes it possible to improve growth and development of plants and thus improve overall mini-tuber and seed yam yields.

From the results discussed in chapter three and five, general conclusions are made based on each specific objective.

6.2.1 Conclusion for Specific Objective one

Specific objective one was to design, set up and test two types of aeroponic systems (powerdependent and power-independent) for propagating seed yams. Two aeroponic systems

were designed and set-up at the CSIR-Crops Research. Technical evaluations of the two systems bring to the fore that both systems can be used effectively for their intended purpose.

6.2.2 Conclusion for specific objective two

Specific objective two was to evaluate the two aeroponic systems for their ability to propagate mini-tubers agronomically. Results from the agronomic evaluations bring to the fore that the power-dependent system performs better in terms of timeliness of production and seed yam multiplication (higher multiplication ratio) than the power independent system. However, as a seed yam rapid multiplication technique (RMT), these two aeroponic systems have proven to be better in their multiplication ratio than some of the RMT's (for example minisett, tissue culture and vine multiplication) currently employed in seed yam generation in Ghana.

6.2.3 Conclusion for specific objective three

Specific objective three was to assess the ability of the resulting mini-tubers to be used for propagating seed yams. Concluding from the results attained under this evaluation proved that mini-tubers from both systems can be used successfully to propagate seed yams.

6.2.4 Conclusion for Specific Objective four

Specific objective four was to determine the economics of using any of the two aeroponic systems to commercially produce seed yams. The power-independent system has proven itself to be financially feasible in terms of investment and production cost, benefit-cost ratio and rate of return. Even though the power-dependent system has a slower rate of return and higher investment and production cost, its advantage as an RMT cannot be overemphasised. Both systems have proven to be different in their financial impositions and thus investors have options to choose either based on budgets or production projections.

6.2.5 General conclusion

The two aeroponic systems were developed to enhance and optimize the rapid multiplication of seed yams. A well designed aeroponic system should be efficient in water/nutrient distribution, water and energy use. A DU and CU of 96.16 % and 97.52 % respectively for the powerdependent system and 90.80% and 94.49 % for the power-independent (gravity-fed system) are very good and enough to recommend the two aeroponic systems for use in propagating seed yam. Both systems can also be adapted for use with other crops to boost food production and security even in the face of climate change, population growth and limited access to farm lands.

In designing and setting up the systems, all items were procured and bought in Ghana. Thus in disseminating the technology, all items needed for the set-up of the systems could be easily procured. For the purpose of dissemination, the power-independent system was designed and evaluated to be used in areas challenged with electricity thus, disputing the awareness that, aeroponics is solely power-dependent. The system, thus, has far proven to be better in terms of financial capabilities and comparable in terms of production to the power-dependent system.

The potential benefits herein discussed such as rapid rooting and tuberisation, high multiplication ratios and economically sound production gives these systems the potential to revolutionalise seed yam production in the country.

6.3 Recommendations

Aeroponics can be recommended to producer organizations, national seed production programmes, private companies, individual farmers or other institutions with interest in seed

production. However, before such recommendations are made, it is important to take notice of the following discussions for future research.

Research on the technical and agronomic aspects of the two aeroponic systems, particularly when focused on intensification of the production edge beyond the current multiplication ratios (growing media and fertilizer doses, age of explants at time of cutting vines, plantlet density, crop duration as well as development of some special cultivation techniques and use of biofertilizers) should also be conducted. The research could be based on customized management by variety (i.e. timings of fertigation, duration of each fertigation incidence), intensive management to hasten multiple tuberisation and shoot biomass, and improved control of the growing environment (temperature and humidity control). Due to the differential responses (significantly different at $p < 0.01$) seen with the varieties of different genotypes, there is the need for developing genotype specific protocols to maximise growth performance and mini-tuber yields of each variety.

Research focusing on ways to maximise the production of bulbils that were observed to be growing on the vines should be conducted. Consideration should be made that mini-tuber production represents only one critical stage in the seed yam production network. Production of the mini-tubers would therefore have to be scheduled to meet the season's seed yam production calendar. Thus, dormancy and its characteristic components are essential research areas that needs to be further advanced.

Healthy planting materials should always be used in the initial propagation of mini-tubers to always ensure healthy harvests. Thus, further research to devise ways of cultivating explants for generating disease-free vine cuttings should be conducted. To use the aeroponics technology for the first time, it is recommended to combine the aeroponics technology with other conventional

methods to prevent losses that can arise from unforeseen eventual collapse of the aeroponic systems. Policies that can enhance rapid dissemination of these technologies should be put in place to enhance speedy dissemination and adoption of the aeroponics technologies for rapid multiplication of seed yams in Ghana.

REFERENCES

Agbarevo, M. N. B 2014. An evaluation of farmers' adoption of yam mini-sett technique in Cross -River State, Nigeria. European Journal of Research in Social Sciences Vol.2 No. 3, 2014. Accessed online at http://www.idpublications.org/wpcontent/uploads/2014/08/AN-EVALUATION-OF-FARMERS%E2%80%99ADOPTION-OF-YAM-MINI-SETT-TECHNIQUE-IN-CROSS-RIVER-STATE-NIGERIA.pdf on 18/03/2014

Anonymous. n.d. Plant Nutrition. Accessed online at docente.ucol.mx/al000404/public_html/plant_nutrients.doc on 25/07/2016

Archiproducts. n.d. Accessed online athttp://archiproducts.com on 23/08/2014

Argo, B. 2003. Understanding pH management and plant nutrition.*Journal of the* International Phalaenopsis Alliance *13(2).*

Arunkumar, M. and Manikand, R. 2011. Aeroponics. Accessed online at http://www.slideboom.com/presentations/263081-/AEROPONICS on 08/02/14

Ascough, G. W. and Kiker, G. A. 2002. The Effect of Irrigation Uniformity on Irrigation Water Requirements. Accessed online at http://www.wrc.org.za/archives on 28/07/2007

Bancroft, R. D. 2000. Relieving post-harvest constraints and identifying opportunities for improving the marketing of fresh yam in Ghana, Crop Post Harvest Programme. Final Technical Report, No: R6505; ZB No: ZB0016

Bank of Ghana (BOG) 2016. Inflation rates April 2016. Accessed online at https://www.bog.gov.gh/ on 17/05/2016

Banwait D. 2008. Choosing the hydroponic system that is right for you. Accessed online at http://ezinearticles.com/?Choosing-the-Hydroponic-System-That-Is-Right-For-You&id=1132892 on 02/07/2016

Barak, P., Smith, J. D., Krueger, R. and Peterson, A. 1998. Measurement of short-term nutrient uptake rates in cranberry by aeroponics. Plant Cell Environ.19:237-242.

Bigelow, T., Davis, Z., Rahim, M., Reeve C and Wright, D. 2010. Design of a low cost aeroponic plant growth chamber. Accessed online at http://seniord.ece.iastate.edu/may1122/SDMay11-22%20Project%20Plan.pdf on 02/07/2016

Biocontrols. n.d. Assessed online at http://www.biocontrols.com/secure/shop/category.aspx?catid=2 on 32/08/2014

Biddinger, E. J., Liu, C. M., Joly, R. J. and Raghothama, K. G. 1998. Physiological and molecular responses of aeroponically grown tomato plants to phosphorous deficiency. J. Am Soc. Hortic. Sci. 123:330-333.

Bradbury, J. H. and Holloway, W. D. 1988. Chemistry of tropical root crops: significance for nutrition and agriculture in the Pacific. ACIAR Monograph No. 6. Australian Centre for International Agricultural Research: Canberra.

Bromley, J. B. n.d. Nutrient deficiency symptons. Accessed online at http://www.mgofmc.org/docs/nutrientdeficiency.pdf on 25/07/2016

Bridge, J., D. L. Coyne, and C. Kwoseh. 2005. Nematode parasites of tropical root and tuber crops. Pp. 221-258 in M. Luc, R. A. Sikora, J. Bridge, eds. Plant parasitic nematodes in subtropical and tropical agriculture (Second edition) CABI Wallingford, UK.

Bugbee, B. G. and F. B. Salisbury. 1989. Controlled environment crop production: Hydroponic vs. lunar regolith. p.107-130. In D. W. Ming and D. L. Henninger (eds.) Lunar base agriculture: soils for plant growth. American Society of Agronomy, Madison, WI.

Burt, C. M., Clemmens, A. J., Bliesner, R., Merriam, J. L., and Hardy, L. 2000. Selection of Irrigation Methods for Agriculture. American Society of Civil Engineers, USA.

Bush, D. S. 1995. Calcium regulation in plant cells and its role in signaling. Annual Review of Plant Pathology and Plant Molecular Biology 46:95-122

Calcino, D., Kingston, G. and Haysom M. n.d. Nutrition of the plant. Accessed online at http://www.sugarresearch.com.au/icms_docs/166943_Chapter_9_Nutrition_of_the_Plant.pdf on 25/07/2016

Carruthers, S. 1992. Practical hydroponics and greenhouses. Issue 05: Aeroponics. Accessed online at http://www.hydroponics.com.au/issue-05-aeroponics/ on 02/07/2016

Carter, W. A. 1942. A method of growing plants in water vapor to facilitate examination of roots. Phytopathology 732:623-625.

Chiipanthenga, M., Maliro, M., Demo, P. and Njoloma J. (2012) Potential of aeroponic system in the production of quality potato (solanum tuberosum L.) African Journal of Biotechnology:11(17), pp. 3993-3999

Christiansen, J. E. 1942. Irrigation by sprinkling. California Agricultural Exp. Stn. Bull. 670 University of California at Berkeley, Berkeley, California

Clawson, J. n.d. Developing a sterile environment for aeroponic plant growth. Accessed online at http://www.biocontrols.com/aero43.htm on 28/07/2016

Correa RM, Pinto JEBP, Faquine V, Pinto CABP, Reis ES.2009. The production of seed potatoes by hydroponic methods in Brazil. Fruit, Vegetable and Cereal Science and Biotechnology.

Coursey, D. G. 1967. Yams, an account of the nature, origins, cultivation and utilization of the useful members of the *Dioscoreaceae*. Tropical Agriculture Series. Longmans: London.

Craufurd P. Q., Summerfield, R. J., Asiedu, R. and Vara Prasad, P. V. 2001. Dormancy in yams. Expl Agric:37, pp. 147-181

CSIR-CRI. 2012. Annual Report. Ghana

CSIR-CRI. 1991. Annual Report. Ghana

D'Anna C. N.d. Hydroponics gardens: the ebb and flow systems. Accessed online at http://hydroponics.about.com/od/hydrosystems/a/Hydroponic-Gardens-Ebb-and-Flow-Systems.htm on 02/07/2016

Delebo, Z. 2008. Minimizing postharvest losses in yam (*Dioscorea* spp): Treatments and Techniques. In: Using Food science and Technology to improve Nutrition and promote National Development. Robertson, G. L. and Lupien, J. R. (Eds). Accessesd online from http://www.iufost.org/publications/books/documents/Osundechapter12.pdf on 21/05/2016

Degras, L. M. 1993. The yam: A tropical root crop. The Technical Centre for Agricultural and Rural Cooperation (CTA). The Macmillan press Ltd, London and Basingstoke.

Demuyakor, B., Dukrog, T. M. and Chikpah, S. K. 2013. Yam Germplasm in Ghana – A Survey on Storage and Varietal Properties of *Dioscorea Rotundata–Alata* in Northern Region of Ghana. International Journal of Scientific and Technology Research: 2(1)

Dupré Minerals. 2008 Minerals safety data sheet: Exfoliated vermiculite. Accessed online at http://www.dupreminerals.com/downloads/vermiculite/vermiculite-msds.pdf on 06/07/2016

Ennin, S. A., Dapaah, H. K. and Asafu-Agyei, J. N. (2003). Land preparation for increased sweet potato production in Ghana. Paper presented at the 13th Symposium of the International Society for Tropical Root Crops (ISTRC-World Branch).

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

Espinosa, P., Crissman, C.C., and Hibon, A.1996. Accounting for seed potato production costs: a computer spreadsheet-based management tool. Lima: International Potato Center (CIP). Training manual.

Ewing E. E., and Struik P. C. 1992. Tuber formation in potato: Induction, initiation, and growth. Horticulture Review, 14, 89-198.

Ezumah, H. C. 1986. Important root crops production systems in southern Nigeria. Paper presented at Seminar on Nigerian Root Culture at the Institute of African Studies, University of Ibadan, Ibadan, Nigeria.

Factor TI, Araujo JAC, Kawakami FPC, Lunck V. 2007. Producao de mini-tuber culos basicas de batata cm tressistemas hydroponicos. Horticultura Brasileira 25(3), 82-87

Farmxchange. n.d. Accessed online athttp://www.farmxchange.org on 23/08/2013

FAO, 2010. Quality declared planting materials: Protocols and standards for vegetatively propagated crops. Accessed online at http://www.fao.org/3/a-i1195e.pdf on 18/03/2016

Fares A. and Abbas F. 2009. Irrigation systems and nutrient sources for fertigation. Soil and Crop Management, 25. Accessed online at http://www.ctahr.hawaii.edu/oc/freepubs/pdf/scm-25.pdf on 27/08/2015

Farran, I. and Mingo-Castel, A. M. 2006. Potato micro-tuber production using aeroponics:

Effects of density and harvest intervals. Am. J. Potato Res. 83(1):47-53.

Forums Garden Web. N.d. Accessed online athttp://www.forums.gardenweb.orgon 23/08/2014

Frugal Hydroponics. N.d. Learning and exploring hydroponic growing methods and techniques. Accessed online at http://frugalhydroponics.blogspot.com/ on 27/07/2016

Ghana Revenue Authority. N.d. Internal Revenue Act 2000 (ACT 592). Accessed online at http://www.gra.gov.gh/docs/info/irs_act.pdf on 23/07/2016

Gopal, J., Minocha, J. L. and Gosal S. S. 1998. Variability in response of potato genotypes to *in vitro* propagation. *J Indian Potato Assoc* 25(3-4)**:** 119-24

Green Tools. N.d. Advanced nutrients. Accessed online at https://greentools.me/author/zazueta/page/2/ on 26/07/2016

Grow Organic. n.d Sunshine peat moss. Assessed online at http://www.groworganic.com/search#q=peat&p=1 on 29/08/2015

Grow Quick. n.d. Accessed online at http://www.quickgrow.com/gardening_articles/aeroponics_misting.html on 25/07/2016

Grower Supply. n.d. Assessed online at https://www.growerssupply.com/farm/supplies/cat1ags_shade_houses_shade_cloth.html on 23/08/2014

Grusak, M. A. 2001. Plant macro and micronutrient minerals.Encyclopedia of Life Sciences. Accessed online at http://www.*onlinelibrary.wiley.com/doi/10.1038/npg.els.0001306/pdf o*n 25/09/2915

Hahn, S. K., Osiru, D. S. O., Akorada, M. O., Otoo J. A. 1987.Yam production and its future prospects. Outlook – Agric. 16: 105 – 110.

Hayden, A. L. 2006. Aeroponic and Hydroponic Systems for Medicinal Herb, Rhizome, and Root Crops. Hortscience:41(3)

He, J. and Lee, S. K. 1998. Growth and photosynthetic response of three aeroponically grown lettuce cultivar (*Lattuca sativa* L.) to different root zone temperatures and growth irradiance under tropical aerial conditions. J.HortSci Biotech 73:173-180.

Holland, P. 2012. Simple introduction to Cost-Benefit Analysis. (Prepared for SPREP PACC Cost-Benefit Analysis Workshop: Food Security Pilot Demonstration Projects, Suva, 24-27 January 2012) Accessed online at http//www.*ict.sopac.org/library/download/index/410?file=PR84.*pdf on 21/05/2016

Home Hydro Systems. N.d. Ebb and flow (flood and drain system) Accessed online at http://www.homehydrosystems.com/hydroponic-systems/ebb-flow_systems.html on 02/07/2016

Hubick, K. T., Drakeford, D. R. and Reid, D. M. 1986. A comparison of two techniques for growing minimally water-stressed plants. Can. J. Bot. 60:219-223.

Hung, L. L. L. and Sylvia, D. M. 1988. Production of vesicular-arbuscular mycorrhizal fungus inoculum in aeroponic culture. Appl. Environ. Microbiol. 54:353-357.

Hydroponics BC. n.d. Accessed online athttp://www.hydroponicsbc.com/nutrients.html on 25/09/2015

Hydroponics. n.d. Accessed online athttp://www.hydroponics.net on 23/08/2014

IITA. 2006. Yams. Accessed online at http://www.iita.org/yam on 01/06/2016

Ile, E. I., Craufurd, P. Q., Battey, N. H. and Asiedu, R. 2006. Phases of Dormancy in Yam Tubers (*Dioscorea rotundata*). Ann. Bot. 97:497-504.

International Peat Society. n.d. What is Peat? Accessed online at

http://www.peatsociety.org/peatlands-and-peat/what-peat on 23/08/2014

James, T. n.d. Water maintenance in hydroponics. Accessed online at http://www.lycaeum.org/~npkaye/phcontrol.html on 26/07/2016

Jensen, M. H n.d. Hydroponics culture for the tropics; opportunities and alternatives. Accessed online at http://agnet.org/htmlarea_file/library/20110729175702/eb329.pdf on 02/07/2016

Jensen, M. and Rorabaugh, P. n.d. Growing tomatoes aeroponically. Accessed online at http://ag.arizona.edu/hydroponictomatoes/propagat.htm on 25/09/2015

Jensen, M. H. and Collins, W. L. 1985. Hydroponic vegetable production. *Hort. Rev.*7: 483-558

Johnson, D. 2007. Plant Propagation in Hydroponics. Accessed online at http://EzineArticles.com/504502 on 25/09/2015

Jones J. B. 2009. Drip irrigation hydroponics. Accessed online at http://www.gardenandgreenhouse.net/articles/april-2009/hydroponics-101-19/ on 02/07/2016

Julius, A., and Charter, M., and Figueroa, L. n.d. Design of gravity-fed drip irrigation system for Macleish fields. Accessed online at http://www.smith.edu/events/docs/collaborations/2013/presentations/48_Bennett,Brittany Proceedings.pdf on 17/03/2016

Kahn B. A., Ewing E. E., and Senesac A. H. 1983. Effects of leaf age, leaf area, and other factors on tuberization of cuttings from induced potato (*Solanum tuberosum* L.) shoots. Canadian Journal Botany, 61, 3193-3201.

Kang, J. G., Kim, S. Y., Om, Y. H. and Kim, J. K. 1996. Growth and tuberisation of potato (*Solanum tuberosum L.*) cultivars in aeroponic, deep flow technique and nutrient film technique culture films. J. Korean Soc. Hort. Sci. 37:24-27.

Keller, J., and Bliesner, R.D. 1990. Sprinkle and trickle irrigation. Van Nostrand Reinhold, New York, ISBN:0-442-24645-5. 632pp.

Kempen E. 2007. The influence of light intensity, light quality and root zone temperature on potato mini-tuber production. Thesis presented in partial of the requirements for the degree of Master of Agricultural Science at the University of Stellenbosch.

Khan, M., Sinclair, J. B. 1992. Pathogenicity of sclerotia- and non-sclerotia forming isolates of *Colletotrichum truncatum* on soybean plants and roots. Phytopathology 82:314-319.

Kim, H. S., Lee, E. M., Lee, M. A., Woo, I. S., Moon, C. S., Lee, Y. B. and Kim, S. Y. 1999. Production of high quality potato plantlets by autotrophic culture for aeroponic systems. J. Korean Soc. Hort. Sci. 123:330-333.

Kliss, M. and R. D. MacElroy. 1990. Salad Machine: A vegetable production unit for long duration space missions. Soc. Autom. Eng. Techn. Paper 901280. SAE, Warrendale, PA

Kochlar, S. L. 1981. Tropical Crops, a Text Book of Economic Botany. Mcmillan Int. 469 pp

Kress, J. W. N.d. *Dioscoreales*: Plant Order. Encyclopaedia Britannica. Accessed online at http://www.britannica.com/plant/Dioscoreales on 09/01/2014

Krauss, A. and. Marschner. H 1982. Influence of nitrogen, day length and temperature on contents of gibberellic and abscisic acid and on tuberization in potato plants. PotatoRes.25:13–21

Kumwenda W. F. 1999. The role of animal traction in soil water conservation tillage practices among smallholder farmers in Malawi (p 74-79). In: Conservation tillage with animal traction. A resource book of the Animal Traction Network for Eastern and Southern Africa (ATNESA). (P. G. Kaumbutho and T. E. Simalenga, Ed.) Harare, Zimbabwe. 173p

Lommen, W. J. M. 1995. Basic studies on the production and performance of potato mini-tubers. PhD Thesis, Wageningen University, Wageningen, The Netherlands.

Lommen, W. J. M. and Struik, P. C. 1992a. Influence of a single non-destructive harvest on potato plantlets grown for mini-tuber production. Netherlands Journal of Agricultural Science 40: 21-41

Lommen, W. J. M. and Struik, P. C. 1992b. Potato Production of potato mini-tubers by repeated harvesting: Plant productivity and initiation, growth and re-absorption of tubers. Netherlands Journal of Agricultural Science 40:342-359.

Love, L. S., Notte, P., Corsini, L. D., Whitmore, C. J., Ewing, L. L. and Whitmore, L. J. N.d. Seed production and certification Accessed on http://www.cals.uidaho.edu/edcomm/pps/chapter4.pdf on 18/03/2016

Lung'aho, C., Nyongesa, M., Mbiyu, M. W., Ng'ang'a, N. M., Kipkoech, D. N., Pwaipwai, P, and Karinga, J. 2010. Potato (*solanum tuberosum*) micro-tuber production using aeroponics: another arrow in the quiver? In: Proceedings of the 12th biennial conference of the Kenya Agricultural Research Institute (2010).

Maroya, N, Balogun, M, Asiedu, R. 2014. Seed Yam Production in Aeroponic system: A Novel Technology. YIIFSWA Working Paper No 2 Institute International of Tropical Agriculture, Ibadan, Nigeria; 9 pages. © IITA-YIIFSWA; 2014. ISBN 978-978- 8444-37-4

Mateus-Rodriguez, J. F., de Haan, S, and Rodríguez-Delfín, A. (2014) Genotype by Environment Effects on Potato Mini-Tuber Seed Production in an Aeroponic system. Agronomy 4:514-528

Mateus-Rodriguez *et al*., 2013. Technical and Economic Analysis of Aeroponics and other Systems for Potato Mini-Tuber Production in Latin America Am. J. Potato Res. DOI 10.1007/s12230-013-9312-5

Mavoungou, Z. C., Beunard, P. and, Truong, B. 1982. Test de resistance a la transpiration de quatr-e varietes de soja en culture aeroponique. E'Agt (*momietropicate*, Paris) 37:288294.

Mbiyu, M. W., Muthoni, J., Kabira, J., Elmar, G., Muchira, C., Pwaipwai, P., Ngaruiya, J., Otieno, S. and Onditi, J. 2012. Use of aeroponics technique for potato (*Solanum tuberosum*) mini-tubers production in Kenya. Accessed online at http://www.internationalscholarsjournals.org on 17/12/2013

McNamara, N. and S. Morse. 2014. Working with farmers to produce clean seed yams. YIIFSWA Working Paper Series No. 5.Yam Improvement for Income and Food Security in West Africa, International Institute of Tropical Agriculture, Ibadan, Nigeria.48 pp.

Merriam, J. L., and Keller, J. 1978. Farm irrigation system evaluation: A guide for management. Dept. of Agricultural and Irrigation Engineering, Utah State Univ., Logan, Utah

Michael, A.M. 1999. Irrigation: theory and practice. Vikas publishing house Pvt. Ltd., New Delhi. 644p.

Mignouna, H. D., Ellis, N. T. H., Knox, M. R., Asiedu, R., and Ng, Q. N. 1998. Analysis of genetic diversity in Guinea yams (*Dioscorea* spp.) using AFLP finger printing. Trop. Agric. 75: 224 - 229.

Millaleo, R., Reyes-Díaz, M., Ivanov, A. G., Mora, M. L. and Alberdi, M. 2010. Manganese as essential and toxic element for plants: transport, accumulation and resistance mechanisms J. Soil Sci. Plant Nutr. 10 (4): 476 - 494

Millennium Development Authority (MiDA). 2010. Annual Report. Ghana

Millennium Development Authority (MiDA) 2009.Annual Report. Ghana

Millenium Development Authority (MiDA). 2008. Yam Seed Production. Accessed online at http://www.mcc.gov/documents/investmentopps/bom-ghana-eng-yams.pdf 08/08/2015

Ministry of Trade and Industry (MoTI). 2013. Yam sector development strategy, Ghana. Eds Lopez-Montez A, Manson H., Lascari, R., Sikpa T and Kodwo N. Accessed online at http://moti.gov.gh/sites/default/files/content/documents/files/Ghana%20Yam%20Sector%20Dev%20Strategy.pdf on 05/07/2016

Miragem, S., F. Nadal, N. Fuentes, J. Porteiro, Pietra, E., Sánchez, B. and Platero, R. 1982. Guíapara la elaboración de proyectos de desarrollo agropecuario, Serie Desarrollo Institucional. San José. Inter American Institute for Cooperation on Agriculture (IICA).

Mirza, M., Younus, M., Hoyano, Y., and Currie, R. 1998. Greenhouse production of Echinacea and other medicinal plants. Paper presented at Opportunities and Profits II: Special Crops into the 21st Century. Nov 1-3, 1998, Edmonton, AB, Canada

MoFA. 2007. "Food and Agricultural Sector Development Plan" (FASDEP II) https://www.grain.org/attachments/2685/download

Molitor, H. D., Ficher, M., and Popadopoulus, A. P. 1999. Effect of several parameters on the growth of Chrysanthemum stock plants in aeroponics. Acta Hort. 481:179-186.

Moran, N. 2014. Hydroponics for a changing market. Accessed online at http://www.producegrower.com/article/pg0614-hydroponics-market-production/ on 02/07/2016

Mother Earth News. n.d. Grow an Early Garden Using Peat Pellets. Assessed online at http://www.motherearthnews.com/organic-gardening/early-garden-using-peat-pelletszmaz71mazgoe on 29/08/2015

Mugundhan, M. R., Soundaria, M., Maheswari, V., Santhakumari, P. and Gopal, V. 2011. Hydroponics – A novel alternative for geoponic cultivation of medicinal plants and food crops. International Journal of Pharma and Bio Sciencess 2(2): 286-296

NC State University N.d. Climate education for K-12 Accessed online at http://climate.ncsu.edu/edu/k12/.instruments on 25/07/2016

Nweke, *et al*. cited in Okoro , J. K. 2008. Awareness and use of the rapid seed yam multiplication technology by farmers in Nigeria's yam belt. Accessed online at www.patnsukjournal.net/currentissue on 18/03/2016

Nweke, F. I., Ugwu, B. O., Asadu, C. L. A. and Ay, P. 1991. Production costs in the yam-based cropping systems of south-western Nigeria. Resource and crop Management Division, Research Monograph No.6 IITA, Ibadan, Nigeria, p. 29.

Odemerho, F. O. and Awunudiogba, A. 1993. Effects of changing cassava management practices on soil loss: a Nigerian example. The Geog. J.159: 63–69.

Okigbo, R. N. and Ogbonnaya, U. O. 2006. Antifungal effects of two tropical plant extracts (*Ocimum gratissimum* and *Aframomum melegueta*) on post-harvest yam rot. African Journal of Biotechnology 5: 9. 727-731 pp

Okoro, J. K. 2008. Awareness and use of the rapid seed yam multiplication technology by farmers in Nigeria's yam belt. PAT 2008; 5 (1):22-29

Onwueme, I. C. 1982. The tropical tuber crops, Yams, Cassava, Sweet potato, Cocoyams. Cited in Okoro, J. K. 2008. Awareness and use of the rapid seed yam multiplication technology by farmers in Nigeria's yam belt. Accessed online at http://www.patnsukjournal.net/currentissueon 29/09/2013

Osei, K, Otoo E., Danso Y, Adomako J., Agyeman A., and Asante J. S. 2013. Organic soil amendments in nematode management in yam production. Nematropica 43:78-82. Accessed online at http://journals.fcla.edu/nematropica/article/viewFile/82435/79469 on 24/08/2014

Osei, K., Awuah R. T., Tabil, M. A., and Asante, J. S. 2004. Prevalence and farmers' perceptions of parasitic nematodes in yam rhizosphere soils from some yam producing areas of Ghana. Agricultural and Food Science Journal of Ghana 3:217-226.

O'Sullivan, J. N. 2010. Yam nutrition: nutrient disorders and soil fertility management. ACIAR Monograph No. 144. Australian Centre for International Agricultural Research: Canberra. 112 pp.

Otazu, V. 2010. Manual on quality seed potato production using aeroponics. Accessed online at http://192.156.137.121:8080/cipotato/publications/pdf/005447.pdf on 23/08/2014

Otoo, E., Opoku-Agyeman, M. O., Aboagye, L. M., Acheremu, K., Tetteh, J. P., Paganini, M. and Dansi A. 2012. Increasing farmers and breeders access to yam (*Dioscorea* Spp) diversity: The case of forest-savannah transition agro-ecology. Final Project Report Presented to the Global Crop Diversity Trust.

Overseas, J. J. N.d. Shade nets in agriculture. The importance of using shade nets. Accessed online at http://jjoverseas.com/upload/download/Screen%20Shadenet%20&%20Automation.pdf on 25/07/2016

Pagliarulo, C. L. and. Hayden, A. L. 2002. Potential for greenhouse aeroponic cultivation of medicinal root crops. Proc. Amer. Plasticult. Soc. Conf., San Diego, Cali. Accessed online at

http://aerofarms.com/wordpress/wpcontent/files_mf/1265411630GrowingMedicinalCropswithAeroponics.pdf on 28/01/2013

Pardossi A., Carmassi G., Diarra C., Incrocci L., Maggini R and Massa D. 2011. Fertigation and substrate management in closed soilless culture. Accessed online at http://www.wageningenur.nl/upload_mm/8/c/0/aa4b4486-a9db-429f-8b03f19d4cec3ee6_Fertigation%20and%20Substrate%20Management%20in%20Closed%20S oilless%20Culture.pdf on 02/07/2016

Patterson, R. and Ramirez, R. 2012. Beneficials: Predatory mites. Accessed online at http://extension.usu.edu/files/publications/factsheet/beneficials-mites.pdf on 23/08/2014

Perlite-hellas. n.d. Accessed online at http://www.perlite-hellas.gr on 23/08/2014

Phocaides, A. 2000. Technical Handbook on Pressurised Irrigation Techniques. Accessed online at ftp://ftp.fao.org/agl/aglw/docs/pressirrig.pdf on 17/09/2015

Powell, W., Brown, J. and Caligari, P. D. S. 1989. Variability in response of potato cultivars to micro-propagation II. Subsequent field performance. Ann Applied Biology 115: 123-28

Purseglove, J. W. 1972. Tropical crops. I. mono cotyledons, Longman, London, pp 39-62

Grow Quick. n.d Aeroponics misting frequency and the root system. Accessed online at http://www.quickgrow.com/gardening_articles/aeroponics_misting.html on 02/07/2016

Reed, W. D. n.d. Cloning Plants: Tissue culture, horticultre and the science of plants. Accessed online at http://www.hort201.tamu.edu/YouthAdventureProgram/TissueCulture/TissueCulture.htm on 23/08/2014

Reed, W. D. 2007. Horticulture workshops: Plant Propagation, soil and soilless growing media, simple soil and water testing. Accessed online at

http://generalhorticulture.tamu.edu/hort604/workshopmex07/propsoilwaterworkshop.htm on 24/08/2014

Resh, H. 1995, Hydroponic food production. Woodbridge Press Publishing Company, Santa Barbara, California, USA, 287 pp.

Reust, W. 2002. Physiological age of potato. Potato Research 29:268 – 271

Ritter, E., Angulo, B., Riga, P., Herran, C., Relloso, J. and San J. M. 2001. Comparison of hydroponics and aeroponics cultivation systems for the production of potato mini-tubers. Potato Res. 44:127-135.

Robertson, J. M., Hubick, K. T., Yeung, E. C. and Reid, D. M. 1990a. Developmental responses to drought and abscisic acid in sunflower roots. I. Root growth, apical anatomy, and osmotic adjustment. J. Exp. Bot. 41:325-337.

RSC. n.d. Signs of nutrient difficiency. Accessed online at http://www.rsc.org/learnchemistry/content/filerepository/CMP/00/001/053/Signs%20of%20nutrient%20deficienc y.pdf on 25/07/2016

Runkle, E. n.d. Greenhouse shading options. Accessed online at http://www.gpnmag.com/article/greenhouse-shading-options-0/ on 02/07/2016

Samborn, R. 2010. TDS and EC meters for hydroponics explained. Accessed online at http://www.tdsmeter.com/img/MaximumYield-NutrientMetersExplained.pdf on 26/07/2016

Sattelmacher, B. and Marschner, H. 1978. Relation between nitrogen nutrition, cytokinin activity and tuberization in Solanum tuberosum. Physiol. Plant 44:65-68.

Schoenstein, G. 1996. Hydro-organics: growing basil during the off-season. Small Farm Today I3 I): 3 9-42.

Shtrausberg, D. V., Rakitina, E. G. 1970. Aeration and gas regime of roots in aeroponics and water culture. Agrokhimiyia 4: 101-110.

Singh, Y. n.d. Aeroponics. Accessed online at https://www.academia.edu/5431258/Aeroponic on 02/07/2016

Smeal, D. 2007. Drip irrigation for small plots (a low-tech, low-cost, gravity system) http://irrigationmanagement.nmsu.edu/documents/drip-for-organicconferencepicreductionforwebpdf.pdf. Accessed 17 March 2016

Soffer, H. and Burger, D. W. 1988. Effects of dissolved oxygen concentration in aeroponics on the formation and growth of adventitious roots. J. Am. Soc. Hortic. Sci. 113:218-221.

Sonnewald, S. and Sonnewald, U. 2014. Regulation of potato tuber sprouting. Planta Journal 239(1):27-38

Stamps, R. H. 2009. Use of colored shade netting in Horticulture. Hort Science 44: 2, 239 – 241p

Stamps, R. H. 1994. Evapotranspiration and Nitrogen leaching during leatherleaf fern production in shade houses. SJRWMD Spec. Publ. SJ94 – SP10.

Steinberg, S. L., Ming, D. W and Henninger D. (Eds). 2002. Plant production systems for microgravity: critical issues in water, air, and solute transport through unsaturated porous media. Accessed online at http://ston.jsc.nasa.gov/collections/trs/_techrep/TM-2002-210774.pdf on 02/07/2016

Stoner, R. J. 1983. Aeroponics versus Bed and Hydroponic Propagation. Florists Rev. 1(173):4477.

Succop, C. E. 1998. Hydroponic greenhouse production of fresh market basil: A master's thesis submitted to the Colorado State University. Accessed online at http://www.ghex.colostate.edu/pdf_files/beth_succop.pdf on 29/09/2013

Suhaimi, M. Y., Mohamad A.M., Mahamud S. and Khadzir D. (2012) Effects of substrates on growth and yield of ginger cultivated using soilless culture. Journal of Tropical Agriculture and Food Science 40(2): 159–168

Sweat, M., R. Tyson and R. Hochmuth. (2003). *Building a floating hydroponic garden*. HS943:4pgs. Gainesville: University of Florida Institute of Food and Agricultural Sciences. http://edis.ifas.ufl.edu/HS184

Sylvia, D. M. and Jarstter, A. G 1992. Sheared-root inocula of *vesicular arbuscular mycorrhizal* fungi. Appl. Environ. Microbiol. 58:229-232.

Tetteh, J. P. and Saakwa, C. 1994. Prospects and Constraints to Yam Production in Ghana. Acta Hort. (ISHS) 380:355-359 http://www.actahort.org/books/380/380_55.htm Accessed on 04/02/2013

Tetteh, J. P. and Saakwa, C. 1991. Prospects and constraints of yam production in Ghana. In Tropical Root Crops in a Developing Economy, F. Ofori and S. K. Hahn (eds). In proceedings of the 9th symposium of the International Society for Tropical Root Crops-Africa Branch, 20-26 October, 1991. Accra, Ghana

Tibbitts, T. W and Cao, W. 1994. Solid Matrix and Liquid Culture Procedures for Growth of Potatoes. University of Wisconsin. Department of Horticulture, Madison, WI 53706, U.S.A.

Trejo-Tellez, L.I and Gomez-Merino, F. C. n.d. Nutrient Solutions for Hydroponic Systems. Accessed online at http://cdn.intechopen.com/pdfs-wm/33765.pdfon 01/04/2016

Truong, B. and Beunard, P. 1978. Etude de la croissanee racinaire de six varietes de riz pluvial en culture aeroponique. Premiers resultats. E'Agronomie Tropicale (Paris) 33:231-236.

Twumasi, J. K. 1986. Fungi associated with tar spot disease of water yam in Ghana. Ghana Journal of Agricultural Science 14-19: 115-116.

Tyson, R., Hochmuth, R. and Cantiff, J. D. n.d. Hydroponic Vegetable production in Florida University of Florida IFAS Extension Publication #HS405 8pgs Accessed online at http://edis.ifas.ufl.adu.hs405 on 17/12/2013.

Venkatasalam, E. P., Latawa, J., Sharma, S., Sharma, S., Sharma, A. K., Sharma, S., Patial, R. and Singh, S. 2011. In vitro and in vivo performance of potato cultivars for different seed production systems. Potato J 38(2):149-54

Wagner, R. E., and Wilkinson, H. T. 1992. An aeroponic system for investigating disease development on soybean taproots infested with *Phytophthora sojae.* Plant Dis. 76:610-614.

Wan, Y. W., Cao W., and Tibbitts, W. T. 1994. Tuber initiation grown potatoes solution pH Hort Science 29(6):621-623.

Wanasundera, J. P. D. and Ravindran, G. 1994. Nutritional assessment of yam (*Dioscorea alata*) tubers. Plant Foods for Human Nutrition 46(1), 33–39.

Went, F. W. 1957. The experiment control of plant growth. New York: Ronald Press.

Wilson J. E. 1989. Rapid multiplication of yams (*Dioscorea* spp.) Agro-Facts Crops IRETA publication No. 3/88 Accessed online at http://www.adap.hawaii.edu/adap/Publications/Ireta_pubs/rapidyams.pdfon 18/03/2016

Wn.com n.d. Raised bed, planter gardening hits new heights Assessed online at https://article.wn.com/view/2016/08/12/Raised_bed_planter_gardening_hits_new_heights / on 29/08/2015

Worldwatch. n.d. Accessed online at http://blogs.worldwatch.org/nourishingtheplanet/innovation-of-the-month-aeroponictechnology/ on 23/08/2014

Worley, J. 2011. Greenhouses: heating, cooling and ventilation. Accessed online at http://extension.uga.edu/publications/detail.cfm?number=B792#Mist on 23/08/2014

Wu, P.T., and Zhu, D.L., and Wang, J. 2010. Gravity-fed drip irrigation design procedure for a single-manifold subunit. Accessed online at ftp://ftp.ecn.purdue.edu/vmerwade/class/GDT/uploaded_documents/India/Stewart_Gravity-fed%20drip%20irrigation%20design%20procedure.pdf on 17/03/2016

Ziegler R. and Rolfe L. 2009. The vertical aeroponic growing system. Accessed online at http://synergyii.com/PDF/2009%20BioChar%20Vertical%20Aeroponic%20Growing%20Systems.pdf on 02/07/2016

Zhao, X., Li, T. L. and Sun, Z. P. 2010. Effects of prolonged root zone CO_2 treatment on morphological parameter and nutrient update of tomato grown in aeroponic system. Journal of Applied Botany and Food Quality 83, 212-216

APPENDEX

Appendix 1 Mister operating pressure and discharge characteristics of the pressurised aeroponic system

Rep	Pump number	Nutrient Concentration	Mister number	Variety grown	Mister operating pressure, kPa	Volume of water collected (litres)/30 min	Discharge l/min	Swath Radius
1	1	C1	1	*Pona*	60.00	15.60	0.52	3.00
1	1	C1	2	*Mankrong Pona*	59.50	14.90	0.49	3.00
1	1	C1	3	*Dente*	59.50	15.70	0.52	2.95
1	2	C4	4	*Dente*	60.00	14.90	0.49	3.00
1	2	C4	5	*Pona*	59.00	15.10	0.50	3.00
1	2	C4	6	*Mankrong Pona*	59.00	14.80	0.49	2.95
1	3	C2	7	*Dente*	59.50	14.30	0.48	2.95
1	3	C2	8	*Mankrong Pona*	59.00	15.10	0.50	2.95
1	3	C2	9	*Pona*	59.50	15.20	0.51	2.95
1	4	C2	10	*Pona*	60.00	14.90	0.49	3.20
1	4	C2	11	*Dente*	60.00	15.30	0.51	3.20
1	4	C2	12	*Mankrong Pona*	60.00	15.40	0.51	3.20
2	5	C3	13	*Pona*	69.50	15.30	0.51	3.00
2	5	C3	14	*Mankrong Pona*	69.50	15.20	0.51	3.00
2	5	C3	15	*Dente*	60.00	15.80	0.53	3.10
2	6	C1	16	*Mankrong Pona*	59.50	14.20	0.47	3.00
2	6	C1	17	*Dente*	59.00	14.90	0.49	3.00
2	6	C1	18	*Pona*	59.50	15.60	0.52	2.95
2	7	C4	19	*Mankrong Pona*	60.00	15.60	0.52	3.00

2	7		C4	20	*Dente*	59.50	15.00	0.50	3.00
2	7		C4	21	*Pona*	60.00	15.10	0.50	3.10
2	8		C3	22	*Pona*	60.00	14.90	0.49	3.20
2	8		C3	23	*Mankrong Pona*	60.00	14.80	0.49	3.20
2	8	C3	24	*Dente*	60.00	15.60	0.52	3.20	
3	9	C2	25	*Mankrong Pona*	60.00	15.00	0.50	3.10	
3	9		C2	26	*Dente*	59.50	15.10	0.50	3.00
3	9		C2	27	*Pona*	59.50	15.30	0.51	3.00
3	10		C3	28	*Pona*	59.50	14.20	0.47	3.00
3	10		C3	29	Mankrong *Pona*	59.50	14.90	0.49	2.95
3	10		C3	30	*Dente*	59.50	14.30	0.48	3.00
3	11		C4	31	*Mankrong Pona*	59.50	14.30	0.48	2.95
3	11		C4	32	*Pona*	59.50	14.90	0.49	2.95
3	11		C4	33	*Dente*	59.50	15.80	0.52	3.00
3	12		C1	34	*Dente*	60.50	14.40	0.48	2.95
3	12		C1	35	*Mankrong Pona*	59.50	15.10	0.50	2.95
3	12		C1	36	*Pona*	69.50	15.10	0.50	2.95
Mean	59.64	3.03	s.e.d	3.724	0.39				

Appendix 2 Experimental design for aeroponic system evaluation

BLOCK 1	A1C2V1	A1C2V3	A1C2V2	A2C4V3	A2C4V2	A2C4V1
	A1C1V3	A1C1V2	A1C1V1	A2C3V2	A2C3V1	A2C3V3
	A1C3V2	A1C3V1	A1C3V3	A2C1V1	A2C1V3	A2C1V2
	A1C4V3	A1C4V2	A1C4V2	A2C2V2	A2C2V1	A2C2V3
BLOCK 2	A2C1V2	A2C1V1	A2C1V3	A1C3V1	A1C3V3	A1C3V2
	A2C4V3	A2C4V2	A2C4V1	A1C1V3	A1C1V2	A1C1V1
	A2C2V1	A2C2V2	A2C2V3	A1C4V2	A1C4V1	A1C4V3
	A2C3V2	A2C3V3	A2C3V1	A1C2V1	A1C2V3	A1C2V2
BLOCK 3	A1C3V1	A1C3V2	A1C3V3	A2C1V2	A2C1V1	A2C1V3
	A1C2V2	A1C2V1	A1C2V3	A2C3V1	A2C3V2	A2C3V3
	A1C4V3	A1C4V2	A1C4V1	A2C2V3	A2C2V1	A2C2V2
	A1C1V2	A1C1V3	A1C1V1	A2C4V2	A2C4V3	A2C4V1

A1 = Pressurised aeroponic system	C1 = Nutrient formulation level 1	V1 = *Pona*
A2 = Gravity-fed aeroponic system	C2 = Nutrient formulation level 2	V2 = *Dente*
	C3 = Nutrient formulation 3	V3 = *Mankrong Pona*
	C4 = Control	

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Appendix Experimental design for field evaluation of mini-tubers

BLOCK 1	C4V2	C1V2	C4V3	C4V2	C1V2	C4V3
	C1V3	C2V2	C2V3	C1V3	C2V2	C2V3
	C3V3	C4V1	C3V1	C3V3	C4V1	C3V1
	C1V1	C2V1	C3V2	C1V1	C2V1	C3V2
BLOCK 2	C4V2	C1V2	C4V3	C4V2	C1V2	C4V3
	C1V3	C2V2	C2V3	C1V3	C2V2	C2V3
	C3V3	C4V1	C3V1	C3V3	C4V1	C3V1
	C1V1	C2V1	C3V2	C1V1	C2V1	C3V2
BLOCK 3	C4V2	C1V2	C4V3	C4V2	C1V2	C4V3
	C1V3	C2V2	C2V3	C1V3	C2V2	C2V3
	C3V3	C4V1	C3V1	C3V3	C4V1	C3V1
	C1V1	C2V1	C3V2	C1V1	C2V1	C3V2

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Appendix Table of means for days to rooting of one node cuttings

Aeroponic unit	**Nutrient concentration**	**Variety**		
		Dente	***Mankrong Pona***	***Pona***
Power-Dependent	C1	14.67	8.33	9.00
	C2	15.00	9.00	9.00
	C3	14.67	8.33	9.33
	C4	14.33	9.33	9.67
Power-Independent	C1	21.33	13.00	14.00
	C2	21.67	14.33	15.33

4				
	C3	22.67	15.00	15.67
	C4	22.33	14.67	15.33
s.e.d		0.354	0.354	0.354

Appendix 5 Table of means for days to rooting of two node cuttings

Aeroponic unit	**Nutrient concentration**	**Variety**		
		Dente	***Mankrong Pona***	***Pona***
Power-dependant	C1	13.667	5.000	5.000
	C2	13.667	5.667	5.667
	C3	13.333	5.000	5.667
	C4	15.333	5.667	6.000
Powerindependent	C1 C2	15.000	8.000	8.667
		15.000	8.000	8.333
	C3	15.333	7.667	7.667
	C4	15.333	8.000	8.333
s.e.d		0.1577	0.1577	0.1577

Appendix 6

Number of roots at rooting and subsequent weeks after planting for one node cuttings

Aeroponic unit	Nutrient concentration	Variety								
		Dente			*Mankrong Pona*			*Pona*		
		NRARI	2WAP	4WAP	NRARI	2WAP	4WAP	NRARI	2WAP	4WAP
Power-Dependent	C1	3.67	3.67	10.67	4.667	6.33	13.67	4.33	6.00	13.33
	C2	5.00	4.00	10.33	6.00	8.33	13.67	4.33	8.67	13.67
	C3	5.00	3.67	10.33	4.33	6.33	13.67	5.33	7.33	14.00
	C4	5.00	3.33	12.67	5.67	7.00	13.67	4.67	6.67	14.67
Power-Independent	C1	2.00	0.00	9.67	3.33	2.67	12.67	2.33	2.00	14.33
	C2	2.33	0.00	10.67	3.33	1.33	12.00	3.33	0.00	12.67
	C3	2.33	0.00	9.67	4.00	1.33	11.67	3.67	1.00	10.67
	C4	2.33	0.00	5.67	4.00	1.33	8.67	3.33	0.00	8.88
s.e.d		0.67	1.80	2.51	0.67	1.80	2.51	0.67	1.80	2.51

Appendix 7

Number of roots at rooting and subsequent weeks after planting for two node cuttings

Aeroponic unit	**Nutrient concentration**	**Variety**								
		Dente			***Mankrong Pona***			***Pona***		
		NRARI	**2WAP**	**4WAP**	**NRARI**	**2WAP**	**4WAP**	**NRARI**	**2WAP**	**4WAP**
Power-Dependent	C1	6.67	6.67	25.33	6.00	13.00	19.33	5.33	12.67	19.33
	C2	6.67	6.67	26.00	5.00	14.67	22.33	6.00	14.00	20.67
	C3	6.67	6.67	29.00	6.00	16.00	24.33	5.00	15.00	23.67
	C4	6.00	6.00	18.67	5.67	13.00	20.33	5.33	13.67	20.67
Power-Independent	C1	3.67	3.67	11.00	2.33	8.67	11.33	2.00	9.67	11.00
	C2	3.00	3.00	12.33	2.67	10.00	13.00	2.00	9.00	11.67
	C3	4.00	4.00	14.33	2.33	10.00	13.33	2.67	9.33	12.33
	C4	3.33	3.33	9.00	2.67	8.00	10.67	2.00	8.00	10.67
s.e.d		0.7617	1.067	1.416	0.7617	1.067	1.415	0.7617	1.067	1.416

Appendix 8

table of means for number of vines and weight of mini-tuber tubers at harvest

Aeroponic unit	Nutrient concn	Variety					
		Dente		*Mankrong Pona*		*Pona*	
		NVAH	Weight of minituber harvest, g	NVAH	Weight of minituber at harvest, g	NVAH	Weight of minituber at harvest, g
Power-Dependent	C1	2	5.82	2	7.26	2	6.86
	C2	3	7.26	3	8.23	2	7.51
	C3	4	8.25	4	8.90	3	8.34
	C4	2	4.46	1	4.28	1	4.22
Power-Independent	C1	1	3.44	1	3.30	1	3.30
	C2	1	3.42	1	3.54	1	3.24
	C3	2	5.95	1	5.12	1	5.00
	C4	1	3.02	1	3.20	1	3.00

NVAH = Number of vines at harvest

Appendix 9

Table of means for number of mini-tubers harvested at first harvest

Aeroponic unit	**Nutrient concentration**	**Variety**		
		Dente	***Mankrong Pona***	***Pona***
Power-Dependent	C1	0.00	2.67	2.33
	C2	0.00	2.67	2.33
	C3	0.00	2.67	2.67
	C4	0.00	2.67	2.33
Power-Independent	C1	0.00	2.00	2.00
	C2	0.00	2.00	2.00
	C3	0.00	2.67	2.33
	C4	0.00	1.33	1.33
s.e.d		0.42	0.42	0.42

Appendix 10 Table of means for number of mini-tubers harvested at second harvest

Aeroponic unit	**Nutrient concentration**	**Variety**		
		Dente	***Mankrong Pona***	***Pona***
Power-Dependent	C1	2.33	1.67	1.33
	C2	2.67	1.33	1.00
	C3	2.33	2.00	1.33
	C4	2.33	0.67	1.00
Power-Independent	C1	2.00	1.33	0.67
	C2	2.00	0.67	0.67
	C3	2.33	1.00	1.00
	C4	1.67	1.33	1.00
s.e.d		0.44	0.44	0.44

Appendix

11 Table of means for total number of mini-tubers harvested per plant

Aeroponic unit	Nutrient concentration	Variety		
		Dente	***Mankrong Pona***	***Pona***
Power-Dependent	C1	2.33	3.33	3.00
	C2	2.67	3.00	3.33
	C3	2.33	3.67	3.00
	C4	2.33	2.67	3.00
Power-Independent	C1	1.33	3.00	1.67
	C2	1.33	2.33	2.00
	C3	1.00	2.67	2.33
	C4	1.00	2.00	1.67
s.e.d		0.55	0.55	0.55

Appendix 12 Table

of means for weight of mini-tubers harvested

Aeroponic unit	Nutrient concentration	Variety		
		Dente	***Mankrong Pona***	***Pona***
Power-Dependent	C1	4	3	4
	C2	5.6	5.8	5.8
	C3	10.2	8.40	8.40
	C4	3.60	4.80	3.20
Power-Independent	C1	3.20 3.80	3.60 4.20	3.60
	C2			5.10
	C3	8.40	7.40	6.00
	C4	3.00	3.20	3.20

Appendix 11

Appendix

13 Table of means for days to breaking dormancy

Aeroponic unit	Nutrient concentration	Variety		
		Dente	***Mankrong Pona***	***Pona***
Power-Dependent	C1	90.67	42.67	54.00
	C2	91.33	43.33	53.33
	C3	90.00	43.33	56.67
	C4	89.67	45.33	57.67
Power-Independent	C1	89.67	43.00	57.00
	C2	89.67	42.00	56.67
	C3	89.00	42.00	58.67
	C4	89.33	44.00	55.67
s.e.d		1.06	1.06	1.06

Appendix 14 Table of means for direct seeding in screenhouse

Aeroponic unit	Nutrient concentration	Variety		
		Dente	***Mankrong Pona***	***Pona***
Power-Dependent	C1	82.33	56.67	43.00
	C2	79.33	54.67	40.67
	C3	80.33	55.67	41.00
	C4	83.33	60.00	49.33
Power-Independent	C1	82.33	55.00	41.67
	C2	79.67	53.00	40.67
	C3	80.33	57.00	47.67
	C4	82	56.67	42.33
s.e.d		2.9	2.9	2.9

Appendix 15 Number of seed yam per plant (mini-tuber)

Aeroponic unit	Nutrient concentration	Number of seed yam (g)		
		Dente	***Mankrong Pona***	***Pona***
Power-Dependent	C1	1.01	1.23	1.25
	C2	1.88	1.98	1.88
	C3	2.58	2.92	2.10
	C4	1.00	1.23	1.23
Power-Independent	C1	1.12	1.00	1.00
	C2	1.27	1.22	1.34
	C3	2.01	2.23	2.12
	C4	1.01	1.10	1.13

Appendix 16 Seed y

ım weight

Aeroponic unit	Nutrient concentration	Variety/weight of seed yam (g		
		Dente	***Mankrong Pona***	***Pona***
Power-Dependent	C1	230.00	212.00	222.00
	C2	423.21	302.98	293.00
	C3	560.00	560.00	543.28
	C4	123.92	121.38	100.23
Power-Independent	C1	221.50	210.22	198.20
	C2	212.45	203.50	221.38
	C3	521.22	501.11	510.00
	C4	134.22	198.24	201.00

Appendix 17 Draft manuscript one from thesis

DESIGN AND EVALUATION OF TWO SIMPLE AEROPONIC SYSTEMS FOR SEED YAM PROPAGATION

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ABSTRACT

Two aeroponic systems were developed by the CSIR-Crops Research Institute in conjunction with the Department of Agricultural Engineering, KNUST, Kumasi, to be used for the production of seed yams propagated from vine cuttings. Two designs were made: one power dependent and the other power independent. In the systems design, the following aspects were taken into consideration: selection of head control and emitter; design of laterals and pipe sizes (inlet and outlet pipes); and the selection of growth chamber and feed tank. Apart from the selection of the growth chamber and the design of laterals and outlet pipe, different design considerations were also taken into account for the gravity fed system. This included the selection of drip lines and emitter flow rate. Technical evaluation of the aeroponic systems were done to ascertain its effectiveness as

a fertigation system based on the performance indicators for a sprinkler and drip irrigation system. There were significant differences between the technical performances of the two aeroponic systems. Results from the technical evaluation gave a mister discharge for the power dependent system ranging from 59.00 – 60.5 kPa. The emitter flow rate, the equivalent evaluation parameter for the power independent system also ranges from 0.10 – 0.12 l/h. There was a linear correlation between the mister operating pressure, mister discharge

and swath diameter for the power-dependent system. For a Christensen's Coefficient (CU) and Distribution Uniformity (DU) values of 97.52% and 96.16% respectively, the power dependent system can be said to be very efficient in its operations. The same could be said for the power independent system having a CU and DU of 94.49% and 90.80% respectively.

Keywords: Pressurised pumps, gravity-fed, drip hydroponics, closed looped.

INTRODUCTION

Hydroponic and aeroponic cultivation has been used for research and crop production around the world in various forms and designs. The technology has advanced a great deal in the last 20 years and has become, possibly, the most intensive method of crop production in today's agricultural industry (Jensen and Collins, 1985).

Aeroponics is a system of hydroponics in which the roots of the plants are suspended in a closed chamber and a nutrient solution is sprayed from below ((Arunkumar and Manikand, 2011; Pagliarulo and Hayden, 2002). A distribution system of pipes, spray nozzles, a pump and timer distributes the spray from a nutrient solution storage tank. The chamber and misting system provide complete control of the root zone environment, including temperature, nutrient level, pH, humidity, misting frequency and duration and oxygen availability. Because of the easy access to the roots,

aeroponics has been used as a research tool since the 1940s, with work done using vegetable crops in the 1970s and 1980s (Jensen and Collins, 1985). Plants often exhibit accelerated growth and maturation in aeroponic systems (Mirza *et al*., 1998). These qualities have made aeroponics a popular research tool for scientists studying root growth and plant nutrient uptake (Barak *et al*., 1998).

With all the evolving advances in aeroponic and hydroponic systems, the technology has not been used much and adapted for research or production in Ghana. Whilst researchers are advocating for its use in research and crop production in Ghana, the future depends on developing systems which are competitive in production costs, adaptable to use in our part of the world and energy use efficient.

Two aeroponic systems were developed for use in the production of disease free seed yams by the CSIR-Crops Research Institute and the Agricultural Engineering Department of the KNUST.

Since a big part of the question of aeroponics technology's feasibility is energy cost, the overall objective of this work was to design one fully functional, low-cost pressurized (energy dependent) aeroponic growth system and one fully functional low cost drip (energy independent) hydroponic system and evaluate its functionality as a fertigation system.

MATERIALS AND METHODS

The design and fabrication processes including the systems design and design components, and the technical evaluation are discussed here. Technical evaluations of the systems were done as per the criteria for evaluating pressurised and gravity-fed drip irrigation systems.

Design of aeroponic systems

The functional requirement of this aspect was to design two fully functional, low-cost aeroponic growth systems. These are power-dependent and power independent systems known hereof as the pressurised closed-loop aeroponic system (PCLAS) and the gravity-fed aeroponic system (GFAS) respectively.

System design of the power-dependent aeroponic system

This is a system that utilizes electricity in its operations. It uses a high pressure pump which is used to atomize the water through small orifice misters to create water droplets of 50 microns or less in diameter. Fertigation is automatically timed using irrigation timers at two minutes and thirty minutes off.

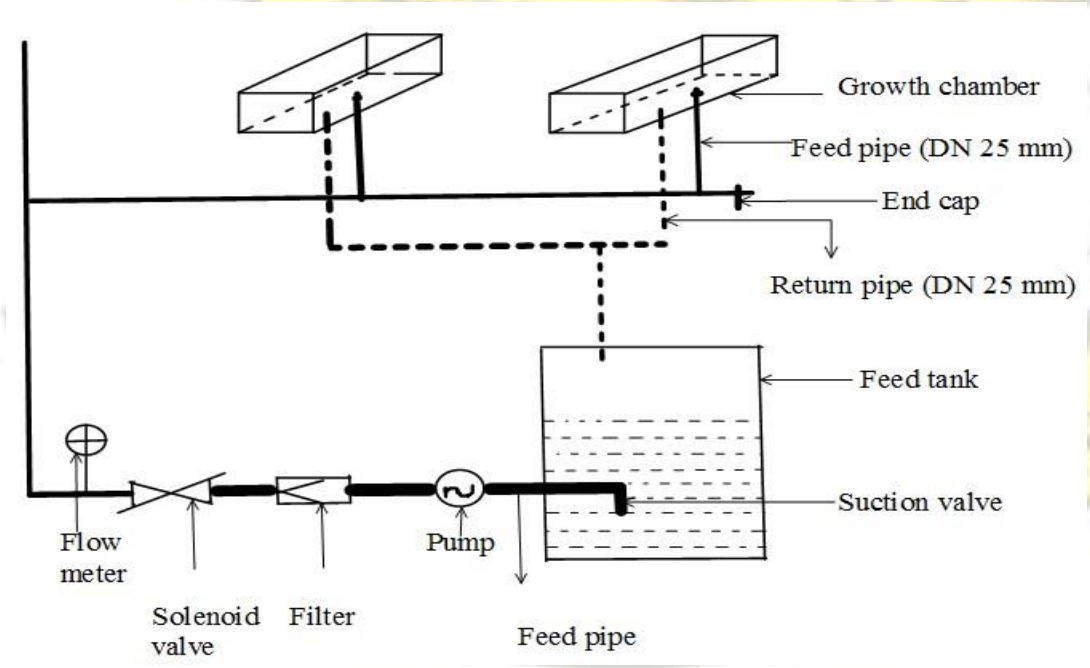

Figure 1 Schematic representation of the pressurised system

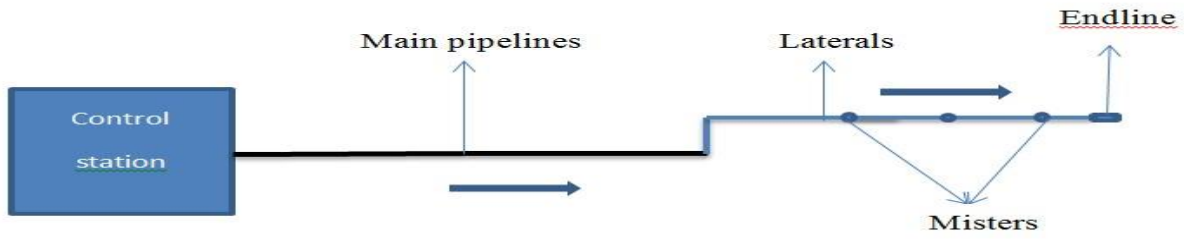

Figure 2 System Flow Chart for one pressurised aeroponic unit

Design and Selection of Emitter

The diameter coverage and height of the growth chamber was considered or used in the selection of the emitter. Since a spray is required in irrigation/fertigation of the roots, a single nozzle micro mister was selected. The number of emitters per lateral was determined based on the number of growth chambers on the lateral. Each growth chamber was designed to have one emitter each base on the size (length, breath and height) of the growth chamber. Thus, each lateral had 3 emitters each.

Lateral Design

The length of the lateral was designed based on the number and arrangement of the growth chamber. According to the experimental design for the agronomic evaluation, three yam varieties, grown in three different chambers, were irrigated with the same nutrient solution at a particular time. Hence three tote boxes (growth chambers) were arranged horizontally (end to end) on a table. The total length of the three arranged boxes was taken. A length of 0.5 m was added to that of the three growth chambers to compensate for the inlet and endlines of the laterals. The total length of the three tote boxes was determined to be 1.5 m (with a length of 0.5 m for each). Compensating with the adjusted 0.5 m length gave a total lateral length of 2.0 m.

The lateral flow rate was determined using the formula given by Phocaides (2000).

Lateral flow rate (LFR) =emitters per lateral × emitter flow rate…… Equation 6

LFR = 3 × 30 l/h

= 90 l/h

Determination of the size of the pipelines

The selection of pipe sizes was based on the equation by Phocaides (2000).

$q = kd\ H^{*}$……. Equation 7

Where; q = Emitter discharge; k and d are coefficients; and

H = Pressure at the emitter and * is an exponent characterized by the emitter flow regime and the flow rate curve as a function of pressure.

The friction factor method, characterized by Equation 3 was used in sizing the laterals.

$F_f = \frac{Po \times Pv}{Lc}$ …….. ……. Equation 8

Where;

F_f = Allowable Psi per 100" of pipe (psi/100" = 9.8 kPa/100m)

P_o = Operating pressure of emitter

P_v = Allowable percentage pressure variance

L_c = Longest run of lateral line (critical length)

Friction pressure loss was computed using Equation 4.

$H_f = [0.2083]\left(\frac{100}{C}\right)^{1.852}\left(\frac{Q^{1.852}}{d^{4.866}}\right) \times 0.433$ …….. Equation 9

Where,

H_f = Friction loss per 100'

C = Coefficient of retardation based on pipe material Q = Flow discharge d = Inside diameter of pipe

Alternatively, the lateral friction loss was calculated using an irrigation calculation online based on Equation 3 and 4. For a 16 mm PVC pipe with 3 misters having a flow rate of 30 l/h (spaced 1 m apart), the frictional loss was estimated to be negligible by the calculator. Hence the 16 mm PVC pipe was chosen to be the ideal pipe size for the laterals.

According to Phocaides (2000), the main pipeline is selected in such sizes that the friction losses do not exceed approximately 15 % of the total dynamic head required at the beginning of the systems piped network. Phocaides (2000) further stated that the flow velocity in the main pipeline should be kept below 1.7 m/s in (plastic tubes) and 2 m/s in other pipes (steel, aluminium, etc). Since the main pipelines supplies directly to the laterals without branching, a 25 mm PVC pipe was chosen based on Equation 5.

$V = Q/A$ ……. Equation 10

Where,

V = Flow velocity

Q = Discharge

A = Pipe cross-sectional area

Head Control

The component parts of the system are complete with pump, filters, non-return valve, union joints and shut off valve. The total pressure head required for the system was designed based on Phocaides (2000) sum of the following pressures:

Pressure at the emitter,

Friction loss in the lateral line,

Friction loss in the valves and pipe fittings,

Differences in elevation, and

Loss of pressure in head control.

The brake horse power was determined using Equation 6 by Phocaides (2000):

$BHP = Q \times TDH \div 270 \times e_1 \times e_2$ ……..Equation 6

Where,

Q = flow capacity in m^3/h,

e_1 = Pump Efficiency, e_2 = Driving Efficiency,

TDH = Total Dynamic Head, and

270 = constant for metric units gives pump efficiency to range between 0.5 – 0.8

Thus BHP = 90 l/h $\times \frac{3}{270} \times 0.7 \times 0.7$

=0.49 hp

Consequently, a pump with a horse power of 0.5 was chosen. Since the 0.5 HP pump came with inlet and exit valves of 25 mm, 25 mm pipes and fittings were used in the design and fabrication.

Design and Selection of Growth Chamber

The agronomic evaluation of this research sought to evaluate the growth and yield performance of three yam varieties propagated by the two systems. It therefore became imperative to design a system that can house each variety in a single unit whilst at the same time give room for connecting in series to the next unit.

Plastic tote boxes 0.5m x 0.4m x 0.3m. In dimension and made locally in Ghana by Century Plastic Products Limited was chosen for the following reasons:

i. Make of plastic material that can withstand rot and infestation from constant contact with water and nutrients and

ii. Its ability to be worked on (cutting and spraying).

Once the pipe sizes to be used in the fertigation system was known, holes were punched through the sides (centrally) to pave way for the insertion of the pipes through the tote boxes. Same was done beneath the tote boxes to allow for drainage.

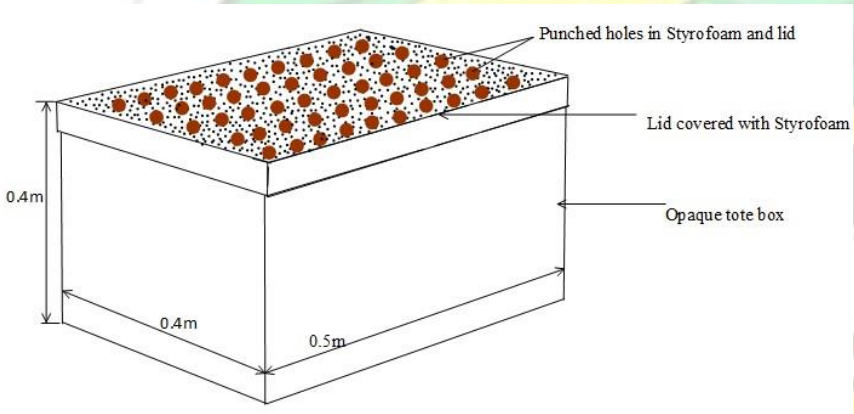

Figure 17 Design specifications of the growth chamber and plant holding tray

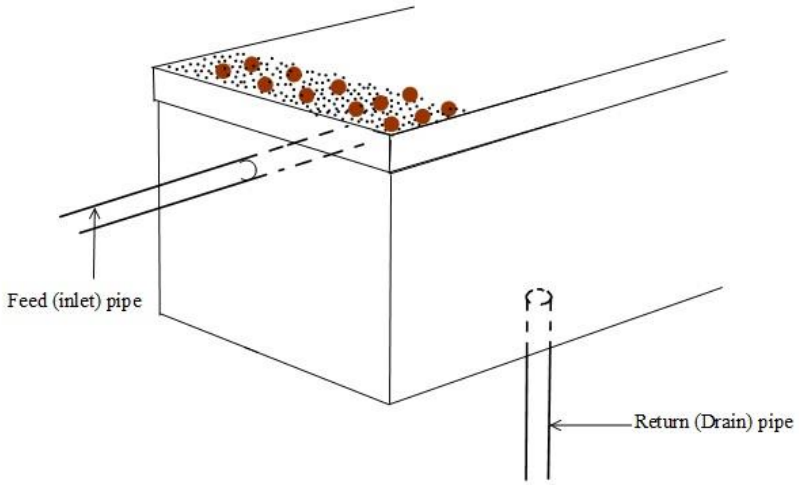

Figure 18 Feed and return pipes of the growth chamber

Design and Selection of Feed Tank

Based on the design flow rate, a 150 m^3 feed tank was selected to hold the nutrient and water.

Systems Design of the Gravity-Fed Drip System

This is a gravity-fed aeroponic system (GFAS) that does not depend on electricity or any other source of electrical power for its operation. The nutrients are fed to the plants by gravity through pipes with drip emitters. The feed tank is elevated at a height conducive for gravity flow. An improvised drip emitter is made by punching micro-holes spaced 6 cm apart on the 4 mm polyethylene (PE) pipe for nutrient delivery to the base of the plant and subsequent flow to the roots.

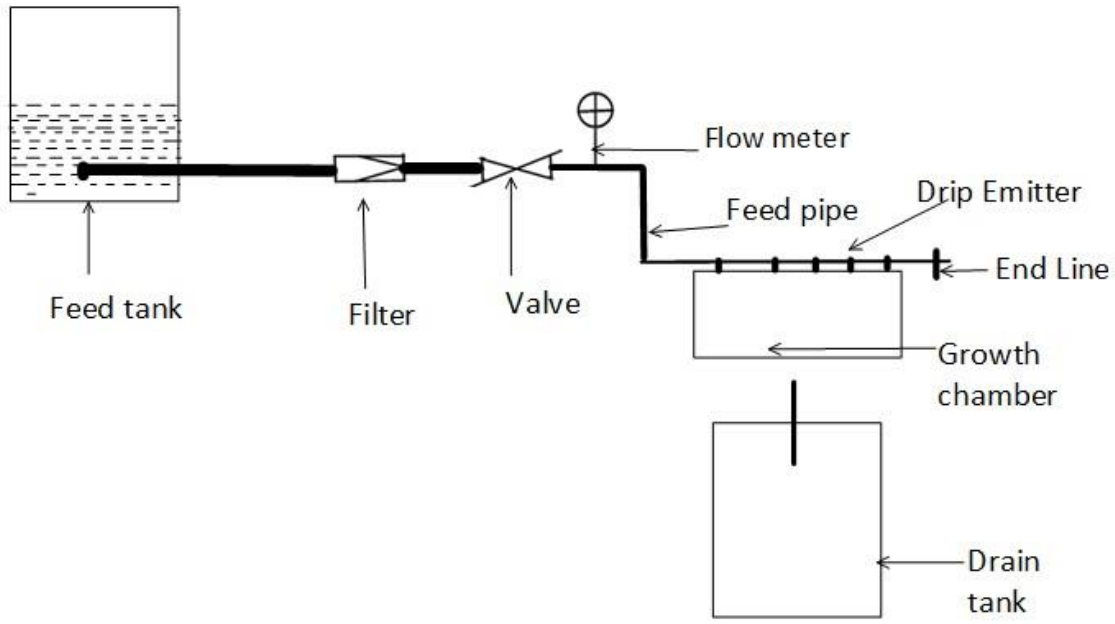

Figure 5 Schematic representation of the gravity-fed system

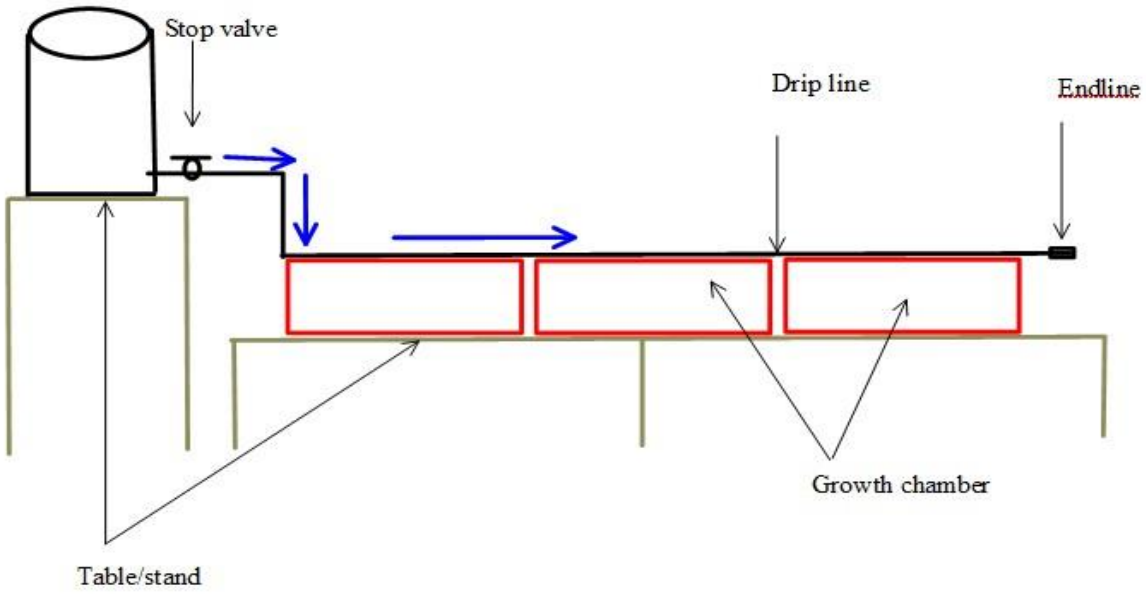

Figure 6 System Flow Chart for one gravity-fed aeroponic unit

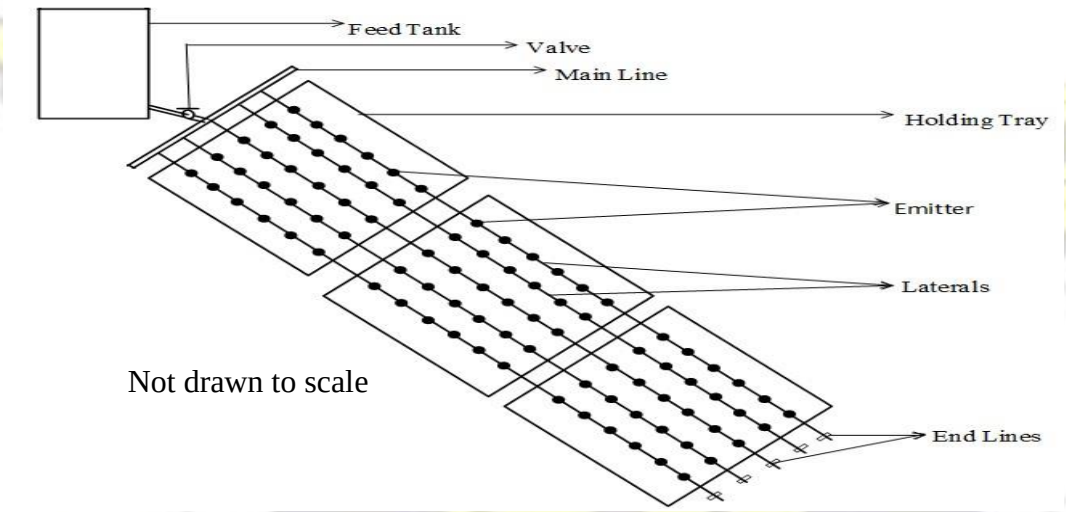

Figure 7 Schematic representation showing laterals and emitters

Design and selection of laterals, emitter spacing and flow rate

Choosing emitters for aeroponics is more complicated than choosing it for soil applications. A lateral system relies on the soil to evenly spread water throughout the planting area whereas a gravity-fed aeroponic system would rely on these emitters to distribute water and nutrients

around the roots of the plants. A flag emitter was chosen for use due to its ability to be inserted directly or close to the root zone of the plant. Pieces of Styrofoam were laid on top of the plant holding tray to absorb and distribute excess moisture from the emitters.

Evaluating the Pressurised system

Measuring mister discharge

A three meter length of a garden hose was connected to the nozzle of a mister and whilst the pump and mister were operating, the water was directed into a bucket over a 10 minute period. The volume collected into the bucket was measured with a measuring cylinder and recorded. The discharge was determined by dividing the volume collected by the time taken to collect the recorded volume. This procedure was repeated for the remaining misters to determine the individual discharges.

Measuring mister operating pressure and swath diameter

The mister operating pressure was taken using a pitot tube connected to a pressure gauge. Each mister was also allowed to operate without being restricted by the growth chamber to determine the swath diameter. The misting head of a system can only distribute the water over a given area. The farthest distance covered by water droplets (throw) from the mister head's centre line at which the mister deposits water in the growth chamber was measured. The swath radius was calculated as the distance from the centre of the mister nozzle to one end of the wetted perimeter and multiplied by two to get the swath diameter.

Measuring pump operating pressure

The pump operating pressure was measured using a pressure gauge connected to the discharge end of the pump. Data was taken and analysed.

Determining uniformity of application and system efficiency

Uniformity of application and irrigation efficiency is two performance measures used to evaluate an irrigation system. The two terms are used to describe the uniformity of application rate and the uniformity of coverage of sprinklers and emitters: these are mean application rate (MAR) and distribution uniformity (DU). The mean application rate (MAR) is defined as the average rate (in mm/h) that water is applied to the wetted area of the soil. Distribution uniformity is defined as a ratio of the smallest accumulated depths in the distribution to the average depths of the whole distribution (Ascough and Kiker, 2002).

From the procedure used to determine the mister discharge, 25% of the catch cans with the lowest volumetric output was selected to form the lower quartile. The irrigation depth was determined by measuring the water in each catch can with a rain gauge calibrated in mm. The mean depth was determined by dividing the total of lower quartile catch depth by the number of catch cans forming the lower quartile. The uniformity of application was determined using Equation 7.

$$DU = 100\% \frac{\text{Average lower quartile depth of application}}{\text{overall averarge depth of application}} \quad \text{……..Equation 7}$$

Evaluating the Gravity-Fed System

Determining flow rate of perforated emitters

To determine the discharge of perforated emitters, catch cans were placed beneath each perforated position along the 2 m drip lines resulting in 90 catch cans for each distributing tank. The valve was opened and irrigation water was collected into the catch for an hour. Water collected from each can was poured into a calibrated measuring cylinder to get the volume of water in litres. The flow rate was calculated using Equation 8.

$$Flow\ rate, Q = \frac{V\ (l)}{T\ (h)}$$ ……..Equation 8

Where;

V is the volume of water collected in litres; and

T is the time used in collecting the said volume.

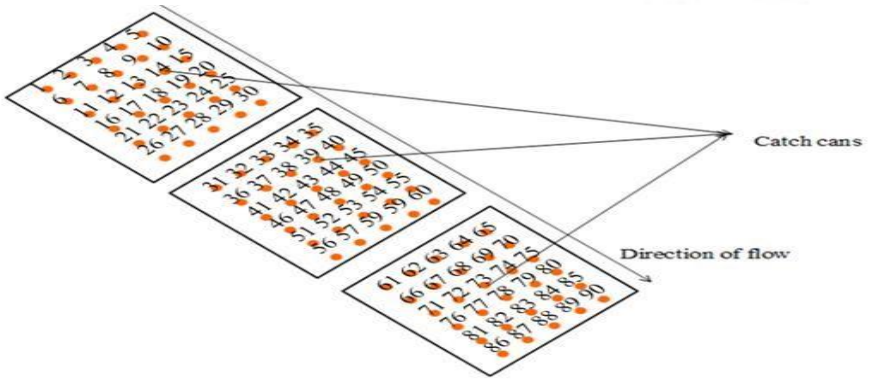

Figure 8 Grid view illustrating position of catch cans

Determining the distribution uniformity/coefficient of variation

If losses are low, and the volume of water flowing through the emitter is correct, the system can still be inefficient if the water is not applied evenly where it is needed. If the application is not even or uniform, some areas will get over-watered while some would not get enough. The uniformity coefficient was derived using the formula for the Christiansen's coefficient (CU) in Equation 9.

$$CU = 100\% \left[1 - \sum_{k=0}^{n} \left(\frac{x}{mn}\right)\right]$$ …….Equation 9

Where;

*Σx i*s the sum of the absolute deviations from the mean (mm or ml) of all the observations; *m* is the mean application depth measured (mm or ml); *n* is the number of observations (catch cans).

RESULTS AND DISCUSSION

The results from the technical evaluation of the two aeroponic systems are discussed in this subsection. Technical evaluations of aeroponic systems are conducted just in the way as with irrigation systems. Thus, the results of the technical evaluation of the aeroponic system are usually discussed following results from evaluations from other irrigation systems.

Mister discharge of the PAS

The results from measuring the mister discharge are as shown in Figure 1. There were no significant differences between any of the mister discharges or swath radius. The results however showed a positive linear correlation between mister discharge and swath radius.

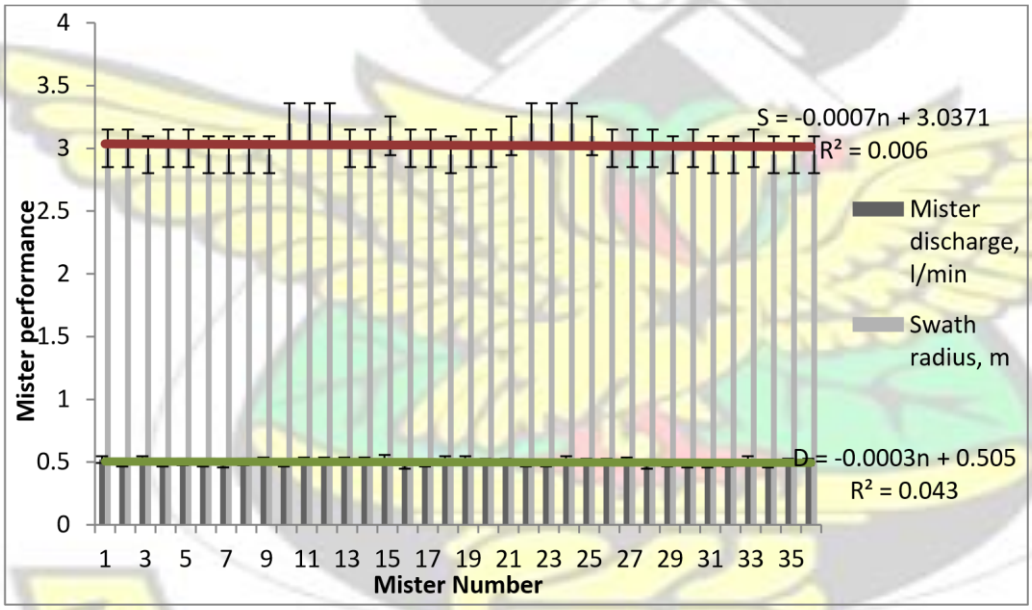

Figure 8 Mister performance showing mister discharge and swath radius

Mister operating pressure and swath diameter

The manufacturer's operating pressure for the mister was 50 kPa whereas the mean operating pressure of the misters was 59.64 kPa. The misters were performing 19.28 % higher than the manufacturer's operating pressure. This can be attributed to the fact that the experimental design used demanded only three misters per pump whereas the pump operating pressure could have powered twice this number. Swath diameter is also a measure to determine the uniformity and reach of water application in a pressurised system. There was a linear relationship between mister operating pressure and the swath diameter (Figure 3-2) suggesting a positive correlation between the two.

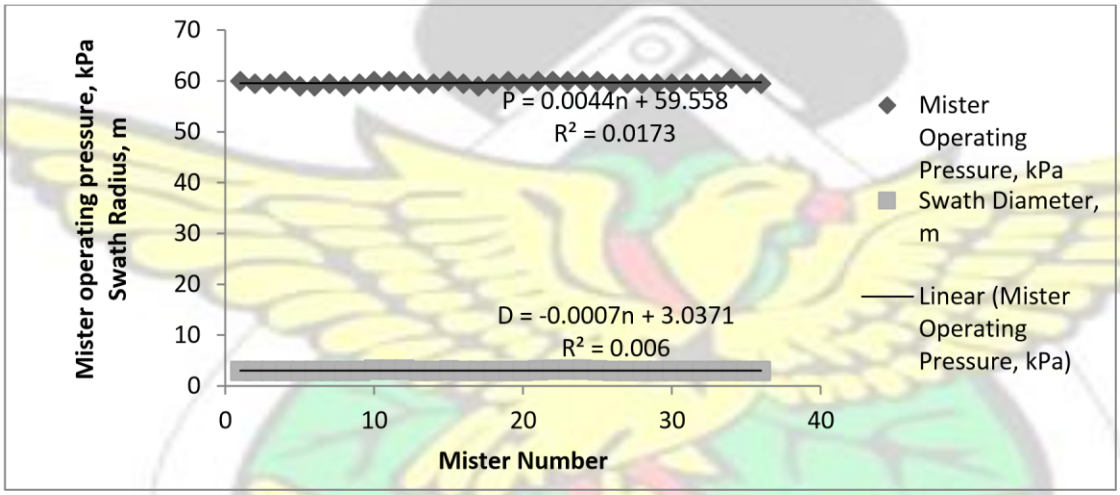

Figure 9 Relationship between mister operating pressure and swath diameter

Data collected from misters were further subjected to an analysis of variance to determine if significant difference existed in interactions between operating pressure and swath diameter. Table 1 showed that no significant differences existed in the interaction between mister operating pressure and swath diameter (MIPR.SWDR). Since swath diameter is a measure of the distribution of water and nutrients in the growth chamber, significant differences between these

interactions is suggestive that distribution in the box varies and thus not uniform. This could subject areas within the growth chamber to different treatments and thus introduce a higher coefficient of variation within the chamber. Thus this result showing no significant differences indicates efficient and effective distribution of nutrients within the set up.

Table 1 Anova for interaction between operating pressure, swath diameter and discharge

Source	d.f	s.s	m.s	v.r	F.pr
MIPR ignoring SWDR	3	7.28	2.43	3.36	0.03*
MIPR eliminating SWDR	3	1.5251	0.50	0.70	0.56
SWDR ignoring MIPR	3	24.43	8.144	11.27	<0.001**
SWDR eliminating MIPR	3	18.79	6.22	8.61	<0.001**
MIPR.SWDR	1	0.25	0.24	0.34	0.563
Residual	26	18.79	0.72		
Total	35	45	1.29		

MIPR = Mister operating pressure
SWDR = Swath diameter

** Significant at p<0.01 * Significant at p<0.05

Uniformity of application of the PAS

Using Christensen's coefficient of uniformity (CU), and the Distribution Uniformity, the uniformity of application for the power-independent system was determined to be 97.52 % and 96.16 % respectively. The CU obtained falls within the acceptable range for both high value crops CU > 84 % and for general field and forage crops: CU > 75 % (Michael, 1999; Keller and Bliesner, 1990). The high distribution uniformity recorded could be attributed to the appropriate selection of the types of misters, mister spacing and efficient operating pressures of the pumps and misters. These high values could also be attributed to the fact that there were minimal frictional and leakage losses in the system set up resulting in a very low pressure differential in the system between the main and laterals. The pressure differential in the system was at a minimum, thus maintaining pressure uniformity along the flow system.

Flow rate of perforated pipes/emitters

Emitter flow rates ranged from 0.10 – 0.12 l/h (Figure 10). The low level of variation in the system could be attributed to the pressure compensating effect given to the system. This was done by tilting the tables holding the growth chambers and the drippers at a 0.1 % slope away from the fertigation tanks. The emitter flow rates were thus compensated in pressure by the slope hence the uniformity or minimum variation in its values. This method is usually employed on drip irrigated fields to compensate for pressure differences of the fields (Julius *et al.*, n.d ; Smeal, 2007; Wu *et al*., 2010). Employing this method also resulted in an opposing slope in the drainage pipes. Hence, the drainage pipes were also sloped at 0.1 % for easy flow of fertigation water back to the collecting/drain tank.

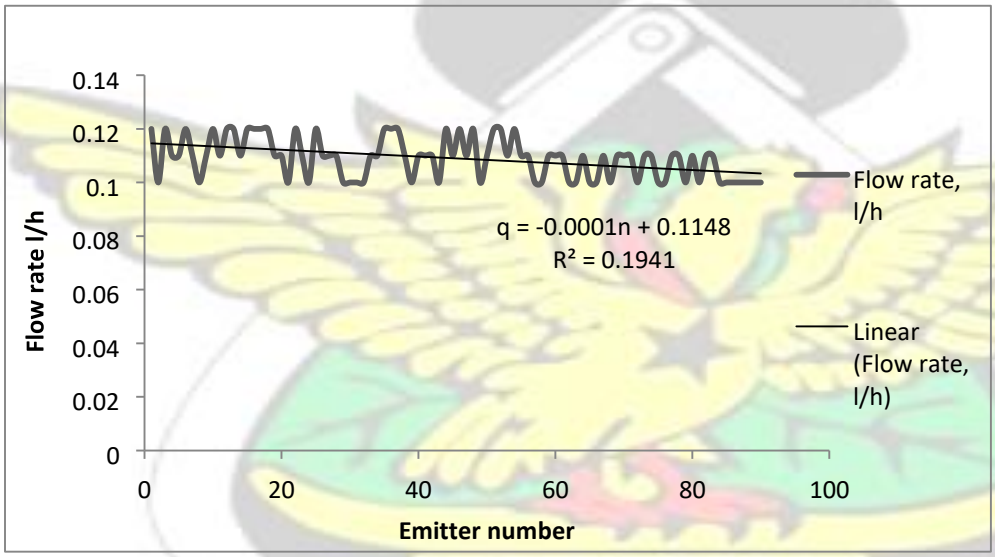

Figure 10 Emitter flow rate of the gravity-fed system

Distribution uniformity

Gravity-fed systems are known for their inherent lower water pressures. This if not well monitored can create variations in the emitter operation and water distribution. The method

employed in ensuring a uniform flow rate also invariably affected the distribution uniformity of the system. A Du and CU of 90.80 % and 94.49 % respectively were attained from the evaluation of the gravity-fed system. For micro sprinkler and drip systems, DU's of 90 % are usually said to be ideal (Burt *et al*., 2000).

Table 2 Parameters for calculating CU and DU

Emitter Number	Flow rate, l/h	Absolute Deviation	Emitter Number	Flow Rate l/h	Absolute Deviation	Emitter Number	Flow rate, l/h	Absolute Deviation
1	0.12	0.011	31	0.10	0.009	61	0.11	0.001
2	0.10	0.009	32	0.10	0.009	62	0.10	0.009
3	0.12	0.011	33	0.11	0.001	63	0.10	0.009
4	0.11	0.001	34	0.11	0.001	64	0.11	0.001
5	0.11	0.001	35	0.12	0.011	65	0.10	0.009
6	0.12	0.011	36	0.12	0.011	66	0.10	0.009
7	0.11	0.001	37	0.12	0.011	67	0.11	0.001
8	0.10	0.009	38	0.11	0.001	68	0.10	0.009
9	0.11	0.001	39	0.10	0.009	69	0.11	0.001
10	0.12	0.011	40	0.11	0.001	70	0.11	0.001
11	0.11	0.001	41	0.11	0.001	71	0.11	0.001
12	0.12	0.011	42	0.11	0.001	72	0.10	0.009
13	0.12	0.011	43	0.10	0.009	73	0.11	0.001
14	0.11	0.001	44	0.12	0.011	74	0.11	0.001
15	0.12	0.011	45	0.11	0.001	75	0.10	0.009
16	0.12	0.011	46	0.12	0.011	76	0.10	0.009
17	0.12	0.011	47	0.11	0.001	77	0.11	0.001
18	0.12	0.011	48	0.12	0.011	78	0.11	0.001
19	0.11	0.001	49	0.10	0.009	79	0.10	0.009
20	0.11	0.001	50	0.11	0.001	80	0.11	0.001
21	0.10	0.009	51	0.12	0.011	81	0.10	0.009
22	0.12	0.011	52	0.12	0.011	82	0.11	0.001
23	0.11	0.001	53	0.11	0.001	83	0.11	0.001
24	0.10	0.009	54	0.12	0.011	84	0.10	0.009
25	0.12	0.011	55	0.11	0.001	85	0.10	0.009
26	0.11	0.001	56	0.11	0.001	86	0.10	0.009
27	0.11	0.001	57	0.10	0.009	87	0.10	0.009
28	0.11	0.001	58	0.10	0.009	88	0.10	0.009
29	0.10	0.009	59	0.11	0.001	89	0.10	0.009

30	0.10	0.009	60	0.11	0.001	90	0.10	0.009

CONCLUSION

A well designed aeroponic system should be efficient in water/nutrient distribution, water and energy use. A DU and Cu of 96.16 % and 97.52 % respectively for the power dependent system and 90.80% and 94.49 % for the power independent (gravity-fed system) are very good and enough to recommend the system for use in propagating seed yam. The system can also be adapted for use with other crops to boost food production and security even in the face of climate change, population growth and limited land in an environmental sound way.

Funding: This study was funded by the World Bank under the West African Agricultural Productivity Programme and supported by the Bill and Melinda Gates Foundation under the Africa Yam project at the CSIR-Crops Research Institute.

Conflict of Interest: The authors declare that they have no conflict of interest.

REFERENCES

Arunkumar, M., and Manikand, R. 2011. Aeroponics.

http://www.slideboom.com/presentations/263081-/AEROPONICS Accessed 8 February 2014.

Ascough, G.W. and Kiker, G.A. 2002. The effect of irrigation uniformity on irrigation water requirements. *Water SA* Vol. 28 No.

Barak, P., Smith, J.D., Krueger, R. and Peterson, A. 1998. Measurement of short-term nutrient uptake rates in cranberry by aeroponics. *Plant Cell Environ.19:237-242.*

Burt, C.M., and Clemmens, A.J., and Bliesner, R., and Merriam, J.L., and Hardy, L. 2000. Selection of Irrigation Methods for Agriculture. American Society of Civil Engineers, USA.

Jensen, M.H. and Collins, W.L. 1985. Hydroponic vegetable production. *Hort. Rev.*7: 483-558

Julius, A., and Charter, M., and Figueroa, L. N.d. Design of gravity-fed drip irrigation system for macleish fields. http://www.smith.edu/events/docs/collaborations/2013/presentations/48_Bennett,BrittanyProceedings.pdf . Accessed 17 March 2016

Keller, J., and Bliesner, R.D. 1990. Sprinkle And Trickle Irrigation, *Van Nostrand Reinhold*, New York, ISBN:0-442-24645-5.

Michael, A.M. 1999. Irrigation: theory and practice. Vikas publishing house Pvt. Ltd., New Delhi. p: 644.

Mirza, M., and Younus, M., and Hoyano, Y., and Currie, R. 1998. Greenhouse production of Echinacea and other medicinal plants. Paper presented at Opportunities and Profits II: Special Crops into the 21st Century. Nov 1-3, 1998, Edmonton, AB, Canada

Pagliarulo, C.L., and Hayden, A.L., 2002. Potential for greenhouse aeroponic cultivation of medicinal root crops. Proc. Amer. Plasticult. Soc. Conf., San Diego, Cali. http://aerofarms.com/wordpress/wpcontent-/files_mf/1265411630GrowingMedicinalCropswithAeroponics.pdf. Accessed 28 January 2013

Phocaides, A. 2000. Technical Handbook on Pressurised Irrigation Techniques. ftp://ftp.fao.org/agl/aglw/docs/pressirrig.pdf Accessed 17 September 2015

Smeal, D. 2007. Drip irrigation for small plots (a low-tech, low-cost, gravity system) http://irrigationmanagement.nmsu.edu/documents/drip-for-organicconferencepicreductionforwebpdf.pdf. Accessed 17 March 2016

Wu, P.T., and Zhu, D.L., and Wang, J. 2010. Gravity-fed drip irrigation design procedure for a single-manifold subunit. ftp://ftp.ecn.purdue.edu/vmerwade/class/GDT/uploaded_documents/India/Stewart_Gravityfed%20drip%20irrigation%20design%20procedure.pdf. Accessed 17 March 2016

APPENDIX

Appendix 1: Mister operating pressure and discharges used in calculating the uniformity of application of the system

Mister number	Mister operating pressure, kPa	Discharge l/min	Absolute Deviation (x)	Descending order
1	60.00	0.52	0.021	0.031
2	59.50	0.49	0.009	0.029
3	59.50	0.52	0.021	0.029
4	60.00	0.49	0.009	0.021
5	59.00	0.50	0.001	0.021
6	59.00	0.49	0.009	0.021
7	59.50	0.48	0.019	0.021
8	59.00	0.50	0.001	0.021
9	59.50	0.51	0.011	0.021
10	60.00	0.49	0.009	0.019
11	60.00	0.51	0.011	0.019
12	60.00	0.51	0.011	0.019
13	69.50	0.51	0.011	0.019
14	69.50	0.51	0.011	0.011
15	60.00	0.53	0.031	0.011
16	59.50	0.47	0.029	0.011
17	59.00	0.49	0.009	0.011
18	59.50	0.52	0.021	0.011
19	60.00	0.52	0.021	0.011
20	59.50	0.50	0.001	0.009
21	60.00	0.50	0.001	0.009
22	60.00	0.49	0.009	0.009
23	60.00	0.49	0.009	0.009
24	60.00	0.52	0.021	0.009
25	60.00	0.50	0.001	0.009
26	59.50	0.50	0.001	0.009
27	59.50	0.51	0.011	0.009
28	59.50	0.47	0.029	0.009
29	59.50	0.49	0.009	0.001
30	59.50	0.48	0.019	0.001
31	59.50	0.48	0.019	0.001
32	59.50	0.49	0.009	0.001
33	59.50	0.52	0.021	0.001
34	60.50	0.48	0.019	0.001
35	59.50	0.50	0.001	0.001

36	69.50	0.50	0.001	0.001
		210		

Appendix 18 Draft manuscript two from thesis

DEMYSTIFYING AEROPONICS: THE GRAVITY-FED OPTION FOR SEED YAM PROPAGATION

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Abstract

Aeroponics has been perceived as a technology crammed innovation, far out of reach to the ordinary farmer. Apart from its continuous dependency on electrical power, the technology comes with very sophisticated inputs such as solenoid valves, timers, misters, CO_2 tanks, and air and water pumps. To maintain the ideal nutrient concentrations, thermometers, hygrometers, electrical conductivity and pH meters are also needed. The main objective of this study was to evaluate the option of using gravity-fed aeroponic system for propagating seed yams from vine cuttings. The study was setup at the CSIR – Crops Research Institute in conjunction with the Agricultural Engineering Department of the Kwame Nkrumah University of Science and Technology. The basic advantage of this system is its non-dependency on electrical power, pumps or timers and its ability for continuous production. The system was set-up used conventional materials and equipment available on the local market. The treatments were arranged in a split-plot design with four nutrient concentrations (C1 - , C2 - , C3 - and C4 -) and vines of three *Dioscorea rotundata* varieties (*Dente*,

Pona and Mankrong Pona) as main plot and sub-plot treatments respectively. Results showed there were significant differences (P<0.05).

Keywords: conventional materials, nutrient concentrations, vine cuttings, propagation

Introduction

Plants require light, water, nutrients and carbon dioxide (for photosynthesis) to grow and thrive. The soil can be a media supplier of nutrients and anchorage, but is not necessary in and of itself nutrients. Substituting the anchoring and nutrient or water holding capacities of the soils has long since being researched into. This has led to the successful introduction and effectiveness of the hydroponic and aeroponic technologies for plant propagation. Hydroponics is a method of plant propagation in which plant roots are submerged in nutrient-rich water needed for plants growth. Aeroponics is also a form of advanced hydroponics where plant roots are hanged in the air or a mist environment and intermittently supplied with nutrient and water through fertigation systems.

Since its introduction into the science arena, aeroponics has offered researchers a non-invasive means to examine plant roots during development (Mbiyu *et al*., 2012). It also allows researchers a large number and wide range of experimental parameters to use in their work (Stoner, 1983). The ability to precisely control the root zone moisture levels and the amount of water delivered makes aeroponics ideally suited for the study of water stress and irrigation/fertigation related research. The aeroponic technology has also been successfully used for crops that are vegatatively propagated, the most recent being the successful application of the technology in the propagation of yams (Oteng-Darko *et al*, 2016; Maroya *et al*, 2014). In further advancement, Oteng-Darko *et al*., (2016) developed the gravity-fed aeroponic option for seed yam production. This paper presents

the findings and enhancements made to the technology and the successes achieved in its application for seed yam generation.

Materials and methods

Two aeroponic systems were designed and set up as has been described by Oteng-Darko *et al*. (unpublished) at the CSIR-Crops Research Institute, Kumasi, Ghana. Two agronomic evaluations were done subsequently to determine the system's ability to produce seed yams. The agronomic evaluation consisted of two steps: evaluating the two aeroponic systems for its ability to produce mini-tubers and evaluating the mini-tubers for its ability to be used in propagating seed yams. In the first agronomic evaluation, one and two node cuttings of three yam varieties were planted on the aeroponic units and fertigated with four different nutrient concentrations. The experimental design was a split-split plot design whereby the aeroponic units were the main plot, nutrient concentrations the sub plots and yam varieties, the sub-sub plot.

In the second agronomic evaluation, three experiments were carried out, all set up in a split-split plot design with the main plot subjected to mini-tubers harvested from the two aeroponic units, the sub plots to mini-tubers from the various nutrient concentrations (C1, C2, C3 and C4) and the sub-sub plots subjected to mini-tubers from the three yam varieties used. The first experiment was subjected to a treatment in which dormant mini-tubers were planted in pots at a screenhouse, one day after harvesting. The second experiment, non-dormant mini-tubers were planted directly in the field. In the third experiment, non-dormant mini-tubers were nursed using sawdust in a screenhouse and transplanted two weeks after emergence.

Data was collected on days to rooting, days to tuber initiation, days to emergence (mini-tubers), yield and yield components. Data collected was analysed using Genstats 9.0 statistical package.

Mean separation was done using the Fishers unprotected least significant difference. Results were judged significant at $p < 0.05$

Results and discussion

Planting with one node cuttings showed significant differences ($p<0.05$) between Aeroponic units and variety; and nutrient concentration and variety (Figure 1) Significant differences ($p<0.05$) existed between the two aeroponic systems and also the various nutrient concentrations.

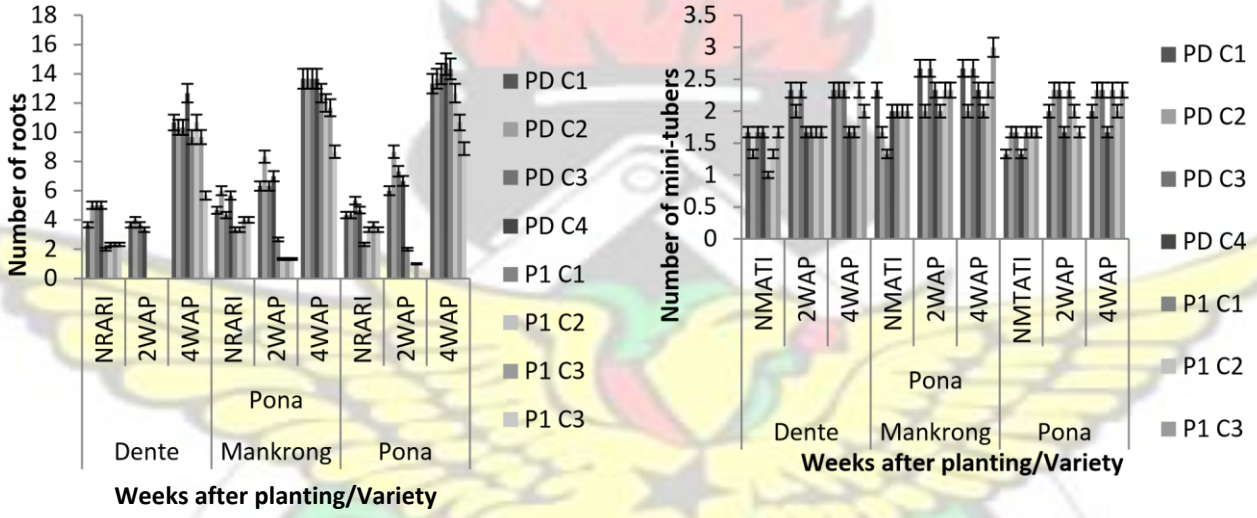

Figure 1 a. Number of roots; b. Number of mini-tubers of varieties under both power dependent and power independent system for the one node cuttings

Significant difference ($p<0.05$) existed between the main treatments (power dependent and power independent aeroponic systems) for both the one and two node cuttings. Varieties also showed highly significant differences at $p<0.01$ (Figure 1) in their response to the number of roots at root initiation for both the one and two-node cuttings. The number of roots observed was also significant for the one-node cuttings under the two-way-aeroponics unit x variety-

interaction.

No significant differences were seen in the number of mini-tubers for any of the treatment interaction at two weeks after planting (Figure 2) for the one node planting. However, with the

two-node cuttings, significant differences were seen in the main treatment (aeroponic units), sub plot (nutrient concentration) and sub-sub plot (variety). Significant differences also existed between the two way interactions aeroponic units x variety and nutrient concentration x variety for the two node cutting but not the one node cuttings. At four and six weeks after planting significant differences ($p<0.05$) are seen in the nutrient concentration treatments (Figure 2) for both the one and two node cuttings

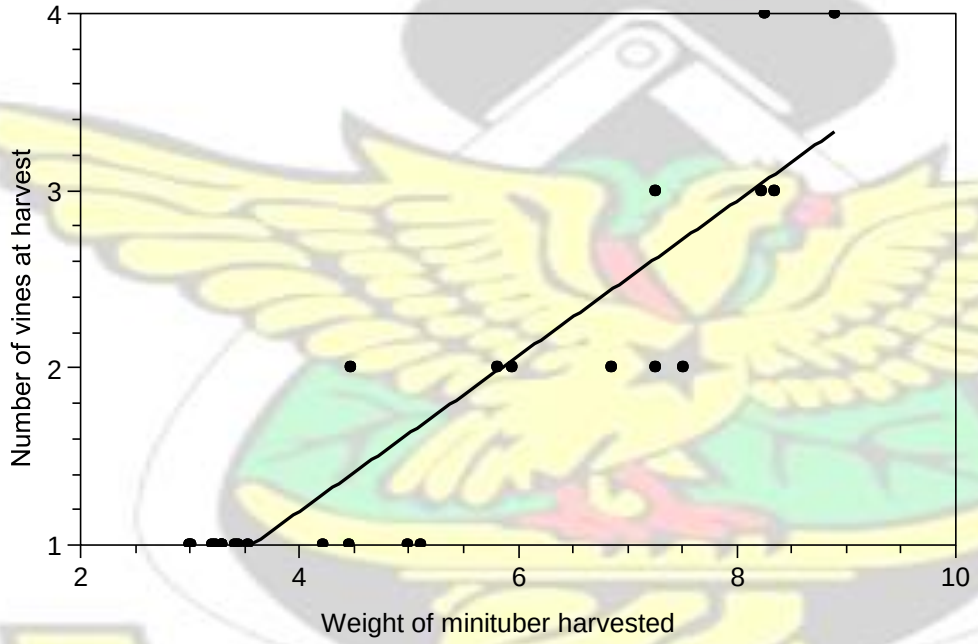

Figure 2 Correlation between number of vines and weight of mini-tubers harvested

The grand mean for the total number of mini-tubers harvested per plant (from both the first and second harvest) was 2.38. The aeroponic systems had means of 2.89 and 1.89 for the power dependent and power independent systems respectively (Figure 3). There were no significant differences in the three-way interaction between aeroponic system, nutrient concentration and

variety. Significant differences were seen in the various nutrient concentrations used. There was a highly significant difference ($p < 0.01$) between the varieties.

In planting with non-dormant seeds in the field, the mean emergence for both the power dependent and gravity-fed aeroponic systems was 5.36 days after planting, showing no significant differences between any of the interaction under this treatment.

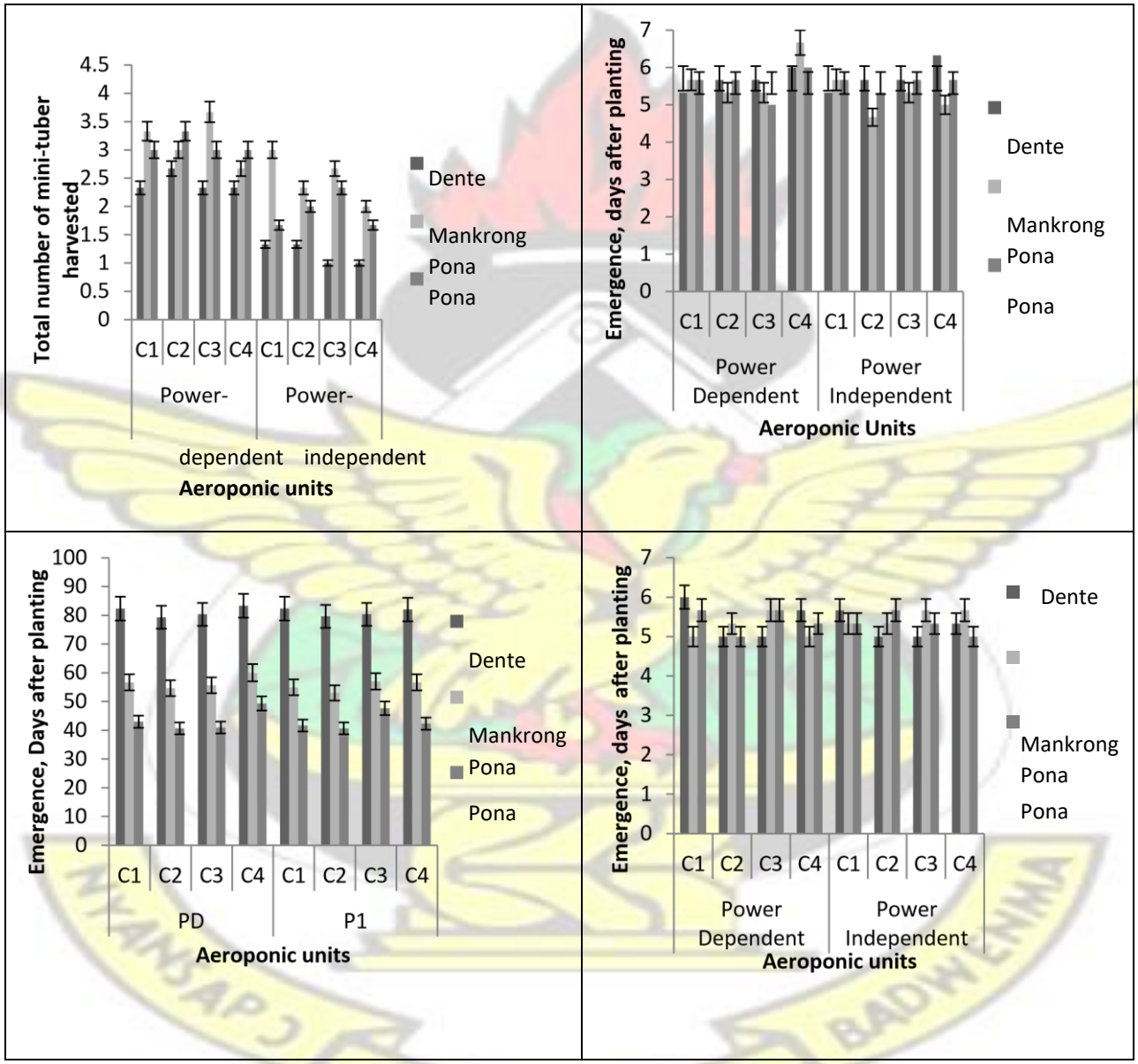

Figure 3 a. Number of mini-tubers harvested per plant b. nursed seeds in the screenhouse; c. directly planted dormant mini-tubers d. Directly planted non-dormant mini-tubers.

Even though significant differences were seen in the number of mini-tubers harvested under the various aeroponic systems, no significant differences were seen in its field performance in propagate seed yams.

Conclusion

The agronomic aspect of the study reported here provides evidence that aeroponics can be a valid option for propagating seed yams if minimal conditions are met. All the germination tests and field evaluations conducted showed that mini-tubers derived from the aeroponic systems can be successfully used in propagating seed yams. The gravity-fed option is thus proven to be effective in propagating mini-tubers for seed yam production.

References

Maroya, N, Balogun, M, Asiedu, R. 2014. Seed Yam Production in Aeroponic system: A Novel Technology. YIIFSWA Working Paper No 2. Institute International of Tropical Agriculture, Ibadan, Nigeria; 9 pages. © IITA-YIIFSWA; 2014. ISBN 978-978- 8444-37-4.

Mbiyu, M. W., Muthoni, J., Kabira, J., Elmar, G., Muchira, C., Pwaipwai, P., Ngaruiya, J., Otieno, S. and Onditi, J. (2013). Use of aeroponics technique for potato (*Solanum tuberosum*) mini-tubers production in Kenya. Accessed online at http://www.internationalscholarsjournals.org on 17/12/2013

Oteng-Darko P., Otoo E., Kyei-Baffour N. and Agyare W. A. (2016). Growth and yield response of three aeroponically propagated yam varieties under four different nutrient concentrations. Poster presented at the World Congress on Root and Tuber Crops, Nanning, Guangxi, China, Jan 18-22, 2016.

Oteng-Darko P., N. Kyei-Baffour, E. Otoo E. and Agyare W. A (unpublished) Design and Evaluation of Two Simple Aeroponic Systems for Seed Yam Propagation. Under review, African Crop Science Journal

Appendix 19Accepted edited abstract from thesis

Growth and yield response of three aeroponically propagated yam varieties under four different nutrient concentrations

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Abstract

New technologies to increase and make available quality seed yams to boost yam production and therefore increase food security and farmers livelihoods are currently being researched into. In this regard, two forms of hydroponics, in which plants are suspended in closed chambers and intermittently fertigated with complete nutrient solution, was designed, set up and evaluated for its ability to propagate disease-free yam micro-tubers. A screenhouse experiment was set up at the CSIR-Crops Research Institute to evaluate the two hydroponic designs, one power dependent using misters and the other power independent using drippers. Three yam varieties and four nutrient concentration levels were used in the evaluation using a split-split plot design with the aeroponic units as the main plot, the nutrient concentrations as the sub plot, and the yam varieties in the sub-sub plot. Data was collected on growth and yield performance for the various treatments and were

subjected to an analysis of variance, judged significant at $p<0.05$. Preliminary results show significant difference in the root initiation for the various varieties and differences in the growth performance under the various aeroponic units and the nutrient concentration levels.