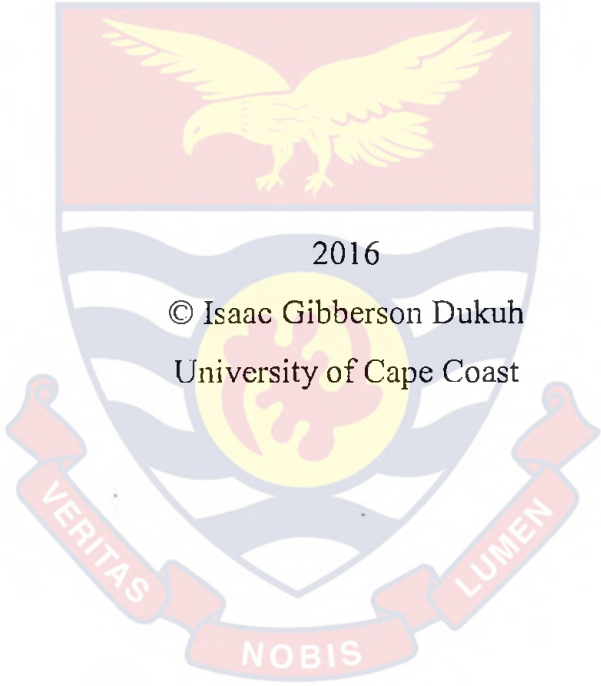

UNIVERSITY OF CAPE COAST

THE EFFCETS OF IRRIGATION AND FERTILIZER ON GROWTH, YIELD AND SHELF LIFE OF OFSP [*Ipomea batatas* (L) Lam] ROOTS IN FOUR STORAGE STRUCTURES

BY

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Thesis submitted to the Department of Agricultural Engineering of the School of Agriculture, University of Cape Coast, in partial fulfillment of the requirements for the award of Doctor of Philosophy degree in Post Harvest Technology

[JULY, 2016]

DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature:..... Date: 2-8-2016

Name: Isaac Gibberson Dukuh

Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor's Signature:..... Date: 4-8-16

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Name: Prof. Ato Bart-Plange.

ABSTRACT

The objective of the research was to investigate the effects of irrigation levels, poultry manure (PM), cow dung (CD), NPK and their interactions on the growth and yield, quality and shelf life of Orange Fleshed Sweet Potato (OFSP) in evaporative cooling structures. Sixteen treatments (four levels of irrigation and four soil amendments) with three replicates were laid out in a Randomized Complete Block Design (RCBD). Irrigation levels did not significantly influence soil physical properties studied (bulk density, pore volume and particle density). Water stress (application of 70 % CWR) increased root yield, water use efficiency, marketable root yield, jumbo root yield and number of roots per plant as compared to full irrigation while growth of leaves, branches and dry matter content were reduced. Soil amendment significantly improved root and marketable yield better under reduced irrigation (70 % CWR) than under full irrigation. PM, CD and NPK significantly increased marketable yields by 40.96 %, 30.34 % and 21.36 % respectively as compared to the control. Cool chamber evaporative structure (CC) reduced root percentage shrinkage, decay, weight loss and weevil infestation in storage while sprouting increased. Soil amendment significantly reduced percentage root decay. Reduced irrigation increased carotenoid and fibre content while sugar content of roots was decreased. Storage in evaporative cooling structure increased the percentage content of sugar, starch, fat, and phenol of roots while fibre, protein, and ash were reduced after 13 weeks of storage.

KEY WORDS

Evaporative Cooling Storage Structure

Growth and yield

Irrigation

Manure Application

Nutrient Content

Orange Fleshed Sweet Potato

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HDEDICATION

This research work is dedicated to God Almighty, my wife and children, my entire family and to the memory of my late parents.

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LIST OF ABBREVIATIONS

CC	Cool chamber
CD	Cow dung
CIP	International Potato Center
CSIR	Council for Scientific and Industrial Research
CWR	Crop Water Requirement
DI	Deficit Irrigation
EC	Electrical conductivity
ET_o	Reference Evapotranspiration
ET_c	Crop Evapotranspiration
FAO	Food and Agriculture Organisation
FAOSTAT	FAO Statistics
HexB	Hexagonal Evaporative Cooling Structure
InG	In-Ground Evaporative Structure
K_c	Crop coefficient
Lsd	Least significance difference
MoFA	Ministry of Food and Agriculture
NPK	Nitrogen, Phosphorous and Potassium
OFSP	Orange Fleshed Sweet Potato
PM	Poultry manure
VAD	Vitamin A deficiency
WP	Water Productivity
WUE	Water Use Efficiency

CHAPTER ONE

INTRODUCTION

Background of the Study

In developing countries, rapid population growth, pressure on land use and systematic decline of agricultural productivity has lowered the profitability of farming, made farming unattractive to most youths and lowered the standard of living of farmers which has resulted in massive rural to urban migration and a shortfall in food production. These are creating food shortage and malnutrition. Even though the present world's food production is enough to feed the current population, the unequal distribution of food, high prices for the sale of food and inadequate infrastructure in many underdeveloped countries has caused a large number of hungry people in the world. An estimated 842 million people in 2011–13 (twelve percent) in the world were suffering from chronic hunger (FAO, IFAD & WFP, 2013).

Furthermore, though global food production has seen remarkable advancement post-harvest losses are estimated at between 20 and 100 % (Wilson, 2013). In Ghana, a tropical country with high temperatures most of the year, post-harvest losses of perishables are estimated to be ranging between 30 and 80 % (Kitinoja, & AlHassan, 2012). Moreover the growth of the world's population is estimated to be about 18 % for the year 2030 which will enable it to exceed 8.2 billion people and this will demand greater amounts of food, more raw materials, higher energy consumption and more water. The increasing demands for food, fibre and fuel, coupled with global

environmental changes (increasing global temperatures and reduced precipitation) are placing increasing constraints on the ability of ecosystems to support productions that are needed (Foresight, 2011). However, the expansion and intensification of agricultural production to meet food demand may severely affect the environment adversely. An alternative solution to the problem of meeting increasing food demand, according to Lieberman (1983) is to reduce post-harvest losses by improving storage and conservation or processing.

Sweet potato has a few advantages, which can play an important role in addressing the increasing food shortages and malnutrition problem in developing countries such as Ghana. Sweet potato [*Ipomoea batatas* (L.) Lam.] is the seventh most important food crop worldwide, after wheat, rice, maize, potato, barley, and cassava (Woolfe, 1992). Sweet potato production worldwide is 103,145,500 tonnes of which China is the leading producer (Food Agricultural Organisation, 2012). China produces about 80 % of global yield and the rest of Asia account for 6 %, Africa 5 %, Latin America 1.5 % and the U.S.A 0.45 % (FAO, 2004). Ghana produces 135,000 tonnes per annum of sweet potato (FAO, 2012) and is ranked 35 in world sweet potato production.

The crop does well on marginal lands and it is also a famine reserved and water use efficient (drought tolerant) crop. Sweet potato is adaptable and can grow under many different ecological conditions. It has a shorter growth period than most other root crops (three to five months) and shows no marked seasonality. It can be cultivated all the year round under suitable climatic

conditions. Adverse weather conditions rarely cause a complete crop loss. Hence sweet potatoes are planted as an "insurance crop" (Food Agricultural Organisation, 1990). Though sweet potato plant is considered tolerant to drought stress (Jones, 1961; Constantin et al., 1974; Bouwkamp, 1985), the crop is adversely affected at the crop establishment stage. Hence yields may be significantly reduced if water stress occurs within the first six weeks after planting (Edmond and Ammerman, 1971). Moreover dry soil conditions can cause lignification of young roots thus limiting their potential for lateral growth and storage of carbohydrate (Ravi & Indira, 1996; Lewthwaite & Triggs, 2009). Prolonged drought may also affect storage root yield and quality (Gollifer, 1980). Villareal et al. (1979) stated that the response to drought stress varies with cultivar. Hence selection of sweet potato cultivars based on drought resistance has become very important internationally (Anselmo et al., 1998; Laurie et al., 2004). However, in areas of water scarcity such as northern Ghana, deficit irrigation can be employed to mitigate yield reductions (Kirda et al., 2004).

In the developing world it is the leading crop in terms of energy produced per hectare per day (Table 1) and in developing countries where production is not mechanized; sweet potato has higher energy utilization efficiency than cereals. It has further been reported that, energy output/input ratio for rice and sweet potato on Fijian farms are 17:1 and 60:1 respectively (Norman et al., 1984). Sweet potato yields are relatively better in tropical countries than in temperate areas where yields of most crops are higher.

Table 1: Comparative Energy and Protein Yields of Sweet potato and other major crops

Crop	Av. Tropical yld. t ha^{-1}	Energy. Value MJ kg^{-1}	Edible Energy 10^3 MJ ha^{-1}	Av. Growth period (days)	Edible Energy 10^3 MJ ha^{-1} d^{-1}	Av. Protein yld kg ha^{-1}	Protein %
Maize	1	15.2	18.8	130	145	118	9.5
Millet	<1	15	8.2	100	82	58	10.5
Sorghum	<1	14.9	11.1	110	101	87	10.5
Rice	2	14.8	20.8	140	149	151	1.5
Cassava	9	6.3	45.6	330	138	90	1.6
Banana	13	5.4	41.4	365	113	143	1.1
Sweet potato	7	4.8	27.2	140	194	110	1.0
Yam	7	4.4	26.2	280	94	140	2.0

Source: Adapted from Norman et al., 1984 and Uries *et al.*, 1967 as cited by Woolfe (1992).

Sweet potato production rose in Africa but fell in Japan, United States and China. In sub-Saharan Africa 3.4 million ha is cultivated with an estimated production of 14.1 million tonnes in 2009 (Low, 2011). In Ghana average yield of sweet potato is 8 t ha^{-1} but yield of 24 t ha^{-1} is achievable (Ministry of Food and Agriculture SRID, 2010).

There exists a large number of sweet potato cultivars which differ from one another in the root skin colour (white, creams, yellow, brown, orange or purple), flesh colour (white, creams, yellow orange or purplish red), the sizes and shape of roots and leaves, the depth of rooting, the time to maturity, the resistance to disease and in the texture of cooked roots (Woolfe, 1992). The Crops Research Institute (CRI) of the Council for Scientific and Industrial Research (CSIR) has developed four improved sweet potato varieties one of

which has the potential of addressing the problem of Vitamin A deficiency in children. The names of the varieties are *Okumkom*, *Faara*, *Santom Pona* and *Sauti* which are said to be high-yielding, early-maturing, disease resistant and also have a high content of protein.

The Bill & Melinda Gates Foundation, Helen Keller International, The International Potato Centre and the Sweet Potato Action for Security and Health in Africa (SASHA) are in partnership to promote the production and consumption of orange-fleshed sweet potato (OFSP) in Burkina Faso, Ghana, Tanzania and Uganda. The main aim of the project is to promote the production and consumption of OFSP in at least 500,000 rural households using radio and ICTs (Farm Radio International, 2013). While animal products generally contain vitamin A, plants contain provitamin A one of which is the ß-carotene or carotenoid pigment. Fruits and vegetables such as sweet potato, carrots, mango and pawpaw which are orange-coloured, have high content of provitamin A or ß-carotene.

Orange-fleshed sweet potatoes can be a very suitable crop for combating vitamin A and micronutrient deficiency in developing countries for target consumers. According to United State Agency for International Development (USAID) (2011) OFSP can serve as a source of energy, nutrients, dietary fibre, sweetener, colour and flavour. Vitamin A deficiency (VAD) is widespread in Africa especially in children (Low et al., 2007). According to West (2002) about 127 million children worldwide suffer from vitamin A deficiency which causes blindness and compromises the immune system. Vitamin A helps protect the surface of the eye (cornea) so it is

essential for good vision. VAD can make humans especially children susceptible to diseases and consequently death from diseases such as malaria and measles (International Potato Center, 2006). Vitamin A deficiency (VAD) remains a significant cause of preventable childhood blindness and increased risk of mortality among children under five years of age. VAD causes blindness in about 250,000-500,000 African children yearly. Half of them die within twelve months of going blind. The adverse effects of VAD are pronounced in developing countries, where abject poverty often prevents people from eating and growing more nutritious food. In such areas, the development and dissemination of highly nutritional, fortified crop varieties has lagged behind that of more developed countries.

Sweet potato especially OFSP can play significant and important role in meeting food shortages and malnutrition in developing countries such as Ghana. In sub-Saharan Africa sweet potato is currently being developed to address one of the most serious health and nutrition problems that is Vitamin A deficiency (International Potato Center, 2006).

In spite of the desirable traits listed which sweet potato possesses, its utilization in many countries has declined, partly due to pre- and post-harvest losses resulting in excessive waste (Woolfe, 1992). The heavy post-harvest losses has resulted in increased prices thereby making it unattractive to those searching for a low cost nutrition substitute for more expensive and prestigious foods. In tropical regions the fresh tuber is normally considered to be difficult to store especially where pre-harvest attack by cylas weevils is common. Thus Worku et al. (2014) reported that insect (weevil) infestation is

a major constraint of sweet potato production. Under tropical conditions of high temperatures and humidites, storage life of sweet potato is short. The causes of post-harvest deterioration of sweet potato in Ghana and other tropical countries can be grouped under the following headings:

- Pathological injury arising from decay caused by fungi and bacteria.
- Mechanical injury arising from cuts, bruises and breakages, which occur during harvesting, handling and transportation.
- Biological injury arising from rodents and insects (cylas weevils) damage.
- Physiological injury arising from unavoidable weight loss from transpiration and tuber sprouting resulting in weight loss as a result of transfer of dry matter and water to the sprouts (Dukuh, 2003).

The rate of deterioration of produce in storage increases as optimum environment for insects and microbial growth is maintained in the bulk and storage period is prolonged. Therefore the storage structure plays a major role in the storage system. However, due to lack of cold storage facilities coupled with high energy cost, a substantial amount of fruits and vegetables are lost during the post-harvest chain in developing countries in the world (Lal Basediya *et al.*, 2013). The introduction of low cost low energy evaporative cooler or cool chambers could increase the shelf life of sweet potato. In evaporative cooling, as water evaporates it has a considerable cooling effect and the faster the rate of evaporation the greater the cooling. When

unsaturated air passes over a wet surface water evaporates into air raising its humidity and at the same time cooling the wet surface.

Agronomic operations such as deficit irrigation and fertilizer application have been applied to crops and found to have beneficial effects on the crops. Deficit irrigation (DI) is the application of water below plant evapotranspiration (ET) requirements. Deficit irrigation is regulated irrigation and may increase crop quality. It is stated that, the protein content and baking quality of wheat, the length and strength of cotton fibres, and the sucrose concentration of sugar beet and grape all increase under deficit irrigation.

Woolfe (1992) indicated that soil fertility, climate, pests and diseases affect the total protein content of sweet potato roots. Improper use of waste products from livestock production such as cow dung, poultry manure and liquid manure can have negative environmental effects such as soil and air pollution. According to Giovanni, Emanuela, and Pasquale (2011) manure produced by livestock activity is a dangerous product and can cause serious environmental pollution.

The use of animal manure coupled with appropriate agronomic management practices in crop cultivation allows the utilization of nitrogen produced by livestock and poultry for crop production (Lithourgidis, Matsi, Barbayiannis, & Dordas, 2007) and reduces the use of chemical fertilizers. Manure appropriately applied to growing crops allows the opportunity to eliminate the nitrogen fertilizer input for crop production. Identifying management practices that will provide a long term agronomic utilization improves the profitably of the manure for agronomic inputs, reducing the impact of the waste products on

soil pollution and cost of nutritive feeding values in dairy farms. The use of manure in dairy farms in developed countries (Asia, Europe and USA) reduces the dependence on the market for feed for livestock, the cost of forage production and the impact of waste products on the environment.

This study evaluated the effect of cattle manure, poultry manure and mineral fertilizer applications for crop growth and development. The study also aimed to determine the combined effect of manure and deficit irrigation on crop growth and development and the quality of sweet potato during storage in evaporative cooling structures.

Problem Statement

Orange-fleshed sweet potatoes can be a bio-fortified crop very suitable for combating vitamin A deficiency in humans (Woolfe, 1992). The production and consumption of orange fleshed sweet potato (OFSP) in Ghana is being promoted by a number of organisations such as SASHA, Helen Keller International, CIP and Bill & Melinda Gates Foundation.

Though global food production has seen remarkable advancement post-harvest losses are estimated at between 20 % and 100 % (Wilson, 2013). Constraints to improved productivity and incomes for smallholder sweet potato farmers in Sub-Saharan Africa including Ghana includes: the lack of quality planting material, lack of improved varieties adapted to local conditions, damage to roots by the sweet potato weevils, little knowledge and use of better agronomic practices and inappropriate storage systems (Low et al., 2009). Inappropriate storage structures and cylas weevil infestation

constitute the major problem associated with sweet potato production in Ghana. In Ghana sweet potato roots storage systems are largely ineffective resulting in short shelf life. Farmers store roots in-mound which results in decay of roots, fibrous roots and weevil infestation. Distributors store roots in rooms, in sacks, underground and under shades. Post-harvest losses can be as high as 40 % percent resulting in high prices for food which is supposed to be cheap. According to Kitinoja and AlHassan (2012) in Ghana, a tropical country, post-harvest losses of perishables are estimated to be ranging between 30 % and 80 %. The high post-harvest losses poses as serious challenge to sweet potato production. Dukuh (2003) indicated that in 2002 prices of sweet potato roots fluctuated from GH¢ 3.00 per bag of 100 kg during the peak season to GH¢ 5.00 per bag of 100 kg during the lean season. However, the high incidence of deterioration does not enable farmers to take advantage of the comparatively high lean season price increase. Sweet potato farmers and distributors therefore need solutions to the high post-harvest losses associated with sweet potato production and storage. Attempt has been made to improve the shelf life and quality of sweet potato roots by removing vines before harvest (defoliation) and curing tubers before storage.

Additionally the population of the world is growing fast and is projected to hit the 10.5 billion mark by 2050, which requires the world's crop production to increase in the coming decades in order to meet the growing demand for food and fibre. Consequently, increased pressure on land for growing food crops will intensify. Increasing food production faces a further challenge of changes in climate, increasing global temperatures and reduced

and erratic precipitation. It has been stated that climate change alone is considered to pose serious challenge to meeting global food demand. Climate change is estimated to increase the number of undernourished people to between 40 million and 170 million, although impacts may be mitigated by socio-economic development (Easterling et al., 2007). Therefore, improved crop production `to meet increasing demands for food, fibre, and fuel will demand greater efficiency in the use of water, nutrients, and more efficient post-harvest handling systems as major contributors to achieving sustainable intensification of crop production (Pretty, 2008; Powlson et al., 2011).

One way to meet greater efficiency in the use of water in crop production is the adoption of deficit irrigation (DI) which produces more crop per drop of water. Hence, there is a widespread belief in environmental and water policy circles that if irrigation is made more efficient then there would be more water for environmental uses and for towns and cities. One of the most important ways of increasing the productivity of crops is the application of fertilizers (Ali, Waddington, Timsina, Hodson, & Dixon, 2009). Manure is an age-old source of fertilizer. In recent years the use of organic manures as fertilizers has increased tremendously as a result of serious environmental pollution (Ofoefule, Eze, Ibeto, & Onah, 2014). Organic manure has been found to improve the fertility and productivity of soils. Almost any kind of organic matter may be used as manure, but some kinds are better than others. Another important factor in meeting increasing food demand is efficient post-harvest system. One important factor in efficient post-harvest handling system to preserve fresh produce is the storage system which does not only take up

the weight of the produce in store but creates microclimate within it that inhibits deterioration of produce. Therefore research efforts to determine and recommend pre-harvest treatment and zero energy evaporative storage system which store sweet potato roots better under tropical conditions can be of great benefit to sweet potato farmers and lead to increased production and utilization of sweet potato.

Justification

The research is justified because it is aimed at developing improved shelf life which will promote whole crop harvesting and discourage mound storage which ties the soils down to the crop. It will allow maximum utilization of the soil and give better returns to the farmer. Improved shelf life will increase the availability of sweet potato roots to consumers throughout the year at current production levels. Improved shelf life will also add value to the produce which will consequently increase returns to the farmer which can lead to improving their standard of living. The research is also important because it aims at increasing the efficiency of water application to crops. It will also determine the level of irrigation which is most efficient. It will also determine whether deficit irrigation can improve the nutrient content (vitamin A content) of the root. Furthermore, it will determine the combined effect of deficit irrigation (DI) and manure application on the production, quality and shelf life of sweet potato in evaporative structures.

The research is in response to the need for improved methods of reducing pre- and post-harvest losses and discourage mound storage, which ties the soil down to the crop.

Main Objective of the Study

The main objective or aim of the study was to improve the water use efficiency, yield performance, quality and shell life of sweet potato roots.

Specific objectives

The study had the following specific objectives:

1. Compare the effectiveness of organic manure (Poultry manure and Cow dung), NPK and irrigation on growth and yield of OFSP.
2. Determine the effect of soil amendments and irrigation on the quality of sweet potato (OFSP) tubers.
3. Compare the effectiveness of three evaporative structures, that is Brick-walled Cool chamber (CC), Jute-walled Hexagonal barn (HexB), Brick-walled In-Ground evaporative structure (InG) and Room storage for the storage of sweet potato roots in terms of: The rate of size loss (shrinkage), weight loss, root sprouting, rate of root decay and pest infestation of root roots.
4. Determine the effect of soil amendment and irrigation on nutrient levels of sweet potato roots.
5. Assess the effect of the storage methods that is Cool chamber (CC), Hexagonal barn (HexB) and In-Ground structure (InG)) and Room storage on the nutrient levels of sweet potato roots.

Statement of hypotheses

Null hypothesis

I. Pre-harvest treatments (Manure and Irrigation) have no influence on the storage performance of orange fleshed sweet potato (OFSP) tuberous roots.

II. Evaporative storage structures have no influence in prolonging the shelf-life of Orange fleshed sweet potato tuberous roots.

Thesis layout

Chapter One is general introduction to the work and Chapter Two is review of literature on sweet potato production and consumption in developing countries such as Ghana and sweet potato crop water use. It also deals with organic and inorganic fertilizer and water stress effect on sweet potato growth and yield and shelf life. It also deals with storage methods of sweet potato. Chapter Three compares the effectiveness of organic manure (Poultry manure and Cow dung), NPK and irrigation levels on growth and yield of OFSP. Chapter Four determines the effect of soil amendments and irrigation on the quality of sweet potato (OFSP) rootss. Chapter Five compares the effectiveness of three evaporative structures Cool chamber (CC), Hexagonal barn (HexB) and In-Ground structure (InG)) for the storage of sweet potato roots in terms of: The rate of size loss (shrinkage), weight loss, tuber sprouting, rate of root decay and pest infestation of root. Chapter Six determines the effect of soil amendment and irrigation on nutrient levels of sweet potato tubers. It also assesses the effect of storage methods; Cool chamber (CC), Hexagonal barn (HexB) and In-Ground structure (InG)) and

Room storage on the nutrient levels of sweet potato roots. Chapter Seven summarizes all the conclusions as well as recommendations.

CHAPTER TWO

LITERATURE REVIEW

Origin and Diffusion of Sweet potato

The sweet potato (*Ipomoea batatas* [L] Lam) is a dicotyledonous plant and belongs to the family Convolvulaceae (Purseglove, 1987). In 1753 it was first described by Linnaeus as Conolvulus batatas. It was, however, placed within the genus *Ipomoea* based on the shape of the stigma and the surface of the pollen grains in 1791 by Lamarck. Among the 50 genera and more than 100 species in this family, only *Ipomoea batatas* is of major economic importance. The crop is believed to have originated from Central America and was domesticated 5000 years ago (Consultative Group on International Agricultural Engineering, 2005). From its origin the crop then spread to other parts of the world; Columbus brought it to Europe and further introduced it to Africa. Sweet potato is now cultivated throughout the tropics and warm temperate regions. According to Scott (1992) it is cultivated in more than 100 countries worldwide and is ranked seventh among the most important crops. China is the biggest sweet potato producer globally and produces approximately 90 % of the worldwide sweet potato production with an annual production of 117 million tonnes (Sweet potato in Asia as cited in Huang et al., 2014). West African produces about 2.516 million tonnes per annum with Nigeria being one of the largest producers (Food and Agricultural Organisation, 2006). Sweet potato contains higher contents of carbohydrates, various vitamins, minerals, and protein than other vegetables (Shi et al., 2007).

Ghana produces about 100 thousand tonnes of different varieties of sweet potato annually in different parts of the country (Food and Agriculture Organisation, 2011).

Sweet potato varieties

There exists a large number of cultivars which differ from one another in root skin colour and flesh colour. The skin colour can be green, white, brown, yellow, orange or purple while the flesh colour can be white, cream, yellow, orange or purplish-red. The different cultivars differ also in size depth of rooting, time to maturity, the resistance to diseases, the size and shape of leaves and the texture of cooked roots (Woolfe, 1992). On the basis of cooked flesh characteristics, there are two main types of sweet potato i.e. soft-fleshed or firm- fleshed. 'Dry types' have firm white or yellow flesh and mildly sweet whilst 'moist type' have soft orange flesh with substantial amounts of sugar (Steinbauer, & Kushman, 1971). Different sweet potato varieties have different nutritional content with variations in ascorbic acid, protein, minerals, carotene and vitamin B (Bouwkamp, 1985).

Sweet potato Production and Consumption

Sweet potato is the world's most important root and tuber crop (Lenne, 1991). Majority is grown in developing countries as a valuable source of food, feed and industrial raw material. It is propagated from vine cuttings or sexually from seed by breeding programmes (Woolfe, 1992). Sweet potato is propagated vegetatively by planting green vines of approximately 30 cm length with at least three leaf nodes into the soil. Sweet potato is most

commonly grown on mounds or ridges, and occasionally on raised beds, or on the flat. Deep cultivation enhances root growth and bulking of the sweet potato roots. Mounds and ridges promote adequate drainage and ease of harvesting (Low et al., 2009).

Current world production of sweet potato is about 130 million tonnes per year. According to FAO (200D1) China is the leading world producer of sweet potato with a production of 10,500,000 tonnes. Average world yields vary from 17.5 to 27.5 t ha^{-1}, depending on variety (Reed, 1976). In Ghana 74,000 ha of sweet potato is cultivated annually yielding 18,000 hectogram per hectare resulting in annual production of 135,000 tonnes (Food and Agricultural Organisation (FAO), 2012). Constraints to improved productivity and incomes for smallholder sweet potato farmers in Sub-Saharan Africa including Ghana include the lack of timely access to virus and pest-free planting material, lack of improved varieties adapted to local conditions, damage to roots caused by the sweet potato weevils, particularly in drier production areas, little knowledge and use of better agronomic practices, and inappropriate storage systems (Low et al., 2009). Sweet potato yields storage roots and vines both of which can be used as nutritious food for humans and animals. Sweet potato has outstanding nutritional qualities that give it an important role in combating nutritional deficiencies in developing countries such as Ghana. It can be used for several purposes: as a vegetable, animal feed, multipurpose flour, alcoholic or non alcoholic beverages, snacks, starch and industrial raw material.

Processing sweet potato into other products for human food has several advantages which include decreasing food losses, promoting all year-round consumption, providing a greater variety and convenience of uses, increasing the economic value of the crop to producers and the efficiency of the food delivery system (Woolfe, 1992). Sweet potato roots can be processed into starch, glucose, syrup, alcohol, non-alcoholic beverages and vinegar which is made from sugar and starch by microbial fermentation of alcohol to acetic acid (Woolfe, 1992). In Africa, sweet potato is mostly grown for human consumption. The roots are made into numerous food types; they are boiled, steamed, baked and fried. They are also made into flour and canned; the flour is further used in sweet dishes such as pies, puddings, biscuit and cakes (Woolfe, 1992). In some countries the roots are processed into starch, glucose, syrup and alcohol for industries. In the United States sweet potato are best known for their use in candied vegetable and thanksgiving dinner. The leafy tops are boiled and eaten as vegetable and fed to animals. Although sweet potato roots are of utmost economic importance, all other parts of the plant are also useful for food and feed. The use of sweet potato has gone beyond its use as subsistence food security and famine relief crop.

Post-Harvest Pests and Diseases of Sweet Potato Roots

Post-harvest pests

Though sweet potato is not seriously affected by fungus and virus diseases, it can be can be affected by sweet potato weevil. It is recommended to use pest free planting material. The sweet potato weevil (*Cylas*

puncticolis and *Cylas brunneus*) is a major pest in Ghana and it is a serious storage pest in tropical and subtropical regions (Talekar, 1982). Fruit flies (*Drosophila* spp) and soldier flies (*Hermetia illucens*) also cause post-harvest and storage losses. The adult weevil feeds on leaves, vines and storage roots. The female insect lays the eggs into stems and root and larvae make holes in roots which affects flavour (Diaz Sanchez, 1980). The larvae which bore holes in the roots reduce the quantity, quality and market value of the crop. The weevil also damages the skin and renders the root susceptible to entry of fungi and bacteria thereby reducing the shelf life of the roots. The extent of damage caused by the weevil ranges from 40-75 % reduction in yield in West Africa and it is more pronounced during the dry season when mounds crack.

Post-harvest diseases

The most common organism causing storage rots are Java black rot, black rot, scurf, bacterial soft rot, surface rot, root rot, charcoal rot, and soft rot. Moyer (1982) indicated that time of infection varies with the organism, field, and harvest/storage conditions. Black rot, fusarium root rot, scurf and bacterial soft rot can occur before harvest, during harvest and after harvest. On the other hand soft rot infection tend to occur at harvest and after harvest but charcoal rot, dry rot surface rot and root rot occur during harvest (Kays, 1991). All these harvest and post-harvest pathogens require wounds to gain entry. It is therefore important to reduce injury during harvesting so as to enhance the shelf-life after harvest. Furthermore, roots should be cured immediately and stored at an optimum storage condition. Another disease in storage is internal

cork which is a virus-induced disorder where root tissue develops necrotic lesions during storage (Kushman & Pope, 1972).

Physico-Chemical Changes in Storage

Sweet potato roots continue to 'live' after harvesting and once detached from the plant, they rely on their own internal food reserves to continue with life processes which leads to changes in both physical and chemical composition of the harvested tuberous root. Sweet potato roots undergo several physical and chemical changes such as weight loss, shrinkage, and decline in sugar and starch content during storage and the extent of changes depend on variety (Teye, 2010). According to Zhitian, Wheatley and Corke (2002), sweet potato roots stored 180 days after harvest showed a decrease in starch content, increase in alpha-amylase activity while, glucose and sucrose concentrations increased early in storage then reduced later on. Storage also influences both sensory and cooking properties. Zhitian et al. (2002) also observed that storage reduced flour pasting property. Sweet potato roots become watery or soften when cooked and also lose their flavour after a long period of storage (Teye, 2010)

Chemical composition of sweet potato

The dominant chemical composition of sweet potato is carbohydrate, 21.3% which is in the form of starch and sugar (Pamplona-Roger, 2006). Sweet potato roots have minimal fat and protein content, however, it contains an appreciable amount of cellulose-type fibre, 3.0 g as shown in Table 2. Abubakar et al. (2010) also observed in a study that the crude fiber content of

sweet potato tuber samples is low. The application of nitrogen fertilizer significantly ($p<0.05$) increased the protein content of various varieties and protein yield was best at 40-80 kg N ha^{-1} (Ukom et al., 2009).

Table 2: Chemical composition of sweet potato roots per 100 g of raw edible portion

Energy	105 kcal = 439 kj
Protein	1.65 g
Carbohydrates	21.3 g
Fiber	3.00 g
Vitamin A	2,006 µg ER
Vitamin B_1	0.066 mg
Vitamin B_2	0.147 mg
Niacin	1.01 mg NE
Vitamin B_6	0.257 mg
Folate	13.8 µg
Vitamin B_{12}	-
Vitamin C	22.7 mg
Vitamin E	0.280 mg
Calcium	22.0 mg
Phosphorus	28.0 mg
Manganese	10.0 mg
Iron	0.590 mg
Potassium	204 mg
Zinc	0.280 g
Total Fat	0.300 g
Saturated fat	0.064 g
Cholesterol	-
Sodium	13.0 mg

Source: Pamplona-Roger (2006).

They further stated that increase in the application of nitrogen fertilizer from 0-80 kg N ha^{-1} increased ß-carotene yield with the highest numerical value of 13.02 µg g^{-1} at 40 kg N ha^{-1} and 18.11 µg g^{-1} at 80 kg N ha^{-1}. According to Luis et al. (2013) sweet potato is a rich source of minerals and they are good source of carbohydrates, fibre, starch, vitamins and antioxidants (Odongo et

al., 2002; Anderson and Gugerty, 2013). Starch content of sweet potato decreased while, glucose and sucrose concentrations increased initially in storage then reduced later on, after 180 days of storage (Zhitian et al., 2002).

Causes of Post-harvest Loss of Sweet potato root

Post-harvest losses result from a combination of either internal or external factors that combine to cause deterioration of harvested roots from planting to harvest. The causes are:

Respiration

Sweet potato tuberous roots are living structures and they respire. The respiration process results in the oxidation of the starch contained in roots, which convert it into water, carbon dioxide and heat energy. The respiration process can be approximately represented by the oxidation of glucose as shown in Equation 1:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + energy \qquad 1$$

The complete combustion of A7 of glucose produces 1.47 g CO_2 + 16 kJ of energy (Diob, 1998). Thirty two percent (32 %) of energy generated (5.1 kJ) is utilized in metabolic activities and the remaining 10.9 kJ is released as heat resulting in temperature built up in the storage environment.

During oxidation of starch the dry matter content of the root reduces, since the root is no more attached to the plant and the food reserve is not replenished. Therefore, high rate of respiration results in rapid reduction in dry matter

which lowers the shelf-life of sweet potato roots. Hence reducing respiration rate results in an increased shelf life.

Ethylene production and sensitivity

Sweet potato is known to produce very low level of ethylene (0.1 $\mu L\ kg^{-1}\ h$). However, chilling, wounding and decay of roots cause increase in ethylene production. Increased exposure of sweet potato roots exposed to ethylene at 1-10 ppm increases respiration rate and phenolic metabolism which adversely affect shelf life, flavor and colour of cooked roots. Exposure of sweet potato roots to ethylene promotes synthesis of phenolic compounds and phenolic oxidizing enzymes which leads to discoloration. It is therefore, necessary to improve ventilation in storage to reduce the level of ethylene concentration.

Physiological disorder

Physiological disorder is mostly the breakdown of tissue caused by the nutritional deficiency and adverse environmental condition. Notable physiological disorder associated with sweet potato root is chilling injury. At temperatures below 12 °C (Picha, 1987) sweet potato roots are very sensitive to chilling injury. Roots show symptoms of internal pulp browning, root shrivelling, formation of surface pitting, abnormal wound periderm formation, fungal decay, internal tissue browning and hardcore formation (Daines et al., 1976) revealed that tissue browning comes as a result of synthesis of chlorogenic acid and other phenolic compounds. Also roots suffering from chilling injury when cooked show "hardcore" defect and are darker in colour than non-chilled roots, this defect is not apparent in fresh roots but appears

after cooking processing. Non cured roots are more susceptible than cured roots of sweet potato. Pithiness in sweet potato results in reduced density and spongy feel of roots. Poor ventilation or anaerobic condition also exposes roots to emit a distinctive sour, fermented odour.

General senescence

Senescence is the progressive disorganization of the metabolic apparatus of the cell and it is caused by the concentration of ethylene around the roots. Senescence in sweet potato is promoted by ethylene which accelerates deterioration and consequently reduces post-harvest life of the crop because the ethylene increases respiratory activity, increases activity of enzymes such as peroxidase, lopoxidase, and alpha-amylase. Furthermore, it also increases cell permeability and loss of cell compartmentalization, which has direct influence on senescence and ageing.

Temperature

Temperature is the single most important factor that causes loss during storage. It influences the rate of respiration which consequently affects loss of food reserve and moisture. Temperature also influences the rate of sprouting, pest infestation and decay. Temperature causes natural breakdown of food reserves and moisture loss. The cooling of produce will extend its shelf-life by slowing the rate of respiratory losses.

Relative humidity

Relative humidity is the ratio of water vapour pressure in the air to the saturation vapour pressure at the same temperature. High humidity retards

wilting and maintains the product in better condition. Most horticultural produce stores best in an atmosphere that has a relative humidity above 85 %.

Gas composition

Composition of gases in the storage structure plays an important role in prolonging the shelf-life of the roots. Sweet potato roots after harvesting under goes respiration and releases carbon dioxide. The build-up of carbon dioxide in the storage structure further increases the respiration and temperature build up, which encourages sprouting and cell break down. Respiration also utilizes the stored nutrients which results in dry weight loss. External concentration of oxygen also influences respiration activity and CIGR (1999) stated that anaerobic metabolic processes start when oxygen concentration is 5 % and 7 % encourages cell decomposition.

Physical damage

The outer covering or the skin of sweet potato root is normally an effective barrier against most potentially invading spoilage microorganisms (bacteria and fungi) causing rotting. However, the skin has soft texture and any careless handling at harvest and transporting often ruptures the barrier causing injury to the skin, and providing an easy entry point for infections. It also stimulates physiological deterioration and dehydration. The wound influences respiration rate which further increases the required healing substances and the defence reaction by the cell (International Commission of Agricultural Engineering, 1999). There is therefore the need to gently handle the roots to minimize

bruising and breaking of the skin. Damaged roots, if not properly cured, should not be stored because of these reasons:

a. High risk of introducing disease causing organisms into good ones

b. Further high losses due to pathogens

c. Lower quality.

Hence careful harvesting and proper handling procedure is an important step towards successful storage.

The Application of Fertilizer to Sweet potato Production

The application of fertilizers is one of the most important ways of increasing the productivity of crops. There is clear correlation between increased production and broader use of NPK fertilizer (FAO/IFDC, 2012). Fertilizer application affects the quality and yield of potatoes positively (Leytem, & Westermann, 2005). Potato is highly responsive to nitrogen (N) fertilization and N is usually the most limiting essential nutrient for potatoes growth, especially on sandy soils (Errebhi et al., 1998). The level of Nitrogen supply determines the balance between vegetative and reproductive growth for potato (Alva, 2004; White et al., 2007). Many previous studies have shown that N fertilizer applications can increase dry matter content, protein content of potato tubers, total tuber yield and marketable tuber yield (Zebarth et al., 2004; Zelalem et al., 2009). In addition to inorganic fertilizers organic fertilizer or manure can be used to increase the productivity of crops. Organic manure covers manures made from cattle dung, excreta of other animals, rural and urban composts, other animal wastes, crop residues and green manures.

Organic manure has been found to improve the fertility and productivity of soils (DjilaniGhemam & Senoussi, 2013). Organic material is used to prevent or improve the negative stresses effects in plants and yield decreasing. Almost any kind of organic matter may be used as manure, but some kinds are better than others. Organic manures vary widely in the amount of plant nutrients that they contain. In India the application of organic manure at the rate of 10t ha^{-1} resulted in increase in rice yield which was equivalent to the yield when inorganic manure (N fertilizer) was applied at the rate of 20 kg ha^{-1} and 40 kg ha^{-1} (Ghosh, & Sharma as cited in Nwaiwu et al., 2010). Some organic manure are more concentrated than others. The most common organic manures available are poultry manure (PM), cow dung (CD), compost and green manure.

Organic material is used to prevent or improve the negative stresses effects in plants and yield decreasing. It decreases soil salinity, increase the organic matter, improve the soil structure and increase water and air permeability by root developing in soil. It is one of the best used fertilizers (Hassanpanah, & Azimi, 2011). They showed that farmyard manure increased average tuberous root length of sweet potato by 17.0 7% when the rate of FYM increased from 5 to 20 t ha -1. This indicates that in addition to providing a wide range of nutrients, farmyard manure enhances the bulking of tuberous roots through improving the bulk density of the soil.

Manure is an age-old source of fertilizer. In recent years the use of organic manures as fertilizers has increased tremendously as a result of serious environmental pollution (Ofoefule et al., 2014). The chemical composition and

contribution to soil nutrient and crop growth and yield varies with crop type, age, handling and moisture nutrient content of the organic material (Onunka et al., 2009). Manure provides all the necessary macronutrients and many micronutrients while increasing organic matter. Cow manure has relatively less nitrogen than some other manures, so it can be added directly to the soil without damaging plants. One of the most important benefits of using manure is the addition of organic matter. Organic matter breaks down into small particles called humus. In sandy soil these particles get between the sand particles and act like sponges, holding both nutrients and water in the soil. In clay soils they help break apart the lumps of clay and make them more permeable to both water and the tiny feeder roots of the plants. Humus also reduces the pH of soil, which is a benefit on high pH soil.

The effect of poultry manure on growth and yield of sweet potato

The leaf area was significantly higher in plants derived from chicken manure and the common fertilization treated plots and lowest in plants derived from chicken manure on first growing period. The number of roots per plant and number of branches per plant were not responsive to both organic manure and inorganic fertilizer (Abdissa et al., 2012). Parwada et al. (2011) also found insignificant number of roots per plant of sweet potato in response to chicken manure applied at planting. Abdissa et al. (2012) therefore suggested that the number of roots per plant is mostly dependent on the plant genetic make-up rather than fertilizer application. Akande and Adediran (2004) found that poultry manure at 5 t ha^{-1} significantly increased tomato and dry matter yield,

soil pH, N, P, K, Ca and Mg and nutrient uptakes. According to Ewulo, Hassan and Ojeniyi (2007) poultry manure applications at 10 to 50 t ha^{-1} increased availability and uptake of N, P, K, Ca and Mg, increased soil organic matter and moisture content and reduced soil bulk density. These modifications led to improved nutrient availability, growth and yield of tomato. Adekiya and Ojeniyi (2002) observed that increased in soil bulk density reduced uptake of N, P, K, Ca and Mg by tomato plant in Alfisols of southwestern Nigeria. Therefore improvement in soil physical properties caused by applications of poultry manure led to improved uptake of nutrients. To achieve efficient use of animal manure there is the need to thoroughly understand crop responses and availability of nutrients supplied by manure and also compare different types of animal manures under similar field conditions. Arisha, Gad and Younes (2003) stated that the beneficial effect of organic manure on yield of crops may be due to improvement of soil structure and aeration which promotes good root development. Tam and Magustad (1935); Vos and Van Der Putten (1998) reported that, increased concentration of nitrogen fertilizer can result in increased nitrogen uptake which results in higher chlorophyll concentration, higher photosynthetic rates and leaf expansion.

The effect of poultry manure on physical and chemical characteristics of the soil

Table 3 shows the chemical composition of poultry manure and cow dung as stated by the Soil Research Institute of Council of Scientific and

Industrial Research (SRI – CSIR Ghana, 1997). Poultry manure contains comparatively higher proportion of Nitrogen, Phosphorus and Potassium.

Agyenim Boateng *et al.* (2006) stated that application of poultry manure increased soil moisture content and reduced bulk density of the soil. They also showed that PM applied at the rate of 8 t ha^{-1} was slightly better than 4 t ha^{-1} and both did better than the chemical fertilizer. They hinted that PM increased the organic matter content of the soil which can retain higher soil moisture, hence increased soil moisture content. Obi and Ebo (1995) similarly reported that addition of poultry manure to the soil significantly decreased soil bulk density. High moisture contents and lower bulk densities are good soil characteristics for good plant growth. PM improved soil physical properties significantly ($P < 0.05$) by reducing soil bulk density and temperature and increasing total porosity and moisture (Agbede et al., 2008). On the contrary, Aluko and Oyedele (2005) observed that poultry manure incorporation had no significant effect on soil density and porosity. PM increased soil pH slightly from 4.3 to 4.5 and 4.6 due to the buffer capacity of the manure (Agyenim Boateng et al., 2006). Hence the finding that PM increased soil N, P, K, Ca, and Mg significantly. The increases in soil fertility is consistent with findings of previous studies, that amendment of soil using poultry manure improved soil organic matter (OM), N, P, K, Ca and Mg (Adenawoola, & Adejoro as cited in Agbede, et al., 2008). PM increased soil organic matter (OM), N, P, K, Ca, & Mg significantly (Agbede et al., 2008). Similarly it has been stated that amendment of soil using poultry manure improved soil OM, N, P, K, Ca and Mg (Adeniyan, & Ojeniyi, 2005).

Table 3: Chemical composition of manure

Properties	Manure values	
	Poultry	Cow dung
Nitrogen	2.20	1.2
Phosphorus	1.8	0.17
Potassium	1.1	0.11
Calcium	2.4	0.35
Magnesium	0.7	0.13

Source: SRI - CSIR, 1997

The effect of poultry manure on sweet potato root formation

Poultry manure increased soil organic matter, N and P. Soil bulk density were reduced and moisture content increased with levels of manure. Abdissa et al. (2012) indicated that farm yard manure (FYM) reduced bulk density of the soil creating conducive environment for the emerging and development of roots. They showed that when the application of FYM was increased from 0 to 20 t ha^{-1}, the average number of tuberous root per plant increased by 84.5 % and treatments that received no FYM resulted in the lowest root number per plant. However, Abdissa *et al.* (2012) found insignificant number of roots per plant of sweet potato in response to chicken manure applied at planting. According to Abdissa *et al.* (2012) increasing the application of FYM from 0 to 180 kg P_2O_5 ha^{-1} decreased number of roots per plant by 20.3 %.

The effect of poultry manure on shelf life of sweet potato

OFSP roots amended with PM suffered much less rot than unfertilized roots (Sowley, Neindow, & Abubakari, 2015). Data *et al.* (1989) reported that sweet potato root from unfertilized plants exhibited higher percentage of weight loss, degree of decay and severity of shriveling. White-fleshed sweet potato roots from plants treated with poultry manure exhibited higher percentage of sprouting than roots from plants treated with NPK and from unfertilized plants.

The effect of cow dung on growth and yield of crops and soil physical characteristics

Growth and yield parameters such as numbers of leaves and branches, number and weight of fruits of sweet pepper increased with the level of CD application up to 7.5 t ha^{-1} (Ewulo, Hassan, & Ojeniyi, 2007). They compared NPK and CD applied at 7.5 and 10 t ha^{-1} and stated that CD increased soils OM, N, Ca, Mg, pH P and K. They however, indicated that NPK fertilizers are acid producing. They also observed that CD increased leaf content of N, P, K, Ca and Mg. Efficient utilization of animal manure requires thorough understanding of the relationship between crop responses and availability of nutrients in the soil following animal manure application. Furthermore, there is also a need for comparing different types of animal manures under similar field conditions. This is important in coming up with indications on manure recommendations.

The effect of cow dung on carotenoid content of crops

The change in carotenoid content for organic manure-treated seedlings and the controls showed no significant differences between the treated plants and the controls (Imoro, Sackey, & Abubakari, 2012). They also found no significant difference in carotenoid content between poultry manure and the cow dung manure-treated seedlings. It was therefore postulated that organic manure may not exert direct influence on this photosynthetic pigment in the leaves of moringa and seedlings (Imoro et al., 2012).

The effect of inorganic fertilizer (NPK) on growth and yield of sweet potato

Abdissa *et al.* (2012) observed that when inorganic fertilizer application is increased by 15 t ha^{-1} and 20 t ha^{-1} sweet potato shoot fresh weight increased by 33.03 % and 54.96 %, respectively. Imbalanced fertilization has been shown to have effect on yields and on the number of roots of sweet potato in the Sudan Savannah Zone of Ghana (FAO, 2005). It was also shown that yield of sweet potato is decreased significantly if potassium is not supplied. FAO indicated that increase in the rate of application of potassium results in significant increase in yields of sweet potato suggesting that potassium is the most important nutrient for sweet potato production. Potassium promotes plant growth and overall health by promoting efficient uptake of water, helping plants to resist the harmful effects of drought, extreme temperatures and other stresses. It was, however, indicated that increasing the rate of application of phosphorus fertilizer does not increase the

yield of sweet potato. Sweet potato yields increase with increasing application of nitrogen fertilizer until the optimum level of 30 kg ha^{-AA2}ove which any subsequent application of nitrogen results in decreased yields (FAO, 2005).

The effect of inorganic fertilizer (NPK) on quality of sweet potato

Poultry manure treated mounds produced more roots per mound but lower average size per root as compared to roots treated with NPK (Sowley et al., 2015). Hartemink (2003) had earlier found that sweet potato yields were higher when organic manure rather inorganic fertilizers were applied. FAO (2005) had also found that inorganic fertilizers produced larger but fewer roots. Sowley et al. observed that sweet potato weight loss in storage was influenced by variety and fertilizer application. They stated that OFSP treated with NPK fertilizer significantly suffered the least weight loss as compared to WFSP and OFSP treated with PM and the control (OFSP and WFSP with no fertilizer treatment).

The effect of inorganic fertilizer (NPK) on shelf life of sweet potato

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al.). Data, Diamante, and Eronico (1989) reported earlier that sweet potato roots from unfertilized plants suffered higher percentage weight loss, decayed more severely and exhibited higher degree of shriveling. Sowley et al. suggested that addition of an N source to soil reduces tuber weight losses in potatoes. They further observed that OFSP tubers from fertilized plants exhibited lower degree of decay in storage than tubers from unfertilized plants.

The Role of Moisture in the Growth of Crops

Nutrients are available to plants only when they are in the soil water solution. Water carries essential nutrients from the roots and acts as a solvent for salts and minerals. Water moves photosynthetic products from the leaves via the phloem. Water is a chemical reactant in photosynthesis. A small part of water absorbed by roots of plants is retained in the plant; the greatest part of the water is lost through the stomata to the atmosphere in a process called transpiration which is necessary to cool the crop. However, moisture or water quality is important because excessive salt in the water may cause leaf burn, root corrosion and poor seed germination (FAO, 1986).

The effect of irrigation on yield of sweet potato roots

Sweet potato moisture requirements is moderate during vegetative growth stage. However, moisture requirements increases during root formation and declines during the late season stage. Excess application of water results in excessive vegetative growth, late development of roots and reduces number of roots. It has been stated that the net application of water should be 200 to 250 m^3 ha^{-1} for every 7 to 10 days (IRNA, 1972). The total water requirement of the sweet potato crop in winter in Cuba have a national average value of 3372 m^3 ha^{-1}, for a crop cycle of 4 months and the total water requirement for the crop in spring is 1095 m^3 ha^{-1} for a crop cycle of 4 months (Juan *et al.*, 1996). Thompson, Smittle and Hall (1992) indicated that sweet potato yields were highest when 76 % of pan evaporation was applied and decreased following further increase in water application. They further showed that marketable yields were slightly reduced when water application was less than 76 % but substantially reduced when irrigation was greater than 76 %. It was also indicated that weight loss and decay of roots in storage was responsive to amount of water applied and were minimal at irrigation levels of maximum yields. Thompson *et al.* further noted that; dry matter content increased with increased irrigation, glucose content was highest at irrigation level of 94 % of E pan and fructose content decreased with increased level of irrigation.

The effect of irrigation on storage of sweet potato roots

Thompson *et al.* (1992) stated that sweet potato decay and weight loss in storage showed quadratic response to the level of irrigation. They further indicated that root decay and weight loss in storage were minimal at irrigation of level of maximum yields (75 %-95 %) of E_{pan}).

Deficit irrigation effect on sweet potato quality

Sweet potato, (*Ipomoea batatas* L. (Lam.), is sensitive to water deficit stress. However, Indira and Wanda (2004) indicated that the use of drought resistant genotypes coupled with appropriate water management practices can improve the yield and quality of the roots. Indira and Wanda (2004) showed that drought stress could significantly reduce sweet potato root yield and nitrogenous compounds content of the roots while root dry matter content increased as water stress increased. They also indicated that sweet potato dry root yield and dry matter, root nitrogenous compounds, root reducing sugars, total sugars and starch were significantly responsive to irrigation treatments (irrigation regimes). Supplying organic matter under deficit irrigation conditions could be a practical solution to compensate the negative effect of water stress. Hirich et al. (2014) concluded that organic matter application improved significantly yield and biomass production better under deficit irrigation than under full irrigation and hence the combined effect of deficit irrigation and organic amendment led to the maximization of crop water productivity. They observed that dry matter yield was significantly affected by deficit irrigation, while harvested yield was affected significantly

($P < 0.05$) by both deficit irrigation and organic manure. They further observed that for quinoa crop the application of 10 t ha^{-1} and 5 t ha^{-1} organic manure significantly increased seed yield by 18 and 11 % respectively under deficit irrigation while the increase in yield were only 13 and 3 % under full irrigation. For pea crop Hirich et al. stated organic amendment of 10 t ha^{-1} and 5 t ha^{-1} increased yield by 41 and 25 % respectively under water-deficit irrigation while the increase in yield was 24 and 11 % under full irrigation.

Laurie, van den Berg, Magoro, and Kgonyane (2012) stated that the best β-carotene yield and water productivity (β-carotene g ha^{-1} mm^{-1} water applied) was achieved at 60 % irrigation treatment. They also indicated that 50 % and 100 % fertilizer treatments produced roots with β-carotene content which was 14 % higher as compared to 10 % in no fertilizer treatment. β-Carotene yield increased two-fold when 50 % of required fertilizer is applied and four-fold at the maximum fertilizer application (Laurie et al., (2012). They further stated that β-carotene content of OFSP at the low water application (low irrigation treatment) was 15- 34 % higher than at optimal irrigation treatment and that increasing water application resulted in about a two-fold increase in β-carotene yield per unit area.

The Influence of the Climate on Crop Water Needs (ET_o)

Water evaporates from soil surfaces, wet surfaces of leaves and open water surfaces into the atmosphere. The two processes, evaporation and transpiration are jointly called evapotranspiration (Evaporation + Transpiration = Evapotranspiration). Direct solar radiation and, to a lesser

extent, the ambient temperature of the air provide the energy required to change water from liquid to vapour during evaporation and transpiration. As evapotranspiration proceeds, the surrounding air becomes gradually saturated and the process will slow down and might stop if the wet air is not transferred to the atmosphere. The replacement of the saturated air with drier air depends greatly on wind speed. Hence, solar radiation, air temperature, air humidity and wind speed are climatological parameters considered when assessing the evapotranspiration process.

Definition of the reference crop evapotranspiration (ET_o)

ET_o is the rate of evapotranspiration from a large area, covered by green grass, 8 to 15 cm tall, which grows actively, completely shades the ground and which is not short of water. There are various methods of calculating ET_o but the commonest is the Penman-Monteith method.

Influence of crop type on crop water needs (K_c)

Effect of crop characteristics on crop water requirements is given by the crop coefficient (K_c). It represents the relationship between ET_o and ET_c as Equation 2. The daily water need of crops is determined by comparing it with daily water need of standard (reference) grass ET_o. The relationship between the reference grass crop and the crop actually grown is given by the crop factor, K_c. Crop water requirements (ET_c) is computed from crop factor (K_c) and evapotranspiration (ET_o) as shown in Equation 2:

$$ET_c = K_c \, x \, ET_o \qquad 2$$

Where:

ET_c : Crop Evapotranspiration or crop water need (mm d^{-1})

ET_o : Reference Crop Evapotranspiration (mm d^{-1})

K_c : Crop Coefficient

Determination of the growth stages

Once the total growing period is known, the duration (in days) of the various growth stages has to be determined.

The total growing period is divided into 4 growth stages:

- The initial stage: This is the period from sowing or transplanting until the crop covers about 10 % of the ground.
- The crop development stage: this period starts at the end of the initial stage and lasts until the full ground cover has been reached (ground cover 70-80 %); it does not necessarily mean that the crop is at its maximum height.
- The mid - season stage: this period starts at the end of the crop development stage and lasts until maturity; it includes flowering and grain-setting.
- The late season stage: this period starts at the end of the mid-season stage and lasts until the last day of the harvest; it includes ripening.

Determination of crop water requirements (ET_c)

In order to calculate ET_c by the indirect method, the reference evapotranspiration (ET_o), which is the evapotranspiration from a reference surface not short of water, is essentially needed. The reference surface is a hypothetical grass reference crop with specific characteristics. ET_o can also be

calculated experimentally using an evaporation pan or theoretically, using measured climatic data e.g. Blaney-Criddle method and Penman-Monteith method (FAO, 1986). The use of the Penman-Monteith method require additional climatic data; mean daily air temperature, net radiation, wind speed at 2 m height and air relative humidity. ET_o can be estimated from pan evaporation. Pans have proved their practical value and have been used successfully to estimate ET_o by observing the water loss from the pan and using empirical coefficients to relate pan evaporation to ET_o. However, special precautions and management must be applied. The two popular types of pans are the Sunken Colorado pan and Class A pan as shown in Figures 1 and 2.

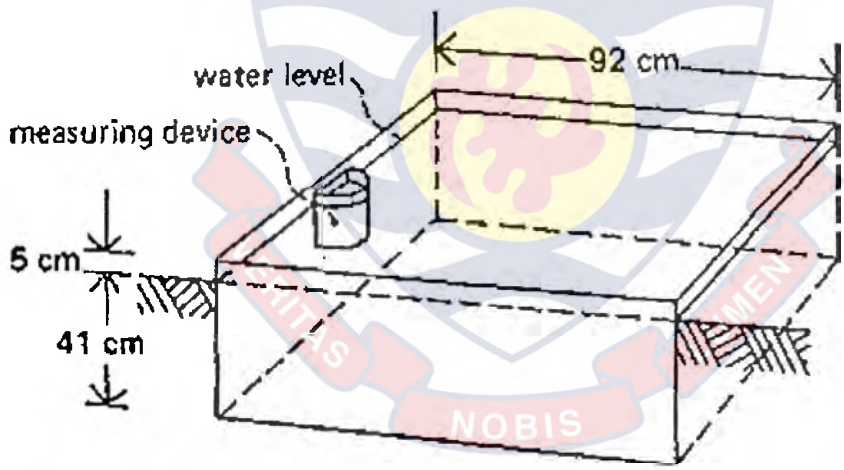


Figure 1: **Sunken Colorado pan [Source: FAO (1986)]**

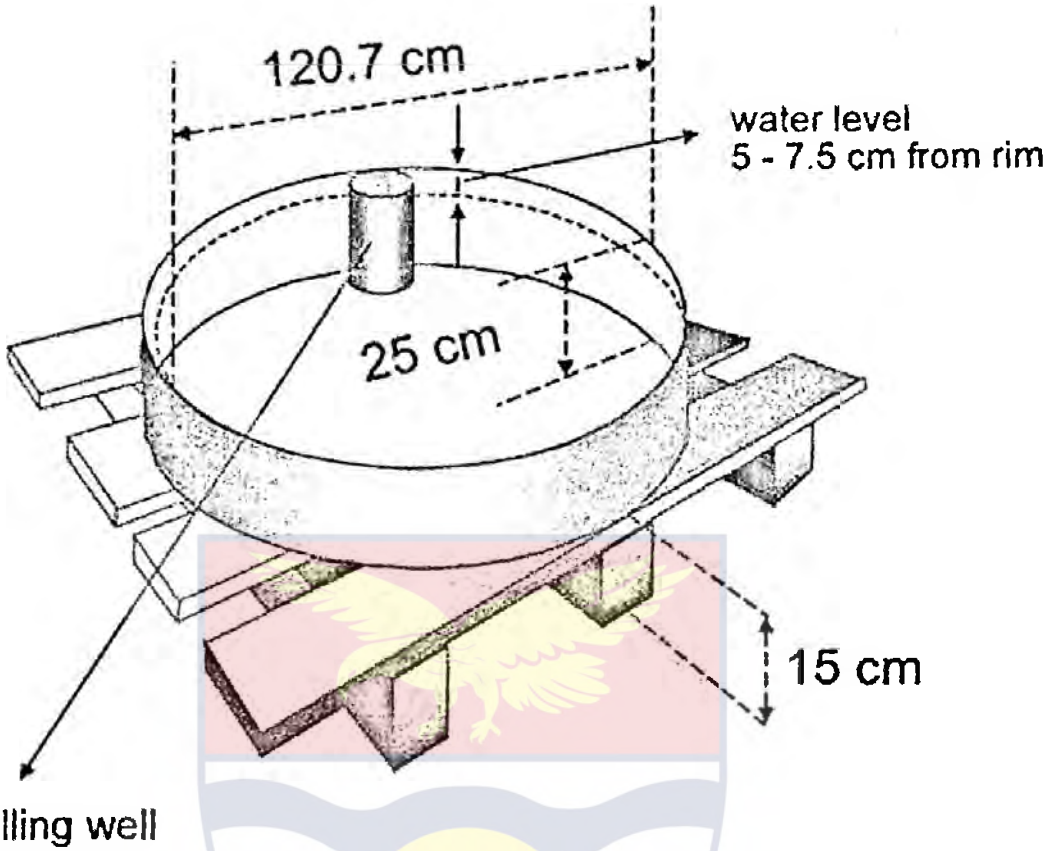


Figure 2: **Class A pan [Source: FAO (1986)]**

Leaf area Index (LAI)

It is important to determine Leaf area index (LAI), which is the ratio of leaf area (one surface only) of a crop to the ground area up on which that crop stands (Salisbury, & Ross, 1992). They further reported that productivity rates increase somewhat with LAI because of increased total light interception. Reddy and Reddi (1992) reviewed that leaf area estimation indicates both assimilating area and growth. Water deficit reduces leaf area, leaf photosynthetic rate (during the stress period, although leaves may recover completely), delays silking and reduces grain yield components, particularly grain number (Hall, Ginzo, Lemocoff, & Soriano., 1980). For crop

production leaf area per unit land area is more important than leaf area of individual plants and the mean maximum LAI ranged from 2.9 to 7.14.

Post-Harvest Treatments

Sorting and grading

The terms sorting and grading are often used interchangeably in the processing industry, but they are different activities. Sorting is a separation based on a single measurable property of raw material units, while grading is the assessment of the overall quality of produce using a number of attributes. It is classification on the basis of quality (Fellows, 2000). Sweet potato roots are sorted by removing diseased and damaged roots from the healthy ones after harvest. After sorting, the roots are further graded using grade standards (Saravacos and Kostaropoulos, 2002). During grading the roots are separated into groups based on attributes such as shape, size, colour and weight. Data et al. (1987) stated that ungraded roots deteriorate faster than graded ones in storage.

Curing

Curing before storage ensures successful storage. Curing of sweet potato is a wound-healing process of exposing roots to high temperature of 29-32 °C and relative humidity of 90-96 % for about 4-8 days before storage (CIGR, 1999). Good ventilation is required to remove carbon dioxide from the curing area. It is a standard procedure accepted by many (Walter and Schadel, 1982). During curing, wounds such as bruises, cuts, and skinned areas are healed and a protective cork layer develops over the entire root surface. Additionally,

suberin, a waxy material, is deposited under the skin which acts as a barrier to decay-causing organisms and to moisture loss during storage (Walter et al., 1989). Furthermore curing prior to storage is known as a standard procedure to protect the roots against pathogens which cause soft rot of sweet potato roots in storage (Snowdon, 1992; Afek & Warshavsky, 1998). Sugar content of sweet potato roots are said to increase during curing (Picha, 1987). Sugar concentration of sweet potato roots vary with storage conditions, and length of storage and curing facilitates the development of flavour during cooking (Wang et al., 1998). Curing involves controlling temperatures and relative humidity and providing ventilation for 7-10 days.

Packaging

Packaging is the science, art and technology of enclosing product for storage, protection, identification and to sell (Mackay *et al.*, 1989). It plays a major role in storage life and marketability of the roots when favourable environment is created. Packaging performs several important functions; containment, facilitates transportation, protects produce from further damage, protection of the environment from contents of package and marketing (CIGR, 1999). Suitable packages reduce damages such bruises, scratched and injuries during transport. Packages such as baskets, wooden crates, jute sacks and plastic sacks are often used in Ghana which provide little or no protection to the roots. Often times there are high losses and damages occur during transportation as a result of poor packaging. In packaging, enough ventilation must be provided to prevent condensation and excess dampness which may

lead to rotting and sprouting. Ventilation removes heat generated through respiration and maintains oxygen levels in the package (CIGR, 1999). Therefore ventilation holes must be provided in packages. However, over ventilation must be avoided as it can result in higher weight loss (Mackey et al., 1989).

Ventilation and stocking bed depth

Sweet potato roots are living material and respire in storage to keep life processes. Respiration converts carbohydrates to carbon dioxide, water and heat. The temperature of the environment and the roots determine the rate of respiration. To control temperature and moisture in the storage structure ventilation is required. Estimation of airflow resistance in stockpiles of agricultural produce is required in designing aeration system (ASAE, 1995).

Airflow resistance equation

Airflow resistance is determined by the relation (ASAE, 1995) as shown in Equation 3:

$$\frac{P}{L} = \frac{aQ^2}{log_e(1 + bQ)} \qquad 3$$

Where

P = pressure drop (Pa)

L = bed depth (m)

a = constant for a particular product (obtained from tables)

Q = airflow ($m^3/s.m^2$)

b = constant for a particular product (from tables)

Air pressure drop is directly proportional to the depth of the stockpile. For adequate ventilation a smaller bed depth (L), is required.

Sweet potato Storage Structures

Sweet potato is stored in various ways in Africa particularly West Africa where the harvested roots are either stored in sacks, heaped under trees, heaped on the farm and covered with palm fronds, clamps or pit storage where roots are buried in the soil. Woolfe (1992) stated that in New Zealand an ancient method practiced consisted of underground storage houses, with timber roofs, dug into the side of a hill, the roots are placed on the floor covered with fern brush. However, Keleny (1965) indicated that losses in this method are heavy resulting from decay and damage. Dukuh (2003) stated that in Kenya the roots are reported to be stored in purpose-built wooden stores roofed with metal sheets that offer convective ventilation and reduced losses about 50 % from 85 %. Pit storage is also practiced in Zimbabwe and Malawi, where the roots are placed in pits and covered with thatch under a shed (Lancaster and Coursey, 1984). Generally, sweet potato can be stored in two main storage structures:

1. Storage without buildings: This involves the traditional way of storing; it is very simple and inexpensive. It includes delayed harvesting or in-situ storage, clamp, covered clamp and pit storage. In-situ or delayed harvesting or in-ground storage involves leaving the sweet potato in the field until it is needed or in high demand (Opara, 1999). This method is not very encouraging because it leads to high weevil infestation and damage up to about 50 %, it

also prevents the use of the farm land for growing other crops. The clamp is very simple; the roots are placed on a bed of straw 1-3 m wide and ventilation duct placed along the bottom and the piled roots covered with straw casing. The pit method is generally considered better than in-situ storage for rural communities and it is mostly practiced in Zimbabwe, Malawi, Zambia and Kenya. In the pit method, a pit is dug on an open ground, ash is sprinkled at the bottom and on the sides of the pit and covered with grass and soil under a shed or woven mat (Mbeza and Kwapata, 1995).

2. Storage in buildings: It involves refrigerated or controlled-atmosphere storage, multi-purpose building and ventilated stores. Refrigerated and controlled-atmosphere storage is mostly practised in developed countries where large scale commercial production is feasible. It involves complex operations which are very expensive but provides long term storage. In ventilated stores the following essentials must be observed:

a. The building should be located at a site where low night temperatures occur over the required storage period.

b. It must be oriented to make maximum use of the prevailing wind ventilation.

c. The material covering the roof and wall should provide a better insulation from the heat of the sun; grass thatch on a bush-pole frame can be very effective, particularly if it is wetted to provide evaporative cooling.

d. White paint applied to the surface of the material will help reflect heat from the sun.

e. Provide ventilation spaces below floors and between walls and roof to give good air circulation.

f. If the store is subjected to cold night temperature, movable louvers are fitted and adjusted to limit the flow of warm air into the store during the day.

g. The structure should be built in the shade of trees if they do not interfere with the prevailing air flow, become a bush fire hazard or fall onto the structure during storms.

Storage structure design requirements

The following requirements should be considered in the design of storage structure for perishable produce such as sweet potato:

a. Adequate structural design to withstand imposed loads both vertical and lateral by stored produce (sweet potato) and wind.
b. Structure should protect produce from rain and sunshine.
c. Structure should allow adequate ventilation.
d. Structure should permit easy inspection of the produce regularly to detect incidence of disease and pest attack.
e. Provision of lowest possible temperature in the storage structure (Lieberman, 1993).
f. The type and volume of produce to be stored in structure.

Heat load factors in a cold storage design

The following heat load factors are normally considered in a cold storage design:

(i) wall, floor and ceiling heat gains due to conduction, ii wall and ceiling heat gains from solar radiation.

(ii) (iii) heat load from air entering as a result of frequent door openings.

(iii) (iv) heat load from products being loaded.

(iv) (v) heat load from the respiration of stored product.

(v) (vi) heat from workers working in the room (Lal Basediya et al., 2013).

Type of structures and site selection

The type of storage structure is influenced by climatic conditions, usage and availability of local materials (Dukuh, 2003). The site should be reasonably level, convenient to reach to allow for frequent inspection and should have good natural drainage. The area should be shady and airy to provide cool environment (FAO/SIDA, 1986).

Material selection

The mechanical properties of the material and economic factors are the criteria used in selecting material for construction. The material selected should fulfill:

a. Service requirements, which include strength, resistance to wear, resistance to weathering, thermal properties, ease of cleaning and workability of material.
b. Economic requirement, which involves the cost of acquiring the material, availability, durability and maintenance cost (FAO/SIDA, 1986).

Construction materials

In general materials for farm structures include: wood (soft and hard), bamboo, thatch, earth, cement, concrete and fasteners.

Wood

Wood is the heartwood from the trunks of large trees which can be classified as hardwood or softwood. However, the classification is not an indication of the physical characteristics of the lumber (Lindley and Whitaker, 1996 as in (Teye, 2010). Hardwoods are generally broadleaved and include mahogany, oak, sapele etc (Ezeji, 1986). Hardwood is resistant to denting and wear and gives a high polish (FAO/SIDA, 1986). Softwood is predominantly used in the paper and pulp industries and includes makore, ebony and wawa. Wood is used in roof trusses, walls, openings, floors stairs. Different types of wood have the following mechanical properties which range from exceptionally strong to weak wood respectively (FAO/SIDA, 1986):

a. Density. kg m^{-3} 801-<400

b. Modulus of elasticity, kN mm^{-2} 10.5-4

c. Bending stress, N mm^{-2} 50-10

d. Compressive stress parallel to grain, N mm^{-2} 29-2.5

Wood has the following merits as construction material (Boyd, 1979):

It is relatively cheap, light in weight and easy to work on with simple tools. Wood is durable if well treated with preservative; adaptable to many uses and it is a poor conductor of heat.

Demerits of wood include the following (Ezeji, 1986):

It is affected by fungi and insects, it can easily catch fire, warps if it is not well seasoned, it is affected by termites, dry rot and wet rot.

Various wood species have the following physical characteristics (Lindley and Whitaker, 1996 as in (Teye, 2010): Strength is the ability to resist breaking in loading as when used in application such as beams, floor joist and rafters. Stiffness is the ability to resist deflection or bending when loaded. It is an important characteristic for members such as studs, joist and beam. Toughness is the ability of wood to withstand shock loading. Hardness is the resistance to denting, wear and gives high polish. Paint holding ability for species that have a uniform grain and exhibit little swelling and shrinkage are likely to hold paint well.

Bamboo

Bamboo is a perennial grass found in the tropical and temperate zones. It has large percentage of fibre which gives it high mechanical properties such as high tensile capacity, high bending stress and high shear stress (FAO/SIDA, 1986). It is used in construction for poles, frames, roof construction, roofing and water pipes. It is also split to form flattened boards, woven wall, floor and ceilings panels. Bamboo reaches maturity in 5-6 years or even later depending on variety (FAO/SIDA, 1986). Bamboo should be harvested before blooming as it dies and loses its resistance after blooming. Bamboo can grow as high as 35 m depending on species while diameters range from 10-300 m (FAO/SIDA, 1986). The density of bamboo is 0.0037 kg m^3. Merits of bamboo as construction material include:

It is as strong as timber in compression, very much stronger in tension and therefore used as poles. Bamboo is light in weight and therefore finds use in roof construction. Bamboo is readily available in tropical countries such as Ghana. It is inexpensive making it a good choice in construction work (FAO/SIDA, 1986).

Demerits of bamboo, which limit its application in construction work, include low durability (decay), it can split, it can change shape and it can burn (FAO/SIDA, 1986).

Thatch

Thatch is an organic building material obtained from grass, reeds, palm (raffia), or banana leaves. It is a common roofing material in rural areas. Thatch has good thermal insulation capacity which keeps the inside of the structure cool and at uniform temperature even when outside temperatures vary considerably. The level of noise from rain splashing on the roof is low.

Jute Sack

Jute sack is made from fibre. In Ghana it is mostly use for packaging Agricultural materials such as cocoa and maize. The sack is 117 cm long and 65 cm wide. It has the capacity to hold water for a long time when wet and it takes a long time to dry. According to Faleh (2002) it has the highest cooling efficiency when it is used as a wet pad for evaporative cooler.

Earth

It is the subsoil excavated for use as building. There are many types of soil which can be classified by chemical composition, geological origin, particle size or consistency. The soil can be mixed with water, treaded and moulded into mud blocks. The soil can also be stabilized and compacted by ramming into blocks. Other types such as soil-cement blocks and burnt clay bricks are also used as building materials. Advantages of earth as a building material are: It is fire resistant, cheaper, readily available at most building sites, easy to work, good noise absorbent and it has a high thermal capacity (FAO/SIDA, 1986).

Despite its good qualities, earth as a building material has the following limitations: It has low resistance to water penetration, very high shrinkage or swelling ratio and low resistance to abrasion (FAO/SIDA, 1986).

However, the quality of earth as a building material can be improved by the addition of stabilizers which cement the particles together to reduce shrinkage and swelling and make the soil waterproof (FAO/SIDA, 1986). Common stabilizers include sand or clay, portland cement, lime, bitumen, pozzolanas, natural fibres, resins, molasses, gypsum, cow dung, etc.

Cement concrete

Concrete is composed of cement, sand and stone aggregates and water. Concrete can be classified into the following: Structural concrete, masonry concrete and insulating concrete (Ezeji, 1986). Merits of concrete as a building material include high strength, hardness, high durability, high imperviousness, high mouldability, high thermal capacity and fire resistance (FAO/SIDA, 1986).

Limitations of cement as a building material include: poor thermal insulation, loss of strength at high temperature, low resistance to acids and sulphates and relatively high cost. In farm buildings the cost of concrete can be reduced by replacing part of the portland cement with pozzolana.

Fasteners

Fasteners in farm building include nails, bolts and screws, hinges, latches and twines. A nail gives strength to a joint by the shear strength of its cross-section and the grip around its shank (FAO/SIDA, 1986). Nails provide

a simple method of joining members of a farm building though they are inefficient from the construction standpoint (Boyd, 1979). It is necessary to select the right type of nail in any particular situation. The kinds most commonly used in farm building are:

Common nails which are used in boards 50.8 mm (1 inch) or less thick. They have thin shank and cannot be relied on to carry loads. Spikes have larger diameter than common nails and have oval shaped head. They are used for trim boards and for flooring. Deformed shank nails have the shank made as a screw. The deformed shank helps to increase the withdrawal resistance and the allowable load on the nail in wood treated with oil-borne preservative (Boyd, 1979). The holding power of nails can be affected by changing the surface of the nail, by direction of driving into the wood, by clinching, or by selecting different style of nails (Boyd, 1979). Nails coated with resins have increased withdrawal resistance because the resins act as adhesive. Roofing nails are zinc coated which increase the withdrawal resistance and prevents rusting. A nail with a long tapered point has lower withdrawal force and more likely to split the wood than a nail with stubby blunt point which is less likely to split the wood and has higher withdrawal force.

The greatest withdrawal resistance occurs when nails are driven perpendicular into the wood (Boyd, 1979). Driving nails into the wood parallel to the grain may reduce withdrawal force by 50 %. Nail driven at an angle to the surface may increase the holding power. Nails should not be subjected to withdrawal force in the design of structure since their resistance to withdrawal force is low. Staples are U-shaped nails with two points used mainly to fasten wires.

Screws and bolts have thread which gives them greater holding power and resistance to withdrawal than nails. Bolts provide stronger joints than nails and screws.

Structural Loads

Estimating loads on farm building must be the first step in design (Boyd, 1979). Structural or design loads are forces and effects which affect structural members. They are considered in the design of structural members and connections. Loads are categorized into the following:

I. Dead loads

The force resulting from the static weight of all permanent elements of the building such as, walls, floors, roofs, foundation and partitions.

II. Live Loads

Loads produced by animals, people, stored products and equipment.

III. Wind Loads

These include all loads due to the effect of wind, pressure or suction.

Elements of construction

The elements of construction include the roof, walls, floor and footings or foundations.

Roof

The roof provides protection from rain, sun, wind (weather) heat and cold. It is therefore an essential part of every building. Technically, the roof consists of the framework (truss) of wood, steel or concrete on which

a covering of thatch, corrugated iron or asbestos, tiles, etc. is placed. The roof structure must be able to withstanding the dead load imposed by roofing and framing and forces of wind and rain. Roof must be weather resistant (leak proof), durable, fire resistant, strong and stable and a good thermal insulator or high in thermal capacity. The choice of shape, frame and covering depends on factors such as the size and use of the building, its anticipated life span, appearance, availability and cost of materials. The style or shape of roof includes shed, gable, gambrel, hip, gothic and combinations.

Walls

Walls are essential components of a building. They enclose space; protect the building from the weather and offer privacy and security to occupants and their property (Ezeji, 1986). Walls may be classified as load-bearing or non load-bearing. Load-bearing walls carry their weight, floor and roof weight; resist wind pressure i.e. vertical and lateral pressures from stored products. Non load-bearing walls carry no other loads except their own weight.

Good quality walls provide strength and stability, weather resistance, thermal insulation, fire resistance and sound insulation (FAO/SIDA, 1986). Traditionally wall material consists of kneaded mud, sometimes interspersed with sticks for reinforcement. Advantages of mud walls include heat and fire resistance but are easily weakened by rain. Concrete blocks are the most popular wall material for permanent structures. Metal

sheets and wood are also used as wall materials. They are used in temporary and semi-permanent structures such as storage structures and animal houses. They are also used in constructions that are not lived in by people.

Floor

The floor could be ground level grade or suspended (above-ground grade). The floor could be compacted soil, concrete or wood. A well-built floor offers protection from vermin and rodents, is easy to clean, dry, durable and is a valuable asset to a building (FAO/SIDA, 1986). It would sustain its weight and other imposed weights. For ground level floors, finish level of a solid floor should be 150 mm above outside ground level to protect it against flooding. Topsoil should be removed and replaced with coarse material before the actual floor slab is constructed. This prevents moisture rising by capillary action (FAO/SIDA, 1986). Suspended ground level floors are useful on sloping sites where much filling would be required to level the ground for a solid floor. Timber floors must be raised above ground (about 45 cm high) to protect it from moisture, fungi and termites. Enough space must be provided underneath the suspended floor to ensure adequate ventilation and allow a person to crawl underneath for inspection of floor (FAO/SIDA, 1986).

Footing and foundations

A foundation may be defined as that part of a structure, which is in direct contact with the ground to which the weight of the structure and

imposed loads on the structure are transmitted (Ezeji, 1986). It provides support for dead loads and live loads; i.e. the structure and loads imposed on it. Footing and foundation material should not fail in the presence of ground or surface water. Footing is an enlarged base for a foundation designed to distribute the building load over a larger area of soil and to provide a firm, level surface for constructing the foundation wall. A 1:3:5 ratio of cement-sand-gravel is recommended with 31 kg of water per 50 kg sack of cement (FAO/SIDA, 1986). The total load on a column and the soil bearing capacity determine the design of footing and foundation. Footing trenches must be dug to reach firm soil and filled with concrete stone or gravel. Estimation of footing area by the formula (FAO/SIDA, 1986) as shown in Equation 4:

$$A = \frac{P}{Sv} \qquad 4$$

Where,

A = Footing area, m^2

P = Load on post/column, N

Sv = Soil bearing capacity or allowable soil pressure .

Properties of structural sections in design

Properties of structural section used in design include: centroid or centre of gravity, moment of inertia (I), section modulus (Z), radius of gyration (r) and slenderness ratio (λ).

Centre of gravity and reference axes

Centre of gravity is the point about which the forces are evenly distributed. The centroid of a section is the point about which the area of the section is evenly distributed. However centroid sometimes lies outside the actual cross section of the structural element. Reference axes of structural section usually pass through the centroid. Generally the x –x axis is drawn perpendicular to the greatest lateral dimension of the section; and the y-y axis is drawn perpendicular to the x-x axis. The x-x and y-y axes intersect at the centroid.

Moment of inertia (I)

Moment of inertia (I) measures the distribution of an area of a section about a particular axis of the cross section. It is used to determine the material resistance to bending and its value as a beam or slender column. Moment of inertia about the x-x axis, I_{xx} of a strip of size Δy is given by Equation 5:

$$I_{xx} = b\ x\ \Delta y\ x\ y^2 \qquad 5$$

Where

y = distance from centroid of strip to the x-x axis.

Δy = size of strip as shown in Figure 3.

B = least dimension of the crosssection.

The exact moment of inertia (I) is given by integration of Equation 5 to give Equation 6.

$$I_{xx} = \int_{-d/2}^{+d/2} by^2\, dy = \frac{bd^3}{12} \qquad 6$$

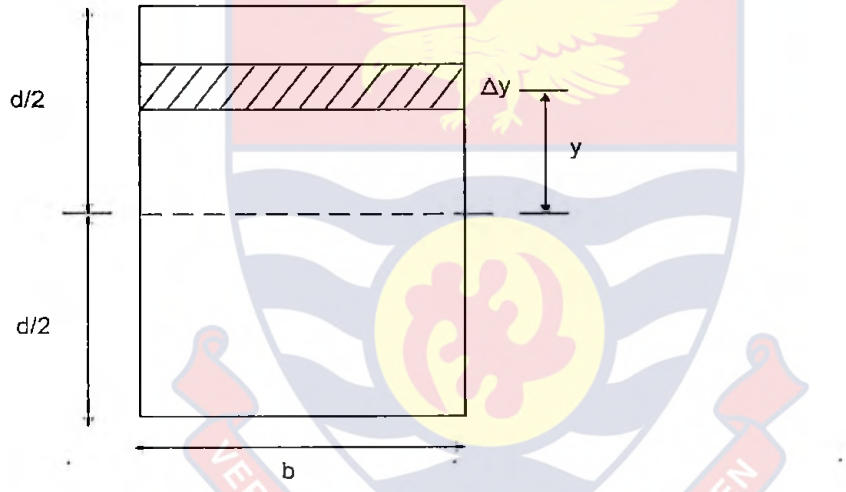


***Figure 3*: Moment of Inertia, I_{xx} of strip.**

Section modulus (Z)

Section modulus (Z) is the ratio of I about neutral axis of section to the distance from neutral axis to the edge of section. It is important in determining bending stresses in beams as shown in Figure 4. The section modulus is the size and shape of the section and it must be selected such that maximum compressive stress does not exceed allowable value in beam design. It is computed with Equation 7:

$$Z = \frac{I_{xx}}{y} = \frac{bd^3}{12} x \frac{2}{d} = \frac{bd^2}{6} \qquad 7$$

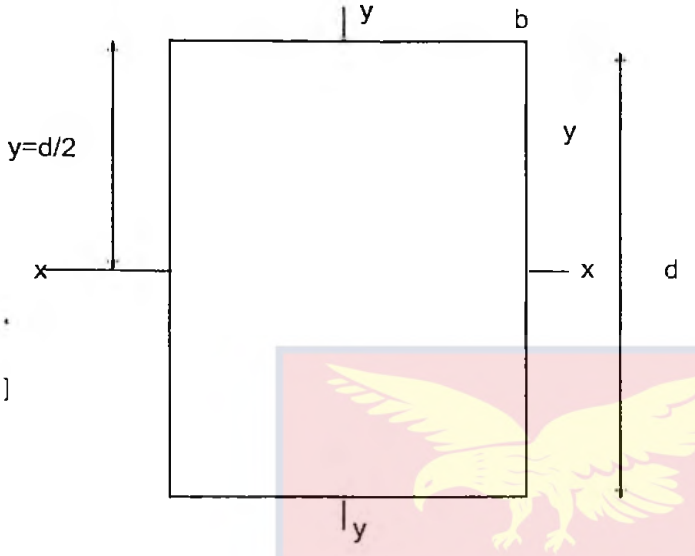


***Fig. 4*: Section Modulus of a Rectangular Beam.**

Radius of gyration is a measure of distribution of area of cross section in relation to the axis. It is the distance at which the entire area could be concentrated and still give the same moment of inertia value (I) about a given axis (Craig, 1996). The importance of radius of gyration lies in the fact that in structural design it is used to determine the appropriate length of compression members such as columns and struts for designed loads. It is used to estimate their slenderness ratio and tendency for bulking (FAO/SIDA, 1986). For columns bulking occurs about the axis for which r is minimum and is given by Equation 8.

$$r_{xx} = \sqrt{\frac{I_{xx}}{A}}; \quad r_{yy} = \sqrt{\frac{I_{yy}}{A}}; \quad I = Ar^2 \qquad 8$$

Slenderness Ratio (ʎ)

Slenderness ratio (ʎ), describes the relationship between the length of a column, its lateral dimensions and the end fixity conditions. It determines the resistance of the column to buckling. When ʎ is small then reduction factor $K_ʎ$ is higher which permits higher allowable load with respect to bulking. FAO/SIDA (1986) states that mathematically, slenderness ratio is expressed as in Equation 9:

$$ʎ = \frac{KL}{r} = \frac{l}{r} \qquad 9$$

Where,

ʎ = slenderness ratio

K = effective length factor which depends on how the ends of the column is fixed

L = length of column

r = radius of gyration

l = effective length of the column (KL)

Theory and Basic Principle of Evaporative Cooling System

Evaporative cooling is an environmentally friendly air conditioning system which uses induced heat and mass transfer process (Camargo, 2007). It is a physical process in which liquid evaporates into surrounding air and cools an object or a liquid in contact with it. In evaporative cooling, the difference between the wet-bulb temperature and the dry-bulb temperature of the air determines the potential for evaporative cooling. The greater the difference between the wet-bulb temperature and the dry-bulb temperature, the

greater the evaporative cooling effect. When water evaporates, it draws energy from its surroundings which produce a considerable cooling effect and the faster the evaporation the greater is the cooling. The efficiency of an evaporative cooler depends on the humidity of the surrounding air and the efficiency of the evaporating surface. Very dry air can absorb a lot of moisture so resulting in greater cooling while saturated air cannot absorb moisture and thus no cooling. When water evaporates from the liquid phase into the vapour phase energy is required. This principle can be used to cool stores by first passing the air through a pad into the storage room as shown in Figure 5. According to Dadhich et al. (2008) the evaporative cool chamber fulfills all these requirements and is helpful to small scale farmers in rural communities.

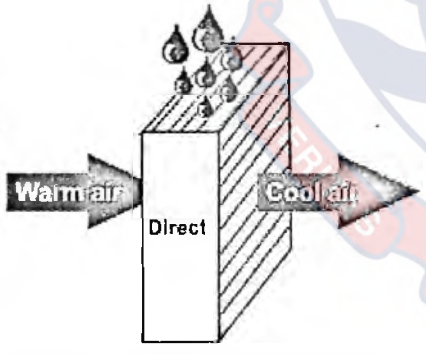


***Figure 5*: Direct Evaporative Cooling**

Psychrometrics and postharvest operations

The psychrometric chart

Psychrometry is the study of the properties of air under varying temperature and moisture conditions and therefore is of interest to drying and postharvest technologists. The psychrometric chart was developed by heating

and ventilation engineers to enable them to design air conditioning plants for buildings. Air conditioning and drying may have aspects which are common to both. There are four functions required of an air conditioning system:

- heating air
- cooling air
- addition of moisture to the air (humidification)
- removal of moisture from the air (de-humidification)

Psychrometric variables

The following terms used in the psychrometric chart are defined as:

Dry bulb temperature: the dry bulb temperature is the temperature of the air as measured by a standard thermometer.

Wet bulb temperature: the wet bulb temperature is the temperature of the air when fully saturated. It can be found by enclosing the bulb of a standard thermometer within a wet cotton sock, which has the effect of simulating atmospheric conditions of 100 % relative humidity (RH). Unless the ambient conditions are 100 % RH the wet bulb temperature will always be less than the dry bulb temperature.

Percentage saturation: relate to the humidity of the air as a percentage of the absolute humidity of air that is fully saturated and are very similar to relative humidity and the values are often interchanged.

Adiabatic cooling: indicates what happens to the temperature and humidity of air during drying. Heat from the warm air is used to provide energy to vaporize

moisture from the food. The air cools as moisture is evaporated from the moist food and absorbed by the warm air as it provides the heat required for evaporation. The relative humidity of the air increases which reduces the capacity of the air to pick up more moisture.

Specific enthalpy: relates to the energy contained in the air. The warmer the air, the higher its energy or enthalpy. The scales are used to calculate the amount of fuel that will be required to heat the air used to dry the food.

Specific volume: represents the change in volume of air at a given temperature. The volume of any gas, including air, will vary with temperature. These lines represent the change in volume for air at a given temperature.

Absolute humidity: this is the weight of water in each unit weight of air. It is normally expressed as kg of water per kg of air.

CHAPTER THREE

THE EFFECT OF DEFICIT IRRIGATION, COW DUNG, POULTRY MANURE AND NPK ON SOIL PROPERTIES, GROWTH AND YIELD OF ORANGE FLESHED SWEET POTATO (OFSP)

Introduction

Orange-fleshed sweet potatoes can be a very suitable crop for combating vitamin A deficiency in humans and it is becoming an important crop among the vulnerable in Ghana. In Ghana sweet potato is becoming an important export crop in the Bawku East District of the Upper East Region where farmers export the crop to neighbouring Burkina Faso, where they obtain good prices for the crop (FAO, 2005). However the production of sweet potato is going down despite its nutritional and economic value. Average yield of 5 t ha^{-1} is low as compared to 14 t ha^{-1} in China and other developing regions of Asia. The reduction in production can be attributed to poor soil nutrient status, high rainfall, crop removal, rapid mineralization of soil organic matter and rapid growth in population leading to excessive cultivation of land (IITA, 1995). The causes of low yields can also be attributed to poor agronomic practices. There is therefore the need to reinvigorate cultivated soils and improve the physical and chemical conditions of the soil. It has been stated that the application of fertilizers is one of the most important ways of increasing the productivity of crops (Ali et al., 2009). Depending on the fertility status of the soil, fertilizer may increase the yield of

sweet potato by 32-83 %. Thus fertilizer application is a means of achieving increased food and fibre production. Increased agricultural production and food availability is as an objective for the agricultural sector in the context of contributing to the broader macroeconomic objectives of society. Manure is an age-old source of fertilizer which modifies soil physical and chemical properties and releases nutrients for a longer period of time. In recent years, the use of organic manures as fertilizers has increased tremendously as a result of serious environmental pollution (Ofoefule et al., 2014) caused by the use of agro-chemicals. To achieve efficient use of animal manure there is the need to thoroughly understand crop responses and availability of nutrients supplied by manure and also compare different types of animal manures under similar field conditions.

Though sweet potato is generally considered as a drought tolerant crop, Nedunchezhiyan et al. (2010) showed leaf area reduction in sweet potato plants as water stress increased and some cultivars exhibited yield reduction under deficit irrigation (Van Heerden & Laurie, 2008). Globally, drought is a problem that inhibits the growth of plants and leads to yield reduction. However, there is greater demand for more food, more raw materials, more water, higher energy consumption, etc. as world population is estimated to exceed 8.2 billion people.

As food requirements increase and water resources decrease, it becomes more and more important to make the best of both rain fed and irrigated crop production (Ahmed, 1999). A worldwide shortage of freshwater resources and

more frequent and severe drought due to climate change has stimulated research into water-saving irrigation strategies aimed at producing more crops. It has become essential to enhance crop water use efficiency to increase crop productivity while sustaining the environment. Therefore research into the combined effect of manure and water stress on growth and yield is considered essential towards meeting food security. Moreover, understanding the relationships between plants and water will help understand the broader issues that govern the optimization of the limited supply of water in crop production (Fereras, & Soriano, 2007).

Though many works have been conducted on the effect of organic manure, chemical fertilizer and deficit irrigation (CDI) on different crops, little information is available on the combined effect of DI, CD, PM and NPK (15:15:15) fertilizer on soil properties, nutrient removal, growth and yield of sweet potato. Farmers in the study area are aware that the application of nutrients such as manure and fertilizer increases the yield of sweet potato and other related crops. However, they do not know the combined effect of manure, inorganic fertilizers, (NPK) and water stress on the production of the crop. Therefore, a systematic investigation into the combined effect of using locally available, accessible and affordable farmyard manure (cow dung & poultry manure), NPK and irrigation is of paramount importance for increasing the yield of sweet potato.

To address those problems, the study was initiated with the objective of evaluating the effect of poultry manure, cow dung, NPK and Irrigation at

different levels on soil physical properties, water use efficiency, growth and yield of sweet potato in the coastal savanna zone of Ghana.

Materials and Methods

Study area

A field experiment was carried out between December 2013 and January 2015 planting season at the Teaching and Research Farm of the University of Cape Coast in the Central Region of Ghana. Cape Coast is located around latitude 5.06° N and longitude 5° W with altitude of 31 m above sea level. The municipality has a double maximal rainfall. The annual rainfall is between 650 mm and 1100 mm (Owusu-Sekyere et al., 2012). Major rainy season is from March to July and the minor rainy season is from September to October. Cape Coast experiences relatively high temperatures throughout the year and is humid. Maximum temperature is between 30 °C to 36 °C while minimum temperatures range between 22 °C to 26 °C (Ayittah, 1996). Natural vegetation is coastal savanna (Teye, 2010) which consists of shrubs, grasses and a few scattered trees. February and March are the hottest months, while June and August are the coolest months. The soil type is classified as sandy-loam of the Benya series, which is a member of the Edina Benya Udu compound association (Assamoah, 1973). In the northern parts of the Cape Coast municipality, the landscape is generally low lying and is suitable for the cultivation of various crops. Soils of the experimental fields are sandy loam in texture, slightly acid in reaction (pH 5.8), low in nitrogen and potassium contents but marginal in available phosphorus (Tables 7 and8).

Experimental Design

The treatments consisted of four levels of irrigation; 100 %, 90 %, 80 %, 70 % of ET_c, three types of Fertilizer, PM, CD, NPK and No Fertilizer (Control). PM was applied at the rate of 15 t ha^{-1}. CD and NPK were applied at the rate of 30 t ha^{-1} and 1300 kg ha^{-1} respectively. The experiment was laid out as a Randomized Complete Block Design in a factorial arrangement with three replications. Each replicate measured 44.6 m x 3 m while a plot size was 3 m x 1.85 m with 16 plots per replicate, giving a total of 48 plots. The inter-block and plot spacing was 2 m and 1 m, respectively.

Treatments

All plots were constructed into seedbeds and the poultry manure, cow dung and NPK incorporated. The OFSP variety was used for the study. There were sixteen treatments (100% ET_c + 15 t ha^{-1} PM, 90% ET_c + 15 t ha^{-1} PM, 80% ET_c + 15 t ha^{-1} PM, 70% ET_c + 15 t ha^{-1} PM, 100% ET_c + 30 t ha^{-1} CD, 90% ET_c + 30 t ha^{-1} CD, 80% ET_c + 30 t ha^{-1} CD, 70% ET_c + 30 t ha^{-1} CD, 100% ET_c + 1300 kg ha^{-1} NPK, 90% ET_c + 1300 kg ha^{-1} NPK, 80% ET_c + 1300 kg ha^{-1} NPK, 70% ET_c + 1300 kg ha^{-1} NPK, 100% ET_c + Control, 90% ET_c + Control, 80% ET_c + Control and 70% ET_c + Control) and three replications. Rain shelter was erected over the plots to prevent any form of precipitation on the plots. The structure of the rain shelter consisted of galvanized steel metal frame roofed with transparent water proof plastic sheet which transmitted solar radiation but kept precipitation off the plots (Figures 6 & 7).

Figure 6: **Rain shelter over plots of sweet potato at initial growth stage**

Figure 7: **Rain shelter over crop at the mid-season stage**

Determination of crop water requirements

The Penman–Monteith equation (Monteith, and Unsworth, 1990; Allen et al., 1998) was used to determine the evapotranspiration (ET_o) requirements of OFSP.

The FAO Penman-Monteith method used to estimate ET_o was derived from original Penman-Monteith equation and aerodynamic estimate of ET_o as shown in Equation 10):

$$ET_o = \frac{0.408\Delta(R_n - G) + y\frac{900}{T+273}U_2(e_s - e_a)}{\Delta + y(1 + 0.34U_2)} \quad 10$$

Where

ET_o is reference evapotranspiration [mm day^{-1}],

R_n is net radiation at the crop surface [MJ m^{-2} day^{-1}],

G is soil heat flux density [MJ m^{-2} day^{-1}],

T is mean daily air temperature at 2 m height [°C],

u_2 is wind speed at 2 m height [m s^{-1}],

e_s is saturation vapour pressure [kPa],

e_a is actual vapour pressure [kPa],

e_s - e_a is saturation vapour pressure deficit [kPa],

Δ is slope vapour pressure curve [kPa $°C^{-1}$],

y is psychrometric constant [kPa $°C^{-1}$].

CROPWAT 8.0 for Windows, a computer program for the calculation of crop water requirements (CWR) and irrigation requirements (IR) based on soil, climate and crop data, was used to estimate ET_o. All calculation procedures used in CROPWAT 8.0 are based on the two FAO publications of the Irrigation and Drainage Series, Crop evapotranspiration – Guidelines for

computing crop water requirements, No. 56 and Yield response to water, No. 33.

The values of ET_o computed with FAO CROPWAT (Table 4) were compared with ET_o calculated with the pan evaporation method.

Formula: $ET_o = K\ pan \times E\ pan$

A crop factor was then used to describe the proportion of water used by the crop at specific growth stage of the crop relative to ET_o, and crop water requirements was estimated (Bithell, & Smith, 2011) by:

Crop water requirements (ET_c) = Crop factor (K_c) x ET_o.

Table 5 is average crop coefficients, K_c and mean maximum plant height for use with FAO Penman-Monteith ET_o.

Estimation of K_c and growth stages of crop

Equation 11 was used to determine initial K_c and Equation 12 to determine K_c for any growth stage.

$$K_{c\ ini} = K_{c\ ini(Fig.20)} + \frac{(1-10)}{(40-10)}\left[K_{c\ ini(Fig.30)} - K_{c\ ini(Fig.29)}\right] \quad 11$$

$$K_{ci} = K_{c\ prev} + \left[\frac{i - \sum(L_{prev})}{L_{stage}}\right](K_{c\ next} - K_{c\ prev}) \quad 12$$

Where

i: the day number within the growing season

K_{ci}: the crop coefficient on day I,

L_{stage}: length of the stage under consideration (days),

$\sum (L_{prev})$: Sum of the length of all previous stages (days).

The consideration was that the K_c during the initial growing stage is constant and the K_c for the mid-season stage is also constant.

Table 4: Climatic Data and ET_o for Cape Coast in 2014 Computed with FAO CROPWAT 8.0

Month	Min Temp °C	Max Temp °C	Humidity %	Wind Km d^{-1}	Sun Shine h	Rad MJ M^{-2} d^{-1}	ET_o mm d^{-1}
January	16.8	32.8	80	570	5.1	16.0	4.96
February	18.7	33.0	80	847	5.3	17.1	5.53
March	19.5	32.9	83	821	3.8	15.3	4.91
April	18.8	33.5	81	855	5.5	17.9	5.66
May	18.4	31.5	84	847	4.5	15.7	4.62
June	18.4	30.6	84	467	4.4	15.2	3.95
July	18.0	29.5	86	363	3.1	13.4	3.33
August	17.3	28.8	86	475	3.0	13.7	3.42
September	18.1	29.6	84	752	3.0	13.9	4.00
October	18.2	30.4	83	804	4.5	15.9	4.47
November	18.9	31.7	83	855	5.3	16.4	4.78
December	18.5	31.3	84	648	5.4	16.1	4.34
Average	18.3	31.3	83	692	4.4	15.5	4.50

Source: Author's Data (2014)

Table 5: Average crop coefficients, K_c and mean maximum plant height for non-stressed crops in sub humid climates for use with FAO Penman-Monteith ET_o

Crop	$K_{c\ ini}$	$K_{c\ mid}$	$K_{c\ end}$	Max. Crop height m
Root and Tuber	0.5	1.10	0.95	
Cassava				
Year 1	0.3	0.80	0.3	1.0
Year 2	0.3	1.10	0.5	1.5
Parsnip	0.5	1.05	0.95	0.4
Potato		1.15	0.75	0.5
Sweet potato	0.5	1.15	0.65	0.4

Source: FAO (1998).

Irrigation water quality

Irrigation water quality was analysed. Major cations and anions such as, Ca, P, NO_3, Fe, Cu and Zn. Ca and NO_3 were determined by titration and P by Flame photometer.

Fe, Zn and Cu were analysed by Atomic Absorption Spectrometer. Soil suspension of 1:2.5 ratio was prepared and pH meter was used to determine pH. Electrical conductivity (EC) was determined by using electrical conductivity meter.

Soil physico-chemical analysis

After application of the treatments, soil sample of one auger per plot were collected. At the end of the study, soil samples from each of the experimental plots were also collected. The samples were air-dried, ground and passed through 2 mm-mesh sieve and used for laboratory analysis.

Estimation of soil nutrient removal by crop

The web based International Plant Nutrition Institute (2015) Crop Nutrient Removal Calculator was used to estimate removal of nitrogen, phosphorus and potassium. The calculator estimates crop nutrient removal of nitrogen (N), phosphorus (expressed as P_2O_5), potassium (expressed as K_2O), and sulphur (S) for a broad, and continually expanding, list of field crops.

Crop data

In each experimental plot, five plants were tagged for the measurement of number of leaves, number of branches and leaf area from 3 weeks after planting to mid-season stage. Three weeks after planting, the number of leaves on tagged plants were counted and the average calculated weekly. Similarly the number of branches per plant were counted three weeks after planting. Leaf area was determined by tracing sampled leaves from five plants on graphs and the area determined.

Harvesting and curing

Harvesting was done by first cutting vines. Cut vines were rolled to the side of the plot and weighed. Tubers were pulled up with the hand and what was left in the soil was dug up with a hoe carefully to reduce damage to

tubers. Tubers weighing 100 g and above from 20 sampled plants per plot were considered and weighed. Harvested root tubers were cured, bulked and stored in three types of evaporative storage structures. Curing was done to determine whether there were significant differences in the parameters studied. Tubers were cured at a temperature of 29-32 °C and relative humidity of 85-90 % for 4 days. Curing is a standard procedure which helps wound healing (Hall, 1994). It prevents entry of pathogens through the wounds and thereby protects the roots against deterioration in storage.

Water use efficiency (WUE)

Water use efficiency (WUE) or crop water productivity for each treatment was calculated as tuber yield (kg ha^{-1}) divided by seasonal evapotranspiration (ET) or water applied (m^3 ha^{-1}).

Data Collection and Analysis

Data were collected on average number of leaves per plant, average number of branches per plant, leaf area index, vine yield, tuber yield, total yield (vine plus tuber yield) and soil chemical and physical properties.

Data collected

The following data were collected:

1. Climatic data for calculation of ET_o

Climatic data for calculating ET_o was obtained from Meteorological Agency of Ghana, Cape Coast.

2. Chemical and physical properties of irrigation water

Irrigation water quality was analyzed by flame photometer, Atomic

Absorption Spectrometer, Electric Conductivity meter and by titration.

3. Estimated soil nutrient removal by crop.

The web based International Plant Nutrition Institute (2015) Crop Nutrient Removal Calculator was used to estimate removal of nitrogen, phosphorus and potassium.

4. Soil physical and chemical properties

Soil samples were air-dried, ground and passed through 2 mm-mesh sieve and used for laboratory analysis. Flame photometer, Atomic Absorption Spectrometer and titration were employed to determine soil chemical properties.

5. Crop water use efficiency

Crop water use efficiency was computed using Equation 13.

$$Crop\ water\ use\ efficiency\ (WUE) = \frac{\text{tuber yield (kg } ha^{-1})}{\text{water applied } (m^3\ ha^{-1})} \quad 13$$

6. Number of branches per plant

Five non-border plants from each treatment plot were randomly sampled for number of branches. The number of branches per plant were counted at the third, fourth and fifth weeks.

7. The number of leaves per plant

Five non-border plants from each treatment plot were randomly sampled for leaf number. The number of leaves per plant were counted at the third, fourth and fifth weeks.

8. Leaf Area

Sampled leaves from five plants were traced on graphs and area

determined.

9. Leaf Area Index

$$Leaf\ Area\ Index\ (LAI) = \frac{Leaf\ area\ (Sampled\ plants)}{Area\ occupied\ by\ sampled\ plants} \quad 14$$

10. Yield

a. Tuber yield

Tubers weighing 100 g and above from 20 sampled plants were considered. Total yield per plot was determined by multiplying the total number of plants by the yield per plant. The yield per plot was projected to per hectare basis.

b. Vine yield

Vines from 20 sampled plants were harvested and weighed. Vine yield per plot was projected to per hectare basis.

c. Total yield

Tuber yield was determined as total tuber yield per plot projected to per hectare basis.

Data analysis

All data were subjected to analysis of variance using Gen-stat Discovery software version 4.0. For treatments that were significant, mean separation was done using the Least Significant Difference (LSD) test at 5 % probability level.

Results and discussion

The effect of Cow dung (CD), Poultry manure (PM), NPK and irrigation level on soil physico-chemical properties

The result of the quality of the irrigation water is shown in Table 6. The pH was 6.5 which is suitable for the growth of sweet potato.

Table 6: Chemical properties of irrigation water

Properties of water	Values
pH	6.5
Ca	2.4 mg $^{-1}$
NO_3^-	1.5 mg L^{-1}
P	0.36 mg L^{-1}
Fe	3.95 mg L^{-1}
Zn	1.1 mg L^{-1}
Cu	0.03 mg L^{-1}
EC	0.01 ds m^{-1}

Source: Author's Data (2015)

The results of the initial soil physical and chemical properties studied are shown in Table 7. The results indicate that with all the parameters studied, there were numerical increases in soil physical and chemical properties as compared to the control (no fertilization). Reduced level of water application resulted in increases in some parameters while it resulted in decreases in other parameters. Bulk density and particle density were highest, 1.52 g cm^{-1} and

2.47 respectively at 70 % water application (70 % ET_c) as compared to 1.47 g cm^{-1} and 2.45 respectively at 100 % water application (Table 7). CD increased potassium by 141.5 % (From 0.41 cmol kg^{-1} to 0.99 cmol kg^{-1}) while NPK and PM increased potassium by 31.7 % and 29.3 % respectively as compared to the control where there was no soil amelioration.

Table 7: Initial Soil physico-chemical properties as influenced by the application of CD, PM, NPK and level of irrigation

Treatments	Soil Properties							
Irr. % ETc	% N	P µg g^{-1}	K cmol kg^{-1}	Ca cmol kg^{-1}	Mg cmol kg^{-1}	ρ_b g cm^{-3}	Pore vol. %	ρ_s g cm^{-3}
70	0.12	53.37	0.55	3.02	2.30	1.52	38.50	2.47
80	0.12	44.41	0.62	2.84	1.65	1.50	38.0	2.41
90	0.13	50.36	0.62	3.10	1.69	1.47	40.0	2.46
100	0.13	44.42	0.67	3.43	1.47	1.47	40.50	2.45
Manure/Fertilizer								
Control	0.11	24.19	0.41	2.36	1.46	1.47	39.50	2.43
NPK	0.12	64.84	0.54	2.94	1.40	1.52	38.50	2.46
CD	0.14	38.15	0.99	2.57	1.53	1.48	39.50	2.44
PM	0.13	65.37	0.53	4.51	2.73	1.49	39.50	2.46

Source: Author's Data (2015)

However, PM, NPK and CD increased P by 170.2 %, 168.0 % and 57.7 % respectively (From 24.19 µg g^{-1} to 65.37 µg g^{-1}, 64.84 µg g^{-1} and 38.15 µg g^{-1} respectively) as shown in Table 7. Application of PM resulted in the highest increase in available P. Percentage N content of the soil was increased by 27.3 %, 18.2 % and 9.1 % by CD, PM and NPK respectively. NPK increased

percentage N from 0.11 % to 0.12 % which was lowest among PM, CD and NPK. This could be attributed to rapid release of nutrients from NPK which could lead to leaching of nutrients. Rapid release and leaching of nutrients from soil treated with NPK could also be responsible for reduction of percentage N from 0.12 % to 0.0925 % (Table 8) representing 22.9 % reduction. Though PM is known to contain more N than CD (Table 6), Table 7 shows CD increased percentage N concentration in the soil by 27.3 % while PM resulted in an increase of 18.1 %. This could be attributed to higher nitrogen removal (199.9 kg ha^{-1}) from plots treated with PM as compared to nitrogen removal of 172.8 kg ha^{-1} from plots treated with CD (Table 9).

Table 8 shows the effect of CD, PM, NPK and level of Irrigation on soil chemical and physical properties after harvest. The results indicate that soil chemical properties and some physical properties studied were significantly responsive to CD, PM and NPK application. This is consistent with findings by Agbede *et al.* (2008), Mbah and Mbagwu, (2006), Adeniyan and Ojeniyi (2005) and Ewulo *et al.* (2007) who found that PM and CD increased soil OM, N, P, K, Ca, Mg and cation exchange significantly. Bulk density was however, not responsive to all of the soil amendments. This finding is contrary to findings by Agyenim Boateng *et al.* (2006) and Obi and Ebo (1995) who stated that application of poultry manure increased soil moisture content and reduced bulk density of the soil. This contrary finding could be due to insufficient accumulation of organic matter after only one year of application of PM and CD. Organic matter builds up upon years of application of organic manure. Application of CD, PM and NPK significantly

increased soil particle density (Table 8). The interaction of CD, PM, NPK and Irrigation significantly affected particle density as shown in Figure 9.

Table 8: The effect of CD, PM, NPK and level of Irrigation on soil physico-chemical properties after harvest

Treatments Irr. % ETc	Soil Properties							
	% N	P µg g^{-1}	K cmol kg^{-1}	Ca cmol kg^{-1}	Mg cmol kg^{-1}	ρ_b g cm^{-3}	Pore vol. %	ρ_s g cm^{-3}
70	0.110	17.63	0.464	2.205	1.45	1.477	40.25	2.4725
80	0.108	23.96	0.456	1.794	1.73	1.507	38.25	2.43F1
90	0.103	19.19	0.482	2.124	1.61	1.490	39.00	2.4438
100	0.104	19.04	0.527	2.039	1.58	1.510	38.25	2.4487
F-test	NS	*	NS	NS	NS	NS	*	NS
Lsd	0.0095	5.837	0.0808	0.445	0.67	0.0259	1.399	0.0548
CV	8.4	27.4	15.7	20.5	39.5	1.6	3.4	2.1
	Manure/Fertilizer							
Control	0.1013	5.33	0.314	1.900	1.77	1.4863	37.75	2.3887
NPK	0.0925	28.00	0.467	1.555	1.07	1.5138	39.00	2.4838
CD	0.1288	15.77	0.721	1.974	2.10	1.4900	39.00	2.4450
PM	0.1025	30.72	0.427	2.732	1.44	1.4950	40.00	2.4837
T-test	**	**	**	**	*	NS	*	**
Lsd	0.00953	5.837	0.0808	0.445	0.67	0.0259	1.399	0.0548
CV	8.4	27.4	15.7	20.5	39.5	1.6	3.4	2.1

Source: Author's Data (2015). Where NS = non-significant at $p<0.05$ and ** = highly significant at $p<0.01$ probability level; CV = coefficient of variation; LSD = Least Significant Difference between means

With the exception of phosphorus (P) and percentage pore volume none of the soil chemical and physical properties were responsive to different levels of water application. Available phosphorus was lowest at 70 % ET_c and

this can be attributed to high estimated crop removal of phosphorus as shown in Table 9. Crop removal of phosphorus was 35.1 kg ha^{-1} at 70 % ET_c which was the highest. Soil irrigated with 70 % ET_c was the most porous with 40 % pore space which facilitate infiltration of moisture and air. Percentage N content and available P of the soil were significantly ($P<0.05$) responsive to the interaction of Irrigation and CD, PM and NPK as shown in Figure 8.

Table 9: Nutrient removal by crop (Estimated)

Treatments	Soil nutrients (kg ha^{-1})		
DI	N	P	K
70	182.0	35.1	290.5
80	158.0	30.5	252.2
90	174.0	33.6	277.7
100	172.1	33.2	274.6
Manure/NPK			
PM	199.9	38.5	319.9
CD	172.8	33.3	275.9
NPK	163.8	31.5	261.0
Control	143.8	27.7	229.6

Source: Author's Data (2015)

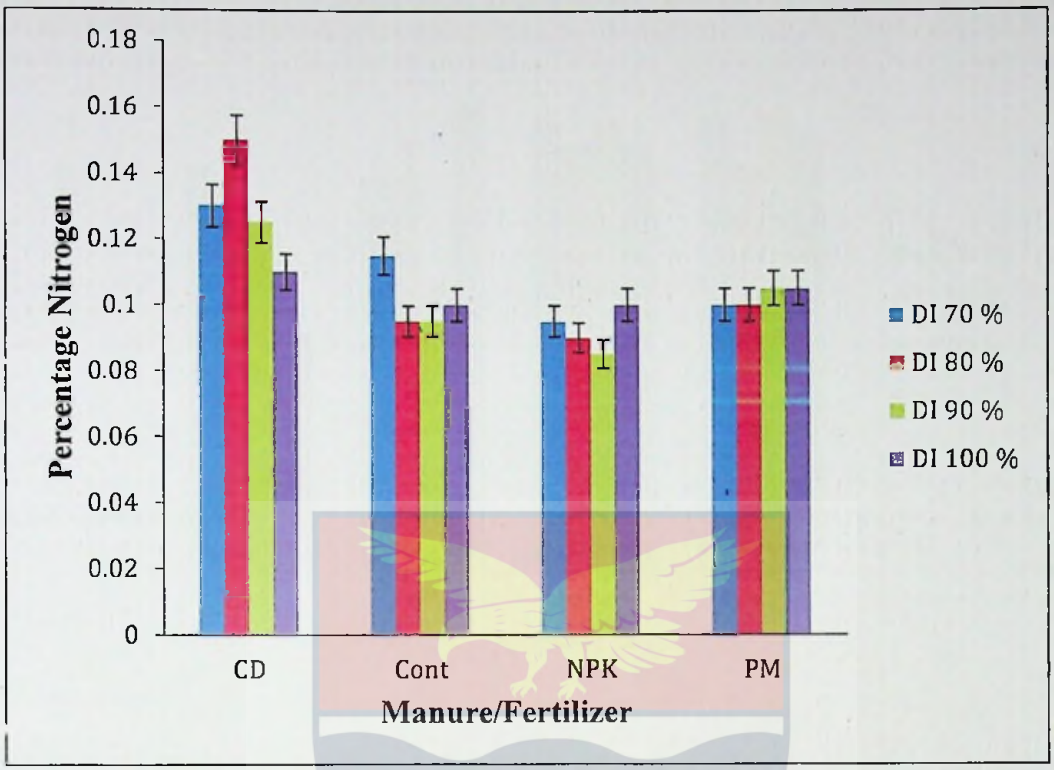


***Figure 8*: Interaction of Irrigation, CD, PM, and NPK on the percentage Nitrogen in the soil (Lsd = 0.00953)**

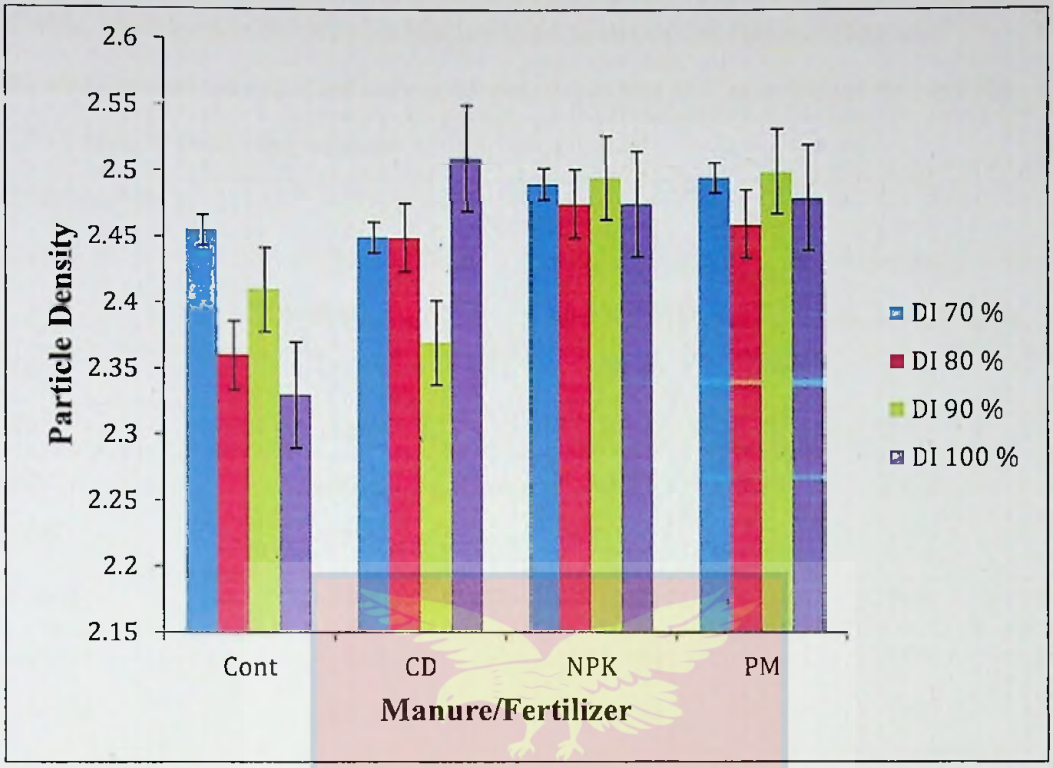


Figure 9: **Interaction of Irrigation, CD, PM, and NPK on particle density of soil (Lsd = 0.0548)**

The Effect of Irrigation, CD, PM and NPK on growth parameters of sweet potato

Sweet potato number of leaves per plant and number of branches per plant at 4 weeks after planting were not responsive to all treatments as shown in Table 10. The interaction of manure, NPK and irrigation also did not result in significant differences in the number of branches and leafs per plant. In agreement with the result of the current study, it has been reported in other studies that stem number is determined very early in the growth and development of plant (Abdissa et. al., 2012; Lynch, & Rowberry, 1997).

Table 10: Main effects of irrigation and manure on the number of branches and number of leaves of sweet potato at Cape Coast during the 2014 minor cropping season

Treatments Irr. % ETc	No. of leafs/plant Crop dev'pt stage	No. of leafs/plant Mid-season stage	No. branches/plant Crop dev'pt stage
70	15.88	23.01	2.18
80	17.03	27.22	2.58
90	14.17	22.03	2.57
100	15.03	23.84	2.22
F-test	NS	NS	NS
LSD	4.313	4.381	0.99
CV (%)	33.3	21.9	49
Manure/NPK			
PM	15.18	23.30	2.53
CD	16.63	27.15	2.28
NPK	12.84	19.49	2.50
Control	17.45	26.17	2.23
F-test	NS	**	NS
LSD	4.313	4.381	0.99
CV (%)	33.3	21.9	49

Source: Author's Data (2015). Where NS = non-significant at $p<0.05$ and ** = highly significant at $p<0.01$ probability level; CV = coefficient of variation; LSD = Least Significant Difference between means.

It has also been stated that potato average number of stem per plant is more dependent on the inherent potential of the cultivar rather than on application of inputs such as fertilizers (Peter, & Huska, 1988). Zelalem et al. (2009) thus stated that stem number may be influenced by other factors such as storage condition of tubers, genetic potential of the cultivar, number of viable sprouts

at planting, sprout damage at the time of planting and growing conditions. However, at the mid-season stage (ie. 5 weeks after planting) sweet potato number of leaves per plant was responsive to CD, PM and NPK (Table 10) but not responsive to levels of irrigation. The response was highly significant ($p<0.01$). Similar findings were made by El-Glamry (2011) who reported that vegetative growth parameters of sweet potato tend to increase with increasing application of mineral fertilizer and different forms of organic manure. Cow dung (CD) treated plots produced the highest number of leaves per plant, 27 as shown in Table 10.

Similarly the interaction between levels of irrigation and manure and NPK application significantly affected number of leaves per plant as shown in Table 11. Cow dung and 80 % ET_c (80 % CWR) interaction produced the highest number of leaves per plant 39, while NPK at full irrigation (100 % ET_c) produced the least number of leaves per plant, 17 as shown in Table 11.

Table 11: Number of leaves at mid-season stage of sweet potato as influenced by interaction effect of CD, PM, NPK and irrigation at Cape Coast during the 2014 minor cropping season

Number of leaves per plant at mid-season stage				
Treatments	Manure/Fertilizer			
Irr. % ETc	Control	NPK	CD	PM
70	29.27	20.38	19.40	23.00
80	24.73	20.53	39.87	23.73
90	23.20	19.07	27.53	18.33
100	27.47	17.97	21.80c	28.13
F-test		**		
LSD		8.763		
CV (%)		21.9		

Source: Author's Data (2015). Where ** = highly significant at $p<0.01$ probability level; CV = coefficient of variation; LSD = Least Significant Difference between means.

Table 12 shows that leaf area at 3, 4 and 5 weeks after planting were not significantly affected by the main effect deficit irrigation (DI), CD, PM and NPK. However, application of 100 % ET_c resulted in highest leaf area at 3, 4 and 5 weeks after planting (Table 12). Thus DI reduces leaf area of sweat potato which is corroborated by findings by Sarawasti et al. (2004) who observed that stem length, diameter and length, leaf area and number decreased in response to drought stress. This observation is further corroborated by Nedunchezhiyan et al. (2012) who showed that leaf area in sweet potato plants decreases as water stress increases. The reduction in leaf area and number could be attributed to physiological, biochemical and molecular changes (Reddy et al. as cited in Placide *et al.*, 2013) induced by

water stress. Consequently changes occur in the chlorophyll, reducing net CO_2 uptake by leaves resulting in reduction in photosynthetic ability of plant (Gong et al., 2005).

Table 12: Leaf Area of sweet potato plant as influenced by CD, PM, NPK and Irrigation

Treatments	Leaf Area (cm^2) Weeks after Planting		
	3	4	5
70	70.9	113.4	120.2
80	79.9	110.9	110.9
90	67.5	111.7	116.2
100	74.0	115.9	125.5
F-test	NS	NS	NS
Lsd	13.84	7.35	15.72
CV	22.7	7.8	16.0
Manure/Fertilizer			
Control	72.4	109.4	112.8
NPK	74.8	119.4	123.9
CD	75.4	112.1	121.8
PM	69.6	111.0	114.2
T-test	NS	NS	NS
Lsd	13.84	7.35	15.72
CV	22.7	7.8	16.0

Source: Author's Data (2015). Where ** = highly significant at $p<0.01$ probability level; CV = coefficient of variation; LSD = Least Significant Difference between means.

At the mid-season stage, however, the interaction of levels of irrigation and soil amendments significantly affected leaf area as shown in Table 13. Interaction of NPK and 70 % ET_c (DI 70) produced the highest leaf area,

134.6 cm^2 per plot while PM and 70 ET_c interaction produced the lowest leaf area, 90.3 cm^2 per lot at the mid-season stage.

Table 13: Leaf Area at mid-season stage of sweet potato as influenced by interaction effect of CD, PM, NPK and irrigation at Cape Coast during the 2014 minor cropping season

Leaf Area at mid-season stage (cm^2)				
Treatments	Manure/Fertilizer			
DI % ETc	Control	NPK	CD	PM
70	118.6	134.6	110.2	90.3
80	109.0	114.6	108.9	111.1
90	113.7	107.4	113.3	112.2
100	96.3	121.0	115.9	130.3
F-test		**		
LSD		14.69		
CV (%)		7.8		

Source: Author's Data (2015). Where ** = highly significant at $p<0.01$ probability level; CV = coefficient of variation; LSD = Least Significant Difference between means.

Similar to leaf area, Table 14 shows leaf area index at 3, 4 and 5 weeks after planting were not significantly affected by levels of irrigation, CD, PM and NPK.

Table 14: Leaf Area Index of sweet potato plant as influenced by CD, PM, NPK and DI

Treatments	Weeks after Planting		
	3	4	5
70	0.426	0.674	0.996
80	0.465	0.667	0.942
90	0.331	0.568	0.841
100	0.418	0.682	1.028
F-test	NS	NS	NS
Lsd	0.1975	0.2971	0.3728
CV	57.8	45.9	39.2
Manure/Fertilizer			
Control	0.440	0.671	0.941
NPK	0.412	0.678	0.958
CD	0.428	0.638	1.012
PM	0.359	0.604	0.895
T-test	NS	NS	NS
Lsd	0.1975	0.2971	0.3728
CV	57.8	45.9	39.2

Source: Author's Data (2015). Where NS = Non significant at $p<0.05$ probability level; CV = coefficient of variation. LSD = Least Significant Difference between means

The Effect of DI, CD, PM and NPK on yield parameters of sweet potato

Water stress (reduced irrigation) did not significantly influence vine yield and total yield (Table 15). However, 100 % ET_c resulted in the highest vine yield, 20.25 t ha^{-1} while 70 % ET_c resulted in the lowest vine yield, 17.88 t ha^{-1}. Thus irrigation reduced growth of leaves and branches. This could be as a result of osmotic stress created by water deficit which causes water to be

removed from the cytoplasm of cells (Bartels, & Sunkar, 2005). The osmotic stress thus created inhibits the growth of leaves and stems of plants (Placide et al., 2013). Conversely irrigation at 70 % ET_c resulted in the highest total yield (33.83 tons ha^{-1}) while 100 % ET_c produced the lowest total yield (33.09 t ha^{-1}).

Table 15: Main effects of DI, CD, PM and NPK on vine yield, tuber yield and total yield per hectare of sweet potato at Cape Coast during the 2014 minor cropping season

Treatments Irr. % ETc	Tuber Yield tons ha^{-1}	Vine Yield tons ha^{-1}	Total Yield tons ha^{-1}
70	15.95	17.88	33.83
80	11.23	19.16	30.39
90	13.50	19.96	33.46
100	12.84	20.25	33.09
F-test	**	NS	NS
LSD	1.672	3.887	5.492
CV (%)	15.0	24.1	19.5
Manure/Fertilizer			
PM	15.85	22.59	38.44
CD	13.35	19.89	33.24
NPK	12.82	18.62	31.44
Control	11.50	16.16	27.66
F-test	**	*	**
LSD	1.672	3.887	5.492
CV (%)	15.0	24.1	19.5

Source: Author's Data (2015). Where NS = non-significant, ** = highly significant at $p<0.01$ probability level and * = significant at $p<0.05$ probability; CV = coefficient of variation; LSD = Least Significant Difference between means

OFSP tuber yield was responded positively response to irrigation levels (water stress). Irrigation at 70 % ET_c produced the highest yield (15.95 t ha^{-1}) as compared to 12.84 t ha^{-1} at 100 % ET_c. This could be beneficial in the sense that lower application of water saves water for other uses. Similar finding has been reported by Lewthwaite and Triggs (2012) that sweet potato cultivar "Toka Toka Gold" had a positive response to drought, producing a higher yield of good quality roots under water stress. This unique characteristic of drought tolerance of OFSP that enabled positive response to water stress can be attributed to the genotype of sweet potato that has efficient mechanisms to control the negative effect of water stress. According to Loebenstein and Thottappilly (2009) the root system of sweet potato has a big surface that allows easy access to available soil water. Additionally sweet potato is very rich in antioxidants such as vitamin C, carotenoids and polyphenols (Lin et al., 2006). They explained, these antioxidants have powerful abilities to scavenge reactive oxygen species (ROS) which are the major cause of reduction of photosynthesis ability and growth under drought stress. It was further explained ROS are mainly hydrogen peroxide (H_2O_2) and superoxide (O_2^-) radicals which cause oxidation of lipid, protein of cell membrane and cell nucleic acid denaturing the cells. Hence the high antioxidant content of sweet potato provides a powerful mechanism to combat the negative effect of water stress. Another drought control mechanism of sweet potato is the accumulation of organic metabolites of low molecular weight collectively known as compatible solutes (Bohnert *et. al.*, 1995). Examples of these metabolites are amino acids, betaines and trehalose. They

accumulate in cells and balance the osmotic difference between cells and surroundings. They are said to stabilize proteins and cell membranes against the denaturing effect of stress on cellular function. Compatible metabolites help cells to retain water without disturbing normal cell function (Yancey *et al.*, 1982).

The interaction of PM, CD, NPK and Irrigation levels significantly affected vine yield, tuber yield and total yield (Tables 16, 17 and 18). Table 16 shows that unfertilized plots gave the highest vine yield at 70 % ET_c irrigation. Vine yields from plots amended with PM decreased with decreasing water application. CD treatment and 80 % ET_c interaction gave the highest vine yield (28.93 t ha^{-1}) while control and 80 % ET_c interaction gave the lowest vine yield (15.12 t ha^{-1}).

Table 16: Interaction effect of CD, PM, NPK and Irrigation on sweet potato vine yield at Cape Coast during the 2014 main cropping season.

	Vine Yield (Tons ha^{-1})			
Treatments	Manure/Fertilizer			
DI % ETc	Control	NPK	CD	PM
70	20.04	16.29	15.02	20.18
80	10.18	15.12	28.93	22.43
90	15.49	23.81	15.65	24.88
100	18.92	19.27	19.97	22.86
F-test		**		
LSD		7.774		
CV (%)		24.1		

Source: Author's Data (2015). Where ** = highly significant at $p<0.01$ probability level; CV = coefficient of variation; LSD = Least Significant Difference between means.

Table 17 shows the interaction effect of irrigation and manure application. The highest root yield from NPK, PM treated and control plot produced the highest yield at 70 % ET_c irrigation. PM and 70 % ET_c interaction resulted in the highest root yield of 20.3 t ha^{-1} which was 24.6 % higher as compared to control (no manure) and 70 % ET_c interaction (Table 17). However PM with full irrigation (100 % ET_c) produced 13.38 t ha^{-1} which was only 18.4 % higher compared to no manure (control) with full irrigation. The results is in agreement with findings by Hirich et al. (2014) who indicated that organic amendment of 10 t ha^{-1} significantly ($P \leq 0.05$) increased pea seed yield by 41 % under water stress and by 25 % under full irrigation. Thus it can be concluded that soil organic amendment improved significantly yield better under deficit irrigation conditions than under full irrigation.

Table 17: Interaction effect of CD, PM, NPK and Irrigation on tuber yield per hectare of sweet potato at Cape Coast during the 2014 minor cropping season.

Tuber Yield per hectare (t ha^{-1})				
Treatments	Manure/Fertilizer			
DI % ETc	Control	NPK	CD	PM
70	16.29	14.84	12.38	20.30
80	7.89	10.43	12.95	13.66
90	10.53	14.37	13.01	16.07
100	11.30	11.64	15.05	13.38
F-test		**		
LSD		3.344		
CV (%)		15.0		

Source: Author's Data (2015). Where ** = highly significant at $p<0.01$ probability level; CV = coefficient of variation; LSD = Least Significant Difference between means

Contrarily, NPK + 70 % ET_c and CD + 70 % ET_c produced reduced root yield as compared to Control + 70 % ET_c (Table 16). However, NPK + 70 % ET_c gave the highest root yield of 14.84 t ha^{-1}. Table 19 also shows that for CD treated plots root yield was highest (15.05 t ha^{-1}) at 100 % ET_c (full irrigation) and lowest (12.38 tons ha^{-1}) at 70 % ET_c. Root yield increased with increasing water application for CD, though differences were not significant. This could be attributable to too much sodium (from CD) for the healthy growth of crop under dry or water stress conditions. It could be that at full irrigation (100 % ET_c) the buildup of sodium from CD was prevented by washing away sodium salt. Conversely, for PM treated plots differences in yield were significant and highest at 70 % ET_c, and lowest at 100 % ET_c (Table 19). Thus amending

the soil with PM improved significantly yield better under reduced irrigation conditions than under full irrigation.

The water use efficiency (WUE) or crop water productivity (WP) took the same trend of root tuber yield. Water use efficiency (WUE) by crops on the amended plots was highest at application of 70 % ET_c as shown in Table 19. The WUE values were 12.1 kg m-3 for PM with 70 % ET_c, 7.4 kg m^{-3} for CD with 70 % ET_c, 8.8 kg m^{-3} for NPK with 70 % ET_c and 9.7 kg m^{-3} for Contorl with 70 % ET_c. The lowest WUE values were by application of full irrigation (100 % ET_c) with all the soil treatments. Thus WUE was highest at the minimum water application whilst full irrigation resulted in the lowest WUE. From Table 19, WUE differences were highly significant. The result agrees with finding by Zwart and Bastiaansen, (2004) and Fan *et al.* (2005) which indicated that WP or WUE increases under DI, relative to its value under full irrigation for many crops. It has been explained that irrigation increases crop ET linearly to a maximum point where maximum yield is achieved and any additional water does not add to yield but lost. At the maximum point the linear relations between irrigation and ET becomes curvilinear. The amount of water needed to ensure maximum yields depends on the uniformity of irrigation. Fereres *et al.* (1993) indicated in a simulation that irrigation depth required for maximum yield increased from 1.3 m to 2.0 m, when the coefficient of uniformity decreased from 90 % to 70 %. It was thus explained that irrigation efficiency decreases and water losses are high when uniformity is low (Fereres, & Soriano, 2007). By contrast, in DI the level of water application is relatively low and water losses are lower. Thus,

under DI WP or WUE is higher than that under full irrigation (Fereres, & Soriano, 2007).

In addition to the factors associated with the disposition of irrigation water, WUE is also affected by the yield response to irrigation. Yield of many crops is also linearly related to ET (Steward, & Nielson 1990; Howell, 2001). The design of a DI programme must be based on knowledge of this response. Yield response also varies with location, stress patterns, cultivar, planting dates, and other factors. However, when the yield decline, in relative terms, is less than the ET decrease, WUE under DI increases relative to that under full irrigation.

Table 18: Interaction effect of CD, PM, NPK and Irrigation on sweet potato total yield at Cape Coast during the 2014 minor cropping season.

Treatments	Total Yield (t ha^{-1}) Manure/Fertilizer			
DI % ETc	Control	NPK	CD	PM
70	39.66	31.13	27.42	40.48
80	18.07	25.55	41.89	39.26
90	31.19	38.18	28.66	40.95
100	30.21	35.08	35.32	36.34
F-test		**		
LSD		10.984		
CV (%)		19.5		

Source: Author's Data (2015). Where ** = highly significant at $p<0.01$ probability level; CV = coefficient of variation; LSD = Least Significant Difference between means

Table 19: The effect of CD, PM, NPK and Irrigation on yield and water use efficiency of sweet potato.

Manure/ Fertilizer	Irr (% ET_c)	Water applied m^{-3}	Yield (tons ha^{-1})	WUE (kg m^{-3})
PM	70	1922.2	20.30	10.56
	80	2196.8	13.66	6.21
	90	2471.4	16.07	6.50
	100	2746	13.38	4.87
CD	70	1922.2	12.38	6.44
	80	2196.8	12.95	5.89
	90	2471.4	13.01	5.26
	100	2746	15.05	5.48
NPK	70	1922.2	14.84	7.72
	80	2196.8	10.43	4.74
	90	2471.4	14.37	5.81
	100	2746	11.64	4.23
Control	70	1922.2	16.29	8.47
	80	2196.8	7.89	3.59
	90	2471.4	10.53	4.26
	100	2746	11.30	4.11
F test				**
Lsd				1.672
CV				15.0

Source: Author's Data (2015) Where ** = highly significant at $p<0.01$ probability level; CV = coefficient of variation; LSD = Least Significant Difference between means.

Conclusions

At the initial stage of the study, soil chemical properties studied were all increased by PM, CD and NPK even though differences were not significant. However, analysis of the soil after harvest indicated that PM, CD and NPK application increased N, P, K, soil particle density and pore volume. Reduced irrigation (water stress) decreased nitrogen, calcium and potassium content of the soil while it increased phosphorous and magnesium content of the soil.

Irrigation did not influence significantly soil physical properties studied i.e. bulk density, pore volume and particle density. Water stress (DI) reduced growth of leaves and branches. Irrigation with 70 % ET_c increased soil pore volume (40 % pore volume the highest), root yield and water use efficiency (WUE). Poultry manure, cow dung and NPK improved root yield, and PM gave the highest yield. Amending soil with PM and NPK improved significantly root yield better under reduced irrigation (70 % ET_c) conditions than under full irrigation.

CHAPTER FOUR

PRODUCTIVITY AND QUALITY OF ORANGE FLESHED SWEET POTATO (*IPOMOEA BATATAS* L) AS AFFECTED BY IRRIGATION, MANURE AND NPK APPLICATION

Introduction

Globally, 102 million tonnes of sweet potato is produced with 12.1 t ha^{-1} as an average yield (Food and Agriculture Organisation Statistics (FAOSTAT, 2010). It is one of the most widely grown root crops in Sub-Saharan Africa (Low et al., 2009). According to FAO (2006) statistics, West African Sweet potato production stood at 2.516 million tonnes. In Ghana, farmers plant 73,400 ha of sweet potato yearly that comes after cassava and yam in order of importance (FAO (FAOSTAT), 2010). In 2010 Center of International Potato (CIP) began operating in Ghana with a goal of reaching an estimated 500,000 households with nutritious sweet potato by 2020. However constraints to improved productivity and incomes for smallholder sweet potato farmers in Sub-Saharan Africa including Ghana includes: the lack of timely access to virus and pest-free planting material, lack of improved varieties adapted to local conditions, damage to tubers caused by the sweet potato weevils, particularly in drier production areas, little knowledge and use of better agronomic practices and inappropriate storage systems (Low et al.). There are also critical challenges to increasing sweet potato availability which includes; poor crop management strategies such as crop-water management regimes, soil nutrient regimes and inefficient technologies to reduce perishability. It has

been stated that sweet potato is sensitive to water stress. Hirich et al. (2014) observed that dry matter yield was significantly affected by deficit irrigation, while harvested yield was affected significantly ($P < 0.05$) by both deficit irrigation and organic manure.

The main problems in postharvest handling of sweet potato roots include the loss of the skin from the surface of the roots, which is referred to as 'skinning'. The skin can also be lost through cuts. Skinning and cuts (skin damage) leads to an increased rate of moisture loss, resulting in weight loss and shrinkage of the root. Skin damage also increases susceptibility to pathogen attack, lowers the value of the crop and economic profits for the farmers.

In recent times organic farming has received tremendous attention worldwide (Stolze and Lampkin, 2009). There is widespread belief that organic farming improves the environment, increases the quality of food products and the health of consumers (Lundegardh and Martensson, 2003). The use and misuse of chemical fertilizers has resulted in pollution of farmlands, surface and ground water, the entire ecosystem and can adversely affect the health of animals and humans. In response to environmental concerns several countries throughout the world are considering the use of organic manure in the production of crops.

Smith-Spangler et al. (2012) indicated that organic produce contain 30 % lower pesticide residues than conventional foods. However, they concluded that the bacteria that cause food poisoning were equally present in both types of foods.

In spite of the lack of strong evidence in literature that organic foods are significantly more nutritious than non-organic foods most producers and consumers worldwide are currently moving towards organic production of crops due to discovered and envisaged advantages. Also, there have been several research efforts to improve sweet potato root and vine yield but there is little information, if at all there is any, on comparative study of organic, inorganic fertilizers and deficit irrigation in improving quality determinants of orange fleshed sweet potato. There is not much information on the effect of irrigation, manure and NPK on quality traits such as storage root dry matter yield, sprouting, decay, weevil infestation, and marketable yield of Orange Fleshed sweet potato.

To solve this problem, the present work, therefore, evaluated the effectiveness of organic, inorganic fertilizer and irrigation on quality traits of OFSP. This study examined the effect of irrigation treatments, manure and NPK application on the response patterns of marketable root yield, percentage decay, percentage weevil infestation, percentage skin damaged, percentage sprouting and root dry matter content of OFSP in the coastal savanna zone of Ghana.

Materials and Methods

Sample collection

A field experiment was carried out between October 2014 and January 2015 planting season at the Teaching and Research Farm of University of Cape Coast in the Central Region of Ghana as described in Chapter 3 of this

thesis. Sampled plants of OFSP were harvested and roots from each plot were examined for quality analysis.

Quality determination of harvested roots

Harvested roots were examined for cracks, sprouting, and decay and weevil infestation. Root yield and marketable yield were also determined.

Data collection and analysis

All data collected were subjected to analysis of variance using Gen-stat Discovery software version 4.0. For treatments that were significant, mean separation was done using the Least Significant Difference (Lsd) test at 5 % probability level.

The following data were collected:

1. Yield

    a. Root yield and quality analyses

    b. All plots were harvested at 97 days after planting. Storage roots were graded into two size classes and weighed. Tubers weighing 100 g and above from 20 sampled plants were considered. Total yield per plot was determined by multiplying the total number of plants (20) by the yield per plant. The yield per plot was projected to per hectare basis

    c. Root yield was determined as total root yield per plot projected to per hectare basis

    d. Economic Yield: marketable yield excluded small roots (<100 g), misshapen and damaged roots. Mean marketable root

weight per plot were determined and projected to per hectare basis.

$$Marketable\ yld = \frac{wt\ of\ marketable\ roots}{Total\ root\ wt\ per\ plot} x\ ha \quad 15$$

e. Jumbo Tuber Yield: Large size roots or jumbo sized roots (>350 g) were graded and weighed. Mean jumbo sized root weight per plot were determined and projected to per hectare basis.

f. $Jumbo\ root\ yld = \frac{Wt\ of\ roots>350\ g}{Total\ root\ yld\ per\ plot} x\ ha$ 16

g. Small tuber yield: tubers less than 100 g were considered small and not marketable. Mean small tuber yield per plot were determined and projected to per hectare basis.

h. $Tuber\ per\ plant = \frac{Number\ of\ roots}{Number\ of\ plants} x\ ha$ 17

i. Weight per root $= \frac{Total\ weight\ of\ roots}{Number\ of\ roots}$ 18

j. Dry matter yield was determined by drying a composite 250 g sample to a constant weight in an oven for 48 h at > 65 °C and re-weighing. Dry matter content was determined as in Equation 19.

$$Dry\ matter\ (\%)\ \frac{Weight\ of\ sample\ after\ drying}{Weight\ of\ sample\ before\ drying} \times 100 \quad 19$$

2. Cracking of tubers in the field

Tubers from sampled plants were examined for cracks. Roots with 5 % of surface having cracks were considered cracked. Percentage cracked roots was determined as in Equation 20.

$$Percentage\ cracked\ roots = \frac{No.of\ cracked\ roots}{Total\ No.of\ roots}\ x\ 100 \quad 20$$

3. Incidence of sprouting in the field

Tubers from sampled plants from each plot were counted and examined for sprouting and percentage sprouting was determined as in equation 21.

$$Percentage\ sprouted\ roots = \frac{No.of\ sprouted\ roots}{Total\ No.of\ roots}\ x\ 100 \quad 21$$

4. Degree of Damage during Harvesting

Tubers with 5 percent or more surface cut, bruised or skinned were considered damaged. The level of damage was determined by using equation 22.

$$Percentage\ damaged\ roots = \frac{Damaged\ roots\ (kg)}{Total\ yield\ (kg)}\ x\ 100 \quad 22$$

5. Insect Infestation in the Field

Tubers from each plot were examined for weevil infestation. Roots with 5 % or more of surface area infestation were considered insect (weevil) infested. The level of insect infestation was determined by using Equation 23.

$$Percentage\ insect\ infestation = \frac{No.of\ infested\ \text{roots}}{Total\ No.of\ \text{roots}}\ x\ 100 \quad (23)$$

6. Degree of Decay in the Field

Tubers from sampled plants from each plot were counted and examined for decay. Roots with decay regardless of the spread were considered rotten and level of decay was determined as in Equation 24.

$$Percentage\ decayed\ tubers = \frac{No.of\ decayed\ \text{roots}}{Total\ No.of\ \text{roots}}\ x\ 100 \quad 24$$

7. Rodent Attack

Tubers were examined for rodent attack and roots with rodent attack regardless of spread were considered eaten by rodents. The extent of rodent attack was determined as in Equation 25.

$$Percentage\ rodent\ attack = \frac{Tubers\ rodents\ attacked}{Total\ No.\ of\ \text{roots}}\ x\ 100 \quad 25$$

Statistical analysis

The data collected were subjected to statistical analysis using Analysis of Variance (ANOVA). The data obtained were analyzed using the GenStat Discovery Edition 4.0 statistical package. Least Significant Difference (LSD) was used to separate the means at 5 % level of probability.

Results and Discussion

The effect of CD, PM, NPK and Irrigation on productivity of OFSP

Table 20 shows that marketable yields or economic yields are significantly responsive to deficit irrigation. Marketable or economic yield decreased from 10.21 t ha^{-1} to 8.57 t ha^{-1} when irrigation amount reduced from 100 % ET_c to 80 % ET_c. However, marketable yield increased to 13.01 t ha^{-1} when water application was further reduced to 70 % ET_c as shown in Table 20. The finding is supported by Thompson *et al.* (1992) who showed that marketable yields of sweet potato were slightly reduced when water application was less than 76 % but substantially reduced when irrigation was greater than 76 % of pan evaporation. Marketable or economic yield was significantly improved by application of PM, CD and NPK. Application of

PM, CD and NPK yielded 11.94 t ha^{-1}, 11.04 t ha^{-1} and 10.28 t ha^{-1}, respectively which significantly ($P<0.01$) improved marketable yields as compared to the control (Table 20). Thus marketable or economic yields were increased by 40.96 %, 30.34 % and 21.36 % by PM, CD and NPK, respectively as compared to the control experiment as shown in Table 20. This could be attributable to higher concentration of nitrogen in PM, CD and NPK fertilized plots.

Table 20: Main effects of irrigation and fertilization on Economic yield of sweet potato at Cape Coast during the 2014 minor cropping season

Treatment				
Irr. % ET_c	Marketable yld t ha^{-1}	Small root yld t ha^{-1}	Root yld t ha^{-1}	Marketable yld %
70	13.01	18.07	15.95	41.85
80	8.57	24.68	11.23	25.78
90	9.93	18.05	13.50	35.49
100	10.21	23.93	12.84	29.91
F-test	**	**	**	**
LSD	1.617	4.671	1.672	
CV (%)	7.2		15.0	
Fertilization				
PM	11.94	23.33	15.85	33.85
CD	11.04	22.06	13.35	33.35
NPK	10.28	23.91	12.82	30.06
Control	8.47	15.43	11.50	35.43
F-test	**	**	**	**
LSD	1.617	9.341	1.672	
CV (%)	7.2		15.0	

Source: Author's Data (2015) NS = non-significant and ** = highly significant at $p<0.01$ probability level; CV = coefficient of variation; LSD = Least Significant Difference between means

The interaction of irrigation and soil amendments significantly ($P<0.05$) affected marketable yield of roots (Table 21). PM and 70 % CWR interaction resulted in the highest marketable yield of 16.34 tons ha^{-1} (Table 21) while the interaction of 80 % ET_c and the Control yielded 5.09 t ha^{-1}, which was the lowest marketable yield. Thus DI increased marketable yield for PM while DI reduced marketable yield for CD. PM and 100 % CWR interaction resulted in the lowest yield (9.82 t ha^{-1}) while PM and 70 CWR and resulted in the highest marketable yield (16.34 t ha^{-1}) as shown in Table 21.

Table 21: Interaction effect of manure and irrigation on marketable yield of sweet potato at Cape Coast during the 2014 minor cropping season

	Marketable yield t ha^{-1}			
Treatments	Fertilization			
Irr. % ET_c	Control	CD	NPK	PM
70	13.56	10.45	11.67	16.34
80	5.09	10.61	7.47	11.13
90	7.07	10.42	11.77	10.47
100	8.14	12.67	10.22	9.82
F-test		*		
LSD		3.324		
CV (%)		20.4		

Source: Author's Data (2015) Where * = significant at $p<0.05$ probability level; CV = coefficient of variation; LSD = Least Significant Difference between means

On the contrary, CD and 100 % CWR gave the highest marketable yield (12.67 tons ha^{-1}) while CD and 70 % CWR yielded 10.45 t ha^{-1} (Table 21). For the control treatment, reduced water application resulted in reduced

marketable yield till 70 % CWR when marketable yield significantly increased to 13.56 t ha^{-1} (Table 21). Marketable yields were not significantly different among 70 CWR, 90 CWR and 100 CWR for NPK fertilization. However, 80 % CWR and NPK interaction resulted in significantly lower marketable yield (7.47 t ha-^{1}).

Small root yield (unmarketable yield) was highly significantly ($p<0.01$) affected by irrigation and fertilization (Table 20). DI (70 % CWR) produced highly significantly ($P<0.01$) lower unmarketable yield (18.07 t ha^{-1}) as compared to irrigation at 100 CWR which yielded (23.93 t ha^{-1}) as shown Table 20. It can thus be stated DI at 70 % ET_c results in reduced unmarketable yield and increased marketable yield. This assertion is shown in Table 20 where 100 % ET_c yielded 29.91 % marketable roots while 70 % ET_c yielded 41.85 % marketable roots. The Control experiment significantly ($P<0.01$) produced lower amount of unmarketable roots (15.43 t ha^{-1}) as compared to PM, CD and NPK fertilization (Table 20). The Control also gave the lowest total yield (11.50 t ha^{-1}). NPK fertilization produced the highest unmarketable root yield (23.91 t ha^{-1}) which was 69.9 % of the total yield (Table 20).

Table 22 shows the effect of interaction of manure, NPK and irrigation on unmarketable yield (small root yield). The effect was highly significant ($p<0.01$). PM and 100 CWR produced the highest unmarketable root (38.35 tons ha^{-1}) while PM and 70 % CWR reduced unmarketable yield by 48.7 % to 19.66 t ha^{-1}. Thus it can be suggested that, to reduce the production of

unmarketable ORFSP roots, PM fertilization should be irrigated with less than 100 % ET_c (CWR).

Table 22: Interaction effect of manure and irrigation on small root yield of sweet potato at Cape Coast during the 2014 minor cropping season

	Small root yield t ha^{-1}			
Treatments	Fertilization			
DI % ETc	Control	CD	NPK	PM
70	16.05	15.94	20.65	19.66
80	27.22	17.73	36.07	17.71
90	25.22	12.16	17.20	17.61
100	27.17	15.92	14.30	38.35
F-test		**		
LSD				
CV (%)				

Source: Author's Data (2015) Where ** = highly significant at $p<0.01$ probability level; CV = coefficient of variation; LSD = Least Significant Difference between means

NPK and 100 % ET_c interaction resulted in the minimum unmarketable root yield (14.3 t ha^{-1}) while NPK and 80 % ET_c interaction produced the highest unmarketable root yield (36.07 t ha^{-1}). The Control and 70 % ET_c produced the lowest amount of unmarketable tubers (16.05 t h^{-1}) while Control and 100 % ET_c produced 27.17 t h^{-1} which was significantly higher. Thus for soils without amendment, reducing water application to 70 % ET_c results in reduced production of small unmarketable roots and increased marketable yield (Tables 21 and 22). This could be attributed to reduced number of roots

development as a result of deficit water application (Bourke, 1989; Pardales et al., 2000).

From Table 23, number of roots per plant was responsive to irrigation, manure and NPK application. Significant differences ($P<0.05$) in number of tubers per plant were observed between different levels of water application. The highest number of roots per plant (3.91) was recorded at 70 % ET_c. However, it was not significantly higher than the number of roots per plant at 100 % CWR and 90 % CWR but significantly higher than 80 CWR (3.10). The increased number of roots at the lower level of water application (70 % ET_c) is supported by Hirich et al. (2014) who stated that deficit irrigation when applied during vegetative growth stage could stimulate root development, increase water and nutrient uptake and subsequently increase the yield. It is therefore suggestive that many more roots of OFSP roots can be produced by reducing water application to 70 % ET_c. From Table 23, PM treated plots produced the highest number of roots per plant (4.22) which was significantly ($p<0.05$) higher than yields per plant from CD (3.39) and NPK (3.35) treated plots. This is consistent with findings by Hartemink (2003) and Sowley et al. (2015) which showed that sweet potato yields were higher when organic manure (PM) was applied as compared to NPK application. However, root count per plant from the Control were not significantly different from PM fertilization. This is contrary to the findings by Sowley et al. (2015) which showed that PM fertilization produced more roots per plant than NPK and control. However, this result is in conformity with the finding of Parwada et al. (2011) who found insignificant root counts per plant of sweet potato in

response to PM manure applied at planting. They suggested that tuberous root number development from a plant is highly dependent on the genetic make-up of a given plant rather than fertilizer application.

Table 23: Main effects of irrigation and fertilization on Root per plant, Jumbo tuber yield, weight per tuber and dry matter content of sweet potato at Cape Coast during the 2014 minor cropping season

Treatment				
Irr % ET_c	Root per plant	Jumbo yld t ha^{-1}	Weight per root (kg)	Dry matter cont. (%)
70	3.91	7.57	0.1983	20.37
80	3.10	4.19	0.2983	21.24
90	3.83	6.11	0.1988	20.84
100	3.74	4.69	0.211	21.02
F-test	*	**	NS	NS
Lsd	0.628	1.834	0.03858	1.188
CV (%)	20.7	39	22.4	6.8
Fertilization				
PM	4.22	7.35	0.2026	21.59
CD	3.39	5.59	0.2123	19.68
NPK	3.35	5.57	0.2157	20.61
Control	3.61	4.05	0.1969	21.58
F-test	*	**	NS	**
Lsd	0.628	1.834	0.03858	1.188
CV (%)	20.7	7.2	22.4	6.8

Source: Author's Data (2015) Where NS = non-significant and ** = highly significant at $p<0.01$ probability level; CV = coefficient of variation; LSD = Least Significant Difference between means

The effect of irrigation level on jumbo root yield was highly significant. DI (70 % ET_c) resulted in the highest jumbo tuber yield (7.57

tons ha^{-1}) which is 61.4 % higher as compared to yields from treatments that received 100 % ET_c (4.69 tons ha^{-1}). It is therefore suggested that larger size tubers could be produced by reducing water application to 70 % ET_c. Treatments that received 80 % ET_c gave the lowest jumbo yield (4.19 tons ha^{-1}) and were not significantly different from results from 100% ET_c treatment. Jumbo yield from 90 % ET_c treatment (6.11 tons ha^{-1}) was, however, not significantly different from 70 % ET_c. Jumbo yield was highly responsive to soil amendment with PM, CD and NPK (Table 23). PM treated plots yielded 7.35 tons ha^{-1} which was the highest jumbo root yield and was 81.5 % higher than yield from control plots (4.05 tons ha^{-1}). CD and NPK treated plots yielded 5.59 tons ha^{-1} and 5.57 tons ha^{-1}, respectively which were higher but not significantly different from yield from control plots.

OFSP weight per root was not responsive to irrigation level, CD and NPK application (Table 23). No significant differences were observed in weight per root among the levels of water application. However 70 % ET_c yielded the lowest weight per root (0.1983 kg) which is consistent with findings by Bourke (1989) and Pardales et al. (2000). They stated that water deficit results in reduced size of sweet potato roots. Similarly no significant differences were observed in weight per root among the different types of soil amendment. However, NPK produced roots had the highest average weight (0.2157 kg) as compared to CD (0.2123 kg), PM (0.2026 kg) and the control (0.1969 kg). This is in line with findings that inorganic fertilizers produce larger roots while number of roots decreases (FAO, 2005; Sowley et al., 2015). The control produced the lowest weight per root. The interaction of

irrigation, CD, PM and NPK also had no significant ($p<0.05$) effect on weight per tuber.

Table 24: Soil chemical properties as influenced by the application of CD, PM and NPK

Treatments	% N	P μg g^{-1}	K cmol kg^{-1}
Control	0.11	24.19	0.41
NPK	0.12	64.84	0.54
CD	0.14	38.15	0.99
PM	0.13	65.37	0.53

Source: Author's Data (2015)

Dry matter accumulation was not significantly influenced by level of irrigation (Table 23). However, DI (70% ET_c) produced the lowest dry matter content (20.37 %) which is consistent with work done by Pardales et al. (2000) who stated that drought condition reduces the formation and growth of roots and dry matter accumulation. Manure and NPK application, however, significantly affected dry matter content of roots (Table 23). CD fertilization produced the lowest dry matter content (19.68 %) while PM gave the highest dry matter yield (21.59 %) which was not significantly different from NPK and the Control.

The interaction of irrigation and fertilization had no significant ($p<0.05$) effect on root count per plant (Figure 10). PM and 70 % ET_c interaction resulted in the highest root count per plant (5.24) while NPK and 80% ET_c gave the lowest root count per plant (2.77).

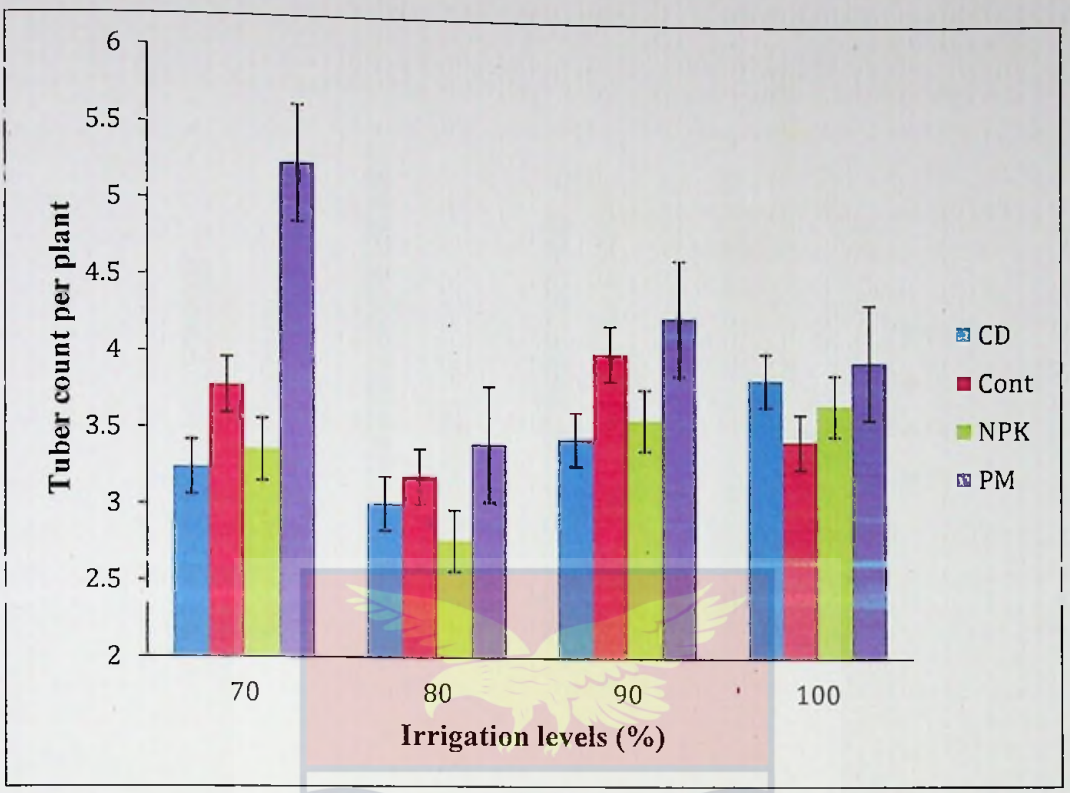


***Figure 10*: Interaction effect of CD, PM, NPK and irrigation level on number of roots per plant (Lsd = 0.628)**

The interaction of CD, PM, NPK and irrigation level had a significant ($p<0.05$) effect on jumbo root yield (Figure 11). PM and 90 % ET_c interaction gave the highest jumbo yield of 10.06 t ha^{-1} while Control and 80% ET_c interaction resulted in the lowest jumbo yield (0.82 t ha^{-1}). For CD, NPK and Control the interaction with 70 % ET_c resulted in 6.47, 7.37 and 8.3 t ha^{-1} jumbo roots respectively which were the highest within each treatment.

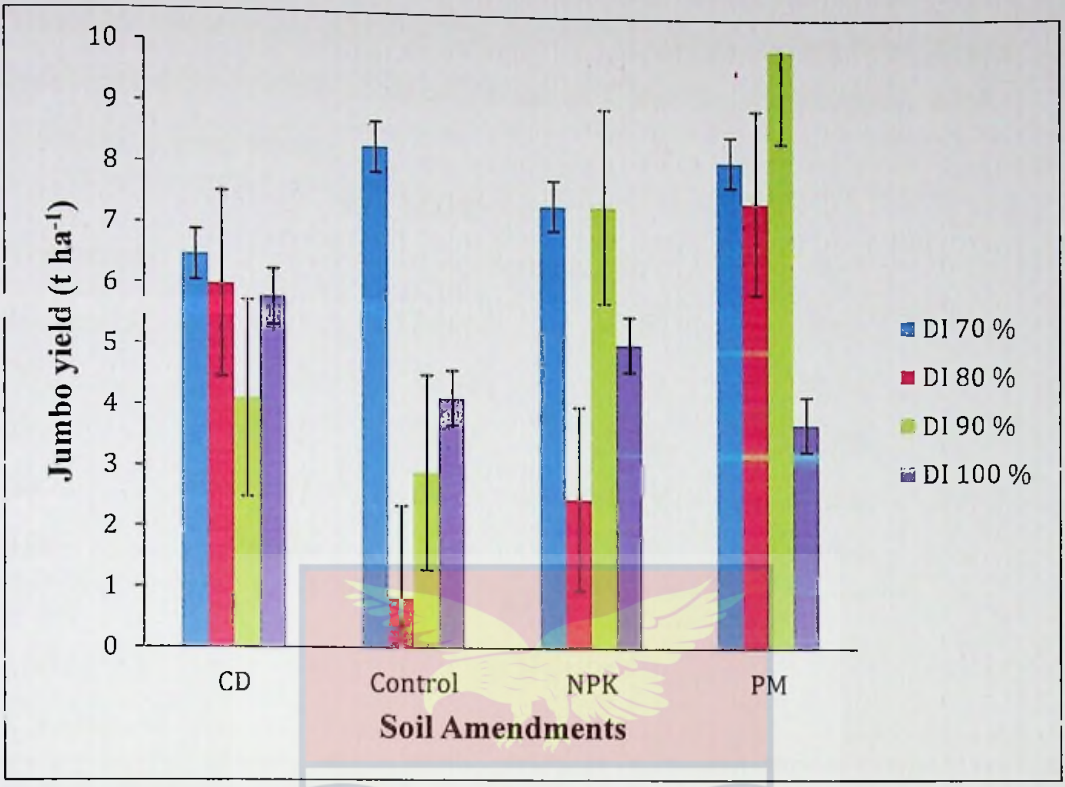


***Figure 11*: Interaction effect of CD, PM, NPK and irrigation level on jumbo root yield per hectare of sweet potato at Cape Coast during the 2014 minor cropping season (Lsd = 1.834)**

The interaction of manure and irrigation level significantly ($p<0.01$) affected dry matter yield as shown in Table 25. CD and 100 % ET_c interaction produced the lowest dry matter (18.59 %) while CD and 70 % ET_c produced 21.62 % dry matter which was the highest for CD fertilization. Conversely PM and 70 % ET_c interaction produced 20.14 % dry matter the lowest while PM and 100 % ET_c produced the highest dry matter (23.48 %) for PM fertilization. NPK and irrigation interaction effect on dry matter production was similar to PM and irrigation interaction.

Table 25: Interaction effect of CD, PM NPK and irrigation level on dry matter content of roots of sweet potato at Cape Coast during the 2014 minor cropping season

	Dry Matter Content			
Treatments	Fertilization			
DI % ETc	CD	Control	NPK	PM
70	21.62	20.38	19.35	20.14
80	18.95	24.15	20.28	21.58
90	19.57	20.88	21.74	21.16
100	18.59	20.9	21.09	23.48
F-test		**		
LSD		2.376		
CV (%)		6.8		

Source: Author's Data (2015)

The effect of CD, PM, NPK and Irrigation on quality of OFSP in the field

Root cracking in the field was not responsive to irrigation levels and soil amendments. Seventy percent CWR (70 % ET_c) resulted in the lowest (1.86 %) cracked roots (Table 26). It was however not significantly different from root cracking at 80 % CWR, 90 % CWR and 100 % CWR which recorded 2.54 %, 2.94 % and 1.88 % root cracking, respectively. Similarly soil amendments did not significantly affect tuber cracking (Table 26).

Table 26: Main effects of deficit irrigation and manure on percent damaged roots, percent root cracked and percent weevil infestation of sweet potato at Cape Coast during the 2014 minor cropping season

Treatments				
Irr. % ETc	Percent root cracked	Percent root damaged	Percent weevil infestation	Moisture content %
70	1.86	13.2	9.1	79.63
80	2.25	13.6	10.2	78.76
90	2.94	10.7	7.4	79.16
100	1.88	15.0	12.2	78.98
F-test	NS	NS	NS	NS
LSD	3.086	6.47	4.81	1.188
CV (%)	7.2	59.1		1.8
Fertilization				
PM	2.79	11.1	10.5	78.41
CD	3.57	13.2	6.2	80.32
NPK	1.79	15.5	13.2	79.32
Control	0.77	12.8	9.0	78.42
F-test	NS	NS	NS	**
LSD	3.086	6.47	4.81	1.188
CV (%)	7.2	59.1		1.8

Source: Author's Data (2015) Where NS = non-significant and ** = highly significant at $p<0.01$ probability level; CV = coefficient of variation; LSD = Least Significant Difference between means

Soil amendment, however, resulted in higher root cracking as compared to the control. CD, PM and NPK treatments resulted in 3.57 %, 2.79 % and 1.79 % root cracking, respectively while the control resulted in 0.77 % root cracking.

Deficit irrigation had no significant effect on root damage during harvesting (Table 26). Though not significant, 100 % ET_c resulted in 15.0 % tuber damage while 70 % ET_c resulted in 13.2 % damage roots. Similarly root damage during handling was not influenced by soil amendment. However, NPK treatment resulted in the highest root damaged (15.5 %) while PM

resulted in the lowest root damage (11.1 %). Irrigation and soil amendment interaction had no significant effect on root damage during harvesting as shown in Figure 12. Though not significant, NPK interaction with 70 % ET_c and 80 % ET_c resulted in the highest root damage during harvesting (16.69 % and 19 %, respectively).

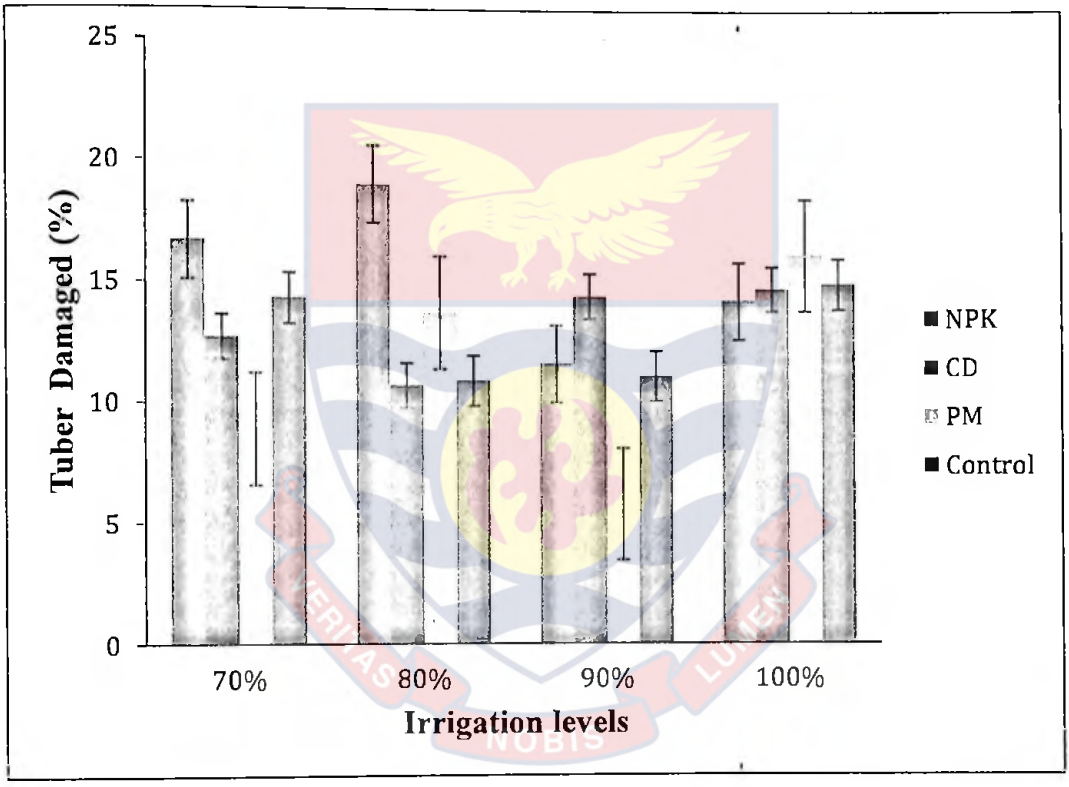


***Figure 12*: Interaction effect of CD, PM, NPK and Irrigation on percent OFSP root damaged at Cape Coast during the 2014 minor cropping season (Lsd = 13.94)**

Root moisture content was not responsive to levels of irrigation (Table 26). Though not significant, the highest moisture content (79.63 %) was recorded by 70 % ET_c as compared to 100 % ET_c which recorded 78.98 %. Fertilization, however affected root moisture content significantly ($p<0.01$). The application of CD recorded the highest moisture content 80.32

% which is significantly ($p<0.01$) higher than PM and control (78.41% and 78.42 %, respectively). NPK recorded 79.32% moisture content and was not significantly different from CD. The interaction of irrigation, CD, PM and NPK had no significant effect on root moisture content.

The effect of irrigation on weevil infestation of tuber in the field was non-significant (Table 26). Though not significant, reduced water application resulted in lower weevil infestation in the field. As shown in Table 26, 100 % ET_c caused 12.2% weevil infestation while 90% ET_c and 70% ET_c resulted in 7.4% and 9.1 % weevil infestation, respectively. Manure and NPK application did not cause significant difference in weevil infestation of roots in the field.. The interaction of irrigation, CD, PM and NPK did not cause significant difference in weevil infestation of roots in the field.

From Table 27 there was no significant difference in root sprouting in the field among the levels of irrigation. Though not significant, DI (reduced water application) resulted in lower root sprouting. As shown in Table 27, 100% ET_c resulted in 1.55% sprouting of roots in the field while 70% ET_c resulted in 0.35% sprouting which was 77.4% lower in root sprouting. Root sprouting in the field was also not responsive to manure or NPK application as shown in Table 27. The application of NPK resulted in the highest sprouting (1.59%) while the control (no soil amendment) resulted in the lowest sprouting of tubers (0.36%).

Table 27: Main effects of irrigation, CD, PM and NPK on percentage sprouted root, percentage root decay of OFSP at Cape Coast during the 2014 minor cropping season

Treatments		
Irr % ET_c	Percent root sprouted	Percent root decay
70	0.35	0
80	0.74	0
90	0.38	0.18
100	1.55	0.01
F-test	NS	NS
LSD	1.605	0.2035
CV (%)	28.4	27.6
Fertilization		
PM	0.38	0
CD	0.69	0
NPK	1.59	0.01
Control	0.36	0.17
F-test	NS	NS
LSD	1.605	0.2035
CV (%)	28.4	27.6

Source: Author's Data (2015) Where CV = coefficient of variation; LSD = Least Significant Difference between means.

Interaction of irrigation, CD, PM and NPK caused no significant difference in root sprouting in the field among the levels of irrigation and manure application (Figure 13). Though not significant, NPK and 70 % ET_c interaction recorded the highest root sprouting (3.44 %) as shown in Figure 13. For NPK and CD amended plots, increased irrigation resulted in increased sprouting in the field. On the contrary for PM and control treatments, increased irrigation (100 % ET_c) resulted in reduced sprouting of roots in the field (Figure 13).

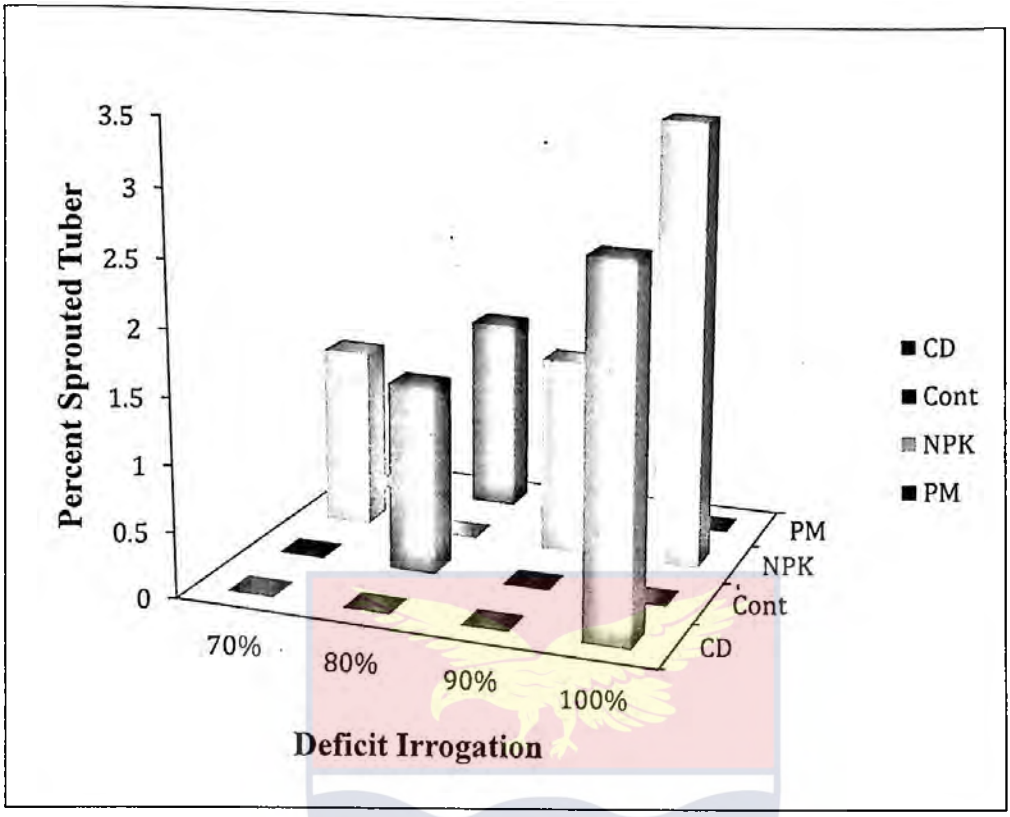


***Figure 13*: Interaction effect of CD, PM, NPK and irrigation on root sprouting OFSP in the field at Cape Coast during the 2014 minor cropping season (Lsd = 3.81)**

The effect of irrigation on root decay in the field was not significant (Table 27). Though not significant, reduced water application (70 % ET_c and 80 % ET_c) resulted in the lowest tuber decay (0%) while 100 % ET_c and 90 % ET_c resulted in 0.01 % and 0.18 % root decay, respectively. The effect of application of manure and NPK on root decay in the field was also not significant ($P<0.05$). The application PM and CD resulted in zero percentage root decay in the field while NPK application resulted in 0.01 % root decay. The control resulted in the highest percentage root decay 0.17 %. The interaction of irrigation and manure and NPK had no significant effect on tuber decay in the field.

Conclusions

Reduced water application (water stress) at 70 % ET_c increased marketable root yield, jumbo root yield and number of roots per plant as compared to full irrigation. On the contrary water stressed plants produced lower dry matter content. DI (reduced water application) did not significantly reduce percentage root decay, root sprouting and root cracking, root damage, percent weevil infestation and moisture content in the field. Soil amendments did not significantly influence percentage root decay, root sprouting and root cracking, root damage and percent weevil infestation in the field. Soil amendments significantly increased marketable yield. The application of PM, CD and NPK significantly increased marketable or economic yields by 40.96 %, 30.34 % and 21.36 % respectively as compared to control. Irrigation and manure interaction effect significantly influenced jumbo root yield. The application of 70 % ET_c to plots treated with CD, NPK and control gave the highest jumbo yield within each manure treatment.

CHAPTER FIVE

THE EFFECTIVENESS OF THREE EVAPORATIVE STRUCTURES FOR THE STORAGE OF OFSP IN THE COASTAL SAVANNA ZONE OF GHANA

Introduction

Storage of fresh horticultural produce after harvest is one of the most pressing problems of tropical countries such as Ghana. Fresh produce such as sweet potato, vegetables and fruits have high moisture content and very short shelf life. Moreover, they are living entities and carry out transpiration, respiration and ripening even after harvest. Metabolism in fresh horticultural produce continues even after harvest and the deterioration rate increases due to ripening, senescence and unfavourable environmental factors (FAO, 1989). Once the roots are detached from the plant, they rely on the stored food reserves to continue with life processes which results in changes in both physical properties and chemical composition of the harvested root. The respiration process results in the oxidation of the starch to release energy for metabolic activities (Kitchen, 2011). The complete combustion of A7 of glucose produces 1.47 g CO_2 + 16 kJ of energy (Diob, 1998). Thirty two percent (32 %) of energy generated (5.1 kJ) is utilized in metabolic activities and the remaining 10.9 kJ is released as heat resulting in temperature build-up in the storage environment. Consequently, sweet potato roots undergo several physical and chemical changes such as weight loss, shrinkage and decline in sugar and starch content during storage and the extent of changes depend on

variety and environmental factors (Teye, 2010). Hence, preserving fresh produce such as sweet potato in the fresh form demands that the chemical, bio-chemical and physiological changes are restricted to a minimum by control of space temperature and humidity (Chandra et al., 1999). However, farmers and traders still practice age-old storage methods leading to large-scale wastage during storage and transportation. Traditionally, after harvest, most roots are kept in temporary huts, bans, pits, cool dry rooms with proper ventilation and on the floor. It is estimated that 30 % to 40 % of the food produced globally is lost in the post-harvest chain or wasted because it is never consumed. However, the world's population is expected to reach 9 billion in 2050 (UNDESA, 2015) and the excessive food lost or wastage will lead to unsustainable use of the world's resources.

Appropriate cool storage technologies are therefore required in tropical countries such as Ghana for on farm storage of fresh produce especially in remote and inaccessible areas, to reduce post harvest losses. Low-cost, zero energy, environmentally friendly and evaporative cooling storage structures built from locally available materials will be of great benefit to farmers. The cool chamber is a zero-energy evaporative structure developed in India, using locally available materials (Roy, & Pal, 1994). It increased shelf life of fruits and vegetables by 2 to 14 days (15–27 % increase) as compared to room storage and root loss in weight was lower (lal Basediya et al., 2013). Adoption of the cool chamber developed in India in Ghana can be of great benefit to sweet potato and vegetable farmers and retailers. The world's population is estimated to grow by about 18 % for the year 2030 and will increase greatly

the demand for food, raw materials, energy consumption and water. This requires all countries and the UN to adopt necessary measures to ensure sustainability of humanity. One way to meet greater demand for food is the adoption of greater efficiency in the use of scarce water in crop production by the adoption of deficit irrigation (DI) which produces more crops per drop of water. Hence, if irrigation is made more efficient then there would be more water for agricultural use, environmental uses and for towns and cities. Additionally one of the most important ways of increasing the productivity of crops is the application of fertilizers (Ali et al., 2009). Manure is an age-old source of fertilizer. In recent years the use of organic manures as fertilizers has increased tremendously as a result of serious environmental pollution (Ofoefule et al., 2014) which has resulted from the use of inorganic fertilizers and pesticides. Organic manure has been found to improve the fertility and productivity of soils. Another important factor in meeting increasing food demand is efficient post harvest system. There are also critical challenges to increasing sweet potato availability which includes; poor crop management strategies such as crop-water management regimes, soil nutrient regimes and inefficient technologies to reduce perishability. The heavy post-harvest losses has resulted in increased prices thereby making it unattractive to those searching for a low cost nutrition substitute for more expensive and prestigious foods.

Therefore research efforts to determine and recommend pre-harvest treatment and zero energy evaporative storage system which store sweet

potato roots better under tropical conditions can be of great benefit to sweet potato farmers and lead to increased production and utilization of sweet potato. The main objective of the study was to compare the effectiveness of three evaporative cooling structures; Cool chamber (CC), Hexagonal barn (HexB) and In-Ground structure (InG) for the storage of sweet potato root tubers. The study also examined the effect of irrigation and manure application on the quality of OFSP during storage.

Materials and Methods

Sample collection

A field experiment was carried out between October, 2014 and January 2015 planting season at the Teaching and Research Farm of University of Cape Coast in the Central Region of Ghana as described in Chapter 3 of this thesis. Sampled plants of OFSP were harvested and roots from each plot were examined for quality analysis.

Curing and storage of tubers.

Harvested roots from each treatment were bulked and cured for 5 days before storage in constructed evaporative structures.

Storage Structures

Four storage structures were used for the study. The structures were Brick-walled Evaporative Cooling Chamber (CC), Brick-walled In-ground Evaporative Structure (InG), Jute fabric-walled Hexagonal Evaporative Cooling Barn (HexB) and Room storage.

Construction of storage structures

Three types of evaporative structures were designed and constructed:

- Brick-walled Evaporative Cooling Chamber (CC)
- Brick-walled In-ground Evaporative Structure (InG)
- Jute fabric-walled Hexagonal Evaporative Cooling Barn (HexB)

The Brick-walled Evaporative Cooling Chamber (CC)

The cool chamber is a zero energy rural storage structure which operates on the principle of direct evaporative cooling. It was built using burnt bricks, wood or bamboo, thatch, wire mesh and mosquito proof netting which are locally available (Figure 17). A floor of size 165 cm by 115 cm was made of burnt bricks. A rectangular double-wall of height 67 cm was erected over the floor. The 8.0 cm space between the double walls was filled with wet riverbed sand. The chamber was covered, drenched with water and covered with a lid made of straw on a wooden frame with insect proof net. The riverbed sand was irrigated from a container filled with water. The process of construction is illustrated Figures 14 to 19.

Design and construction of the Brick-walled Evaporative Cooling Chamber (CC)

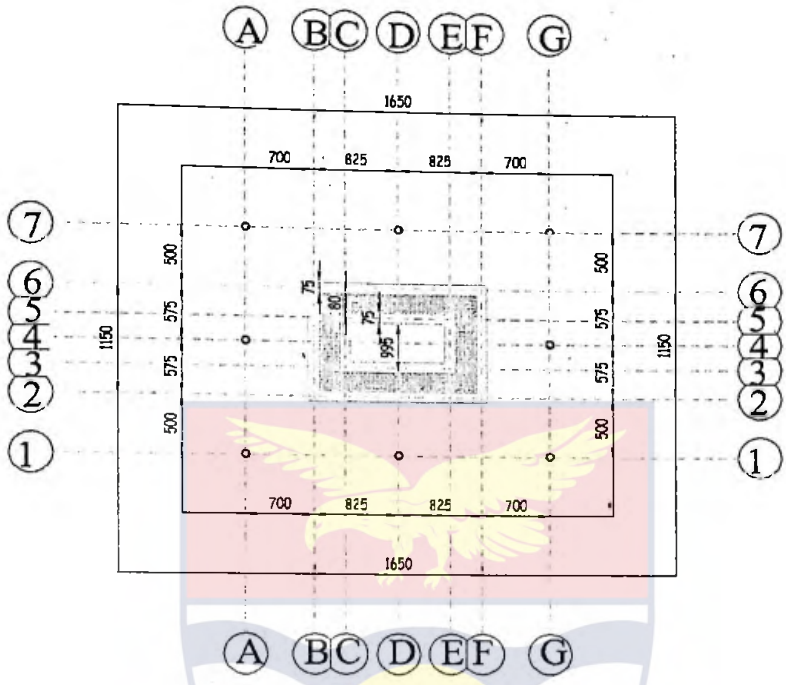


***Figure 14*: Sketch of Ground Plan of Cool Chamber (Evaporative structure)**

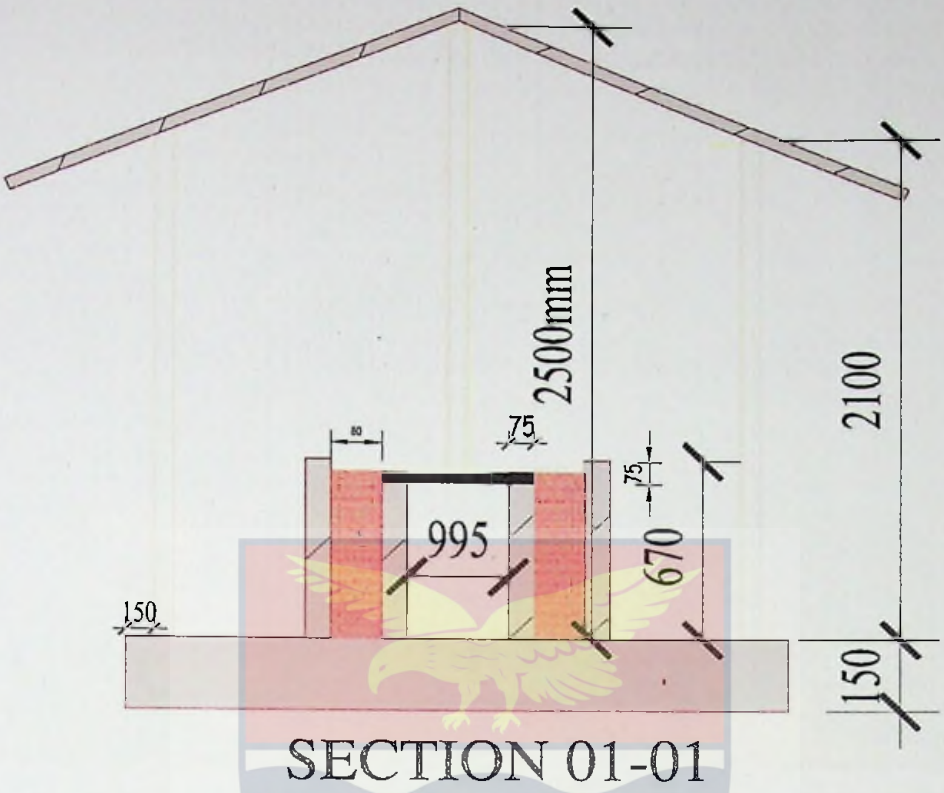


Figure 15: Sketch of Y-Y section of Cool Chamber

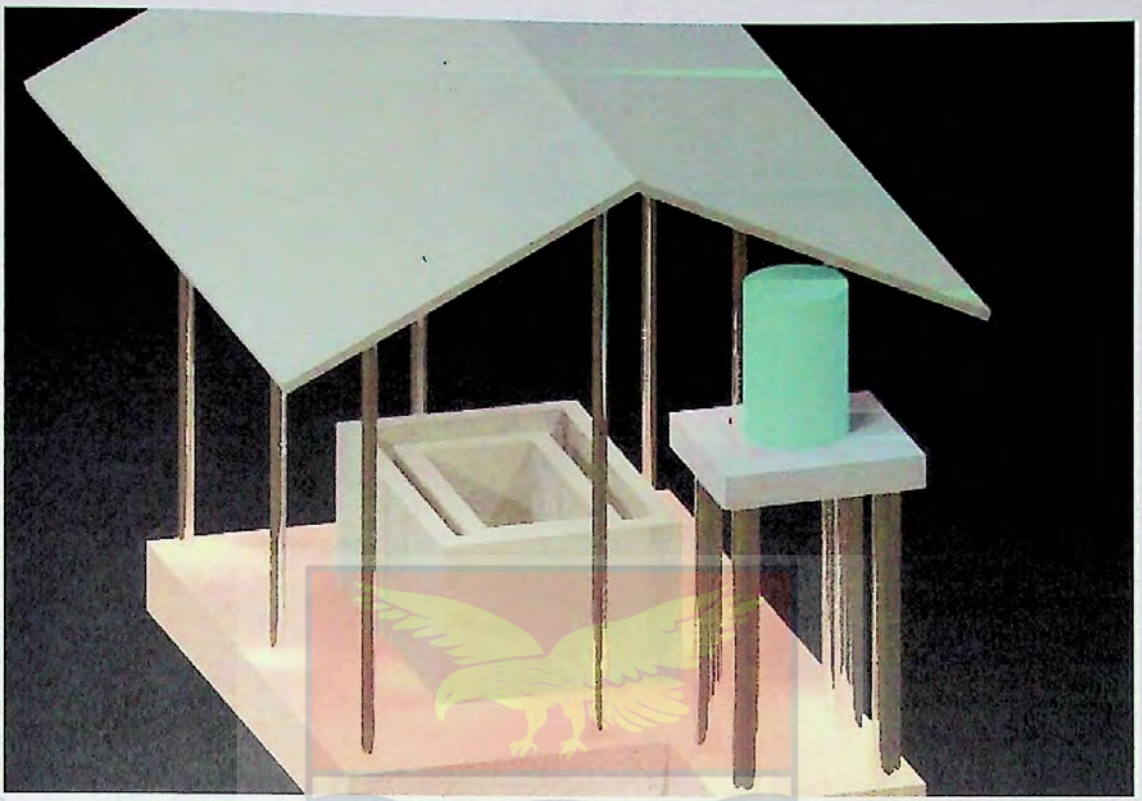


Figure 16: Sketch (C4) of Cool Chamber (Evaporative structure)

Figure 17: Constructed Cool Chamber (Evaporative structure)

Figure 18: **Brick-walled Cool Chamber containing sweet potato**

***Figure 19*: Brick-walled Cool Chamber (Evaporative structure) with thatch cover**

Brick-walled In-ground Evaporative Structure (InG)

The in-ground evaporative structure is a zero energy rural storage structure and its operation is based on the principle of evaporative cooling. It was built of bricks, chippings, wood or bamboo, thatch, etc. which are locally available raw materials. A pit of size 165 cm by 115 cm and 820 cm deep was dug in the ground as shown in Figures 20 to 24. The walls of the pit were lined with burnt clay bricks. The construction of the structure is illustrated Figures 20 to 24.

Design and construction of In-ground Evaporative structure

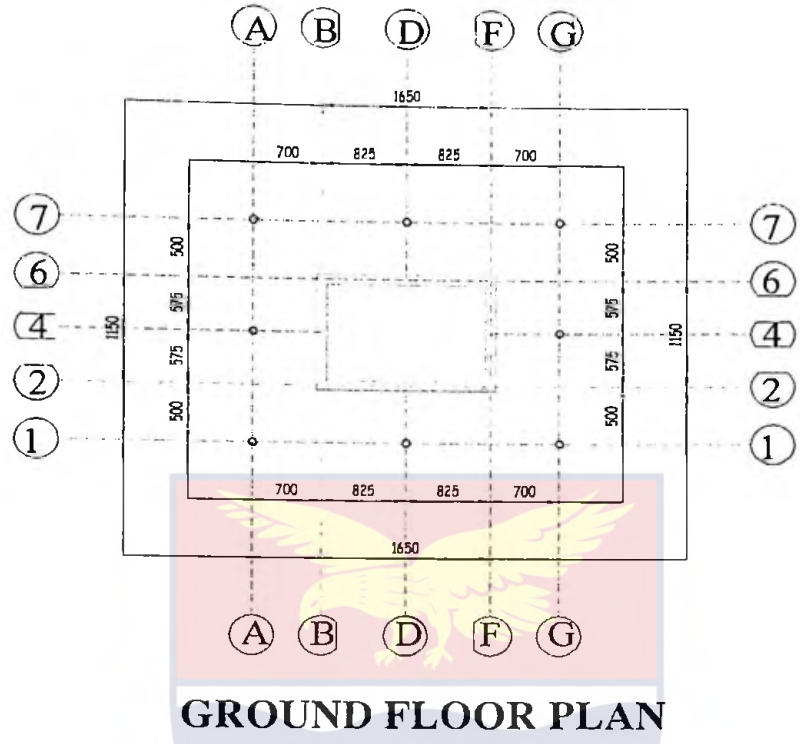


Figure 20: Sketch of Ground Plan of In-Ground Evaporative structure

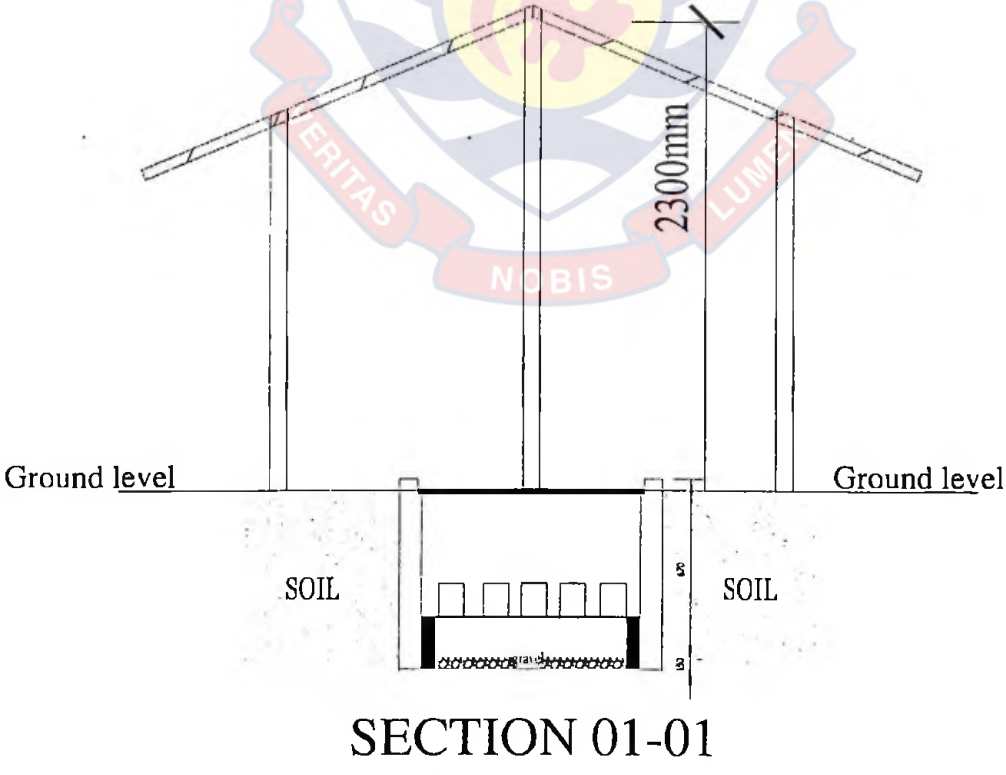


Figure 21: Sketch of X-X Section of In-Ground Evaporative structure

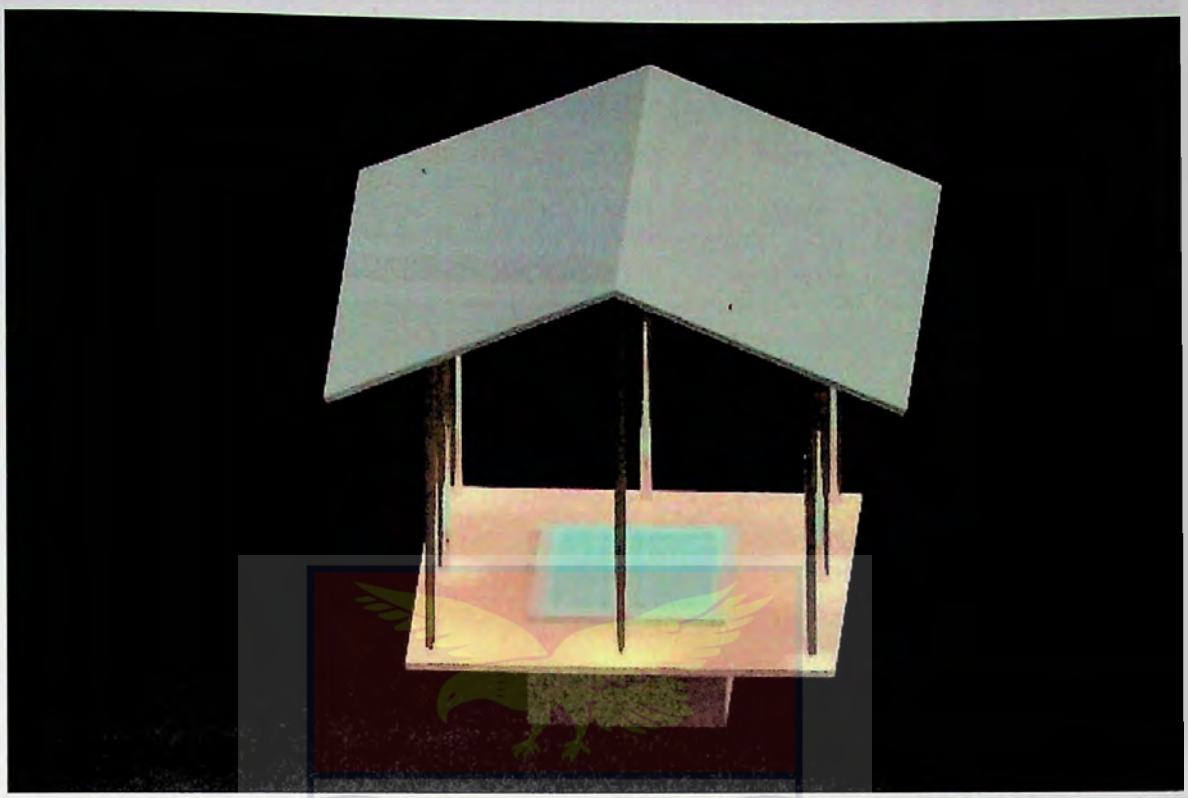


Figure 22: **Construction of In-Ground Evaporative structure**

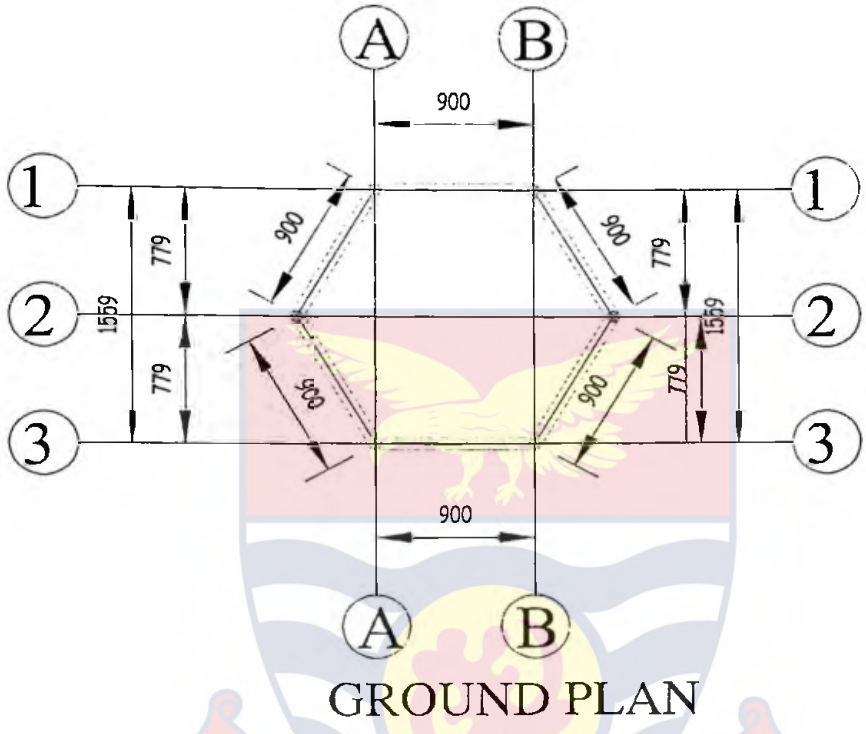
Figure 23: **Brick-walled (InG) Evaporative structure with roots in storage**

Figure 24: **Brick-walled (InG) Evaporative structure with thatch cover.**

Jute fabric-walled Hexagonal Evaporative Cooling Barn (HexB)

The hexagonal evaporative structure is a zero energy rural storage structure. The cooling process is based on the principle of evaporative cooling. It was built using wood or bamboo, thatch, jute sack, wire mesh and mosquito proof netting which are locally available. The barn was built on six posts (Figs. 25-29). Each side measured 900 mm and the floor was raised 900 mm off the ground. There were wooden beams to support the raised floor. The floor was made of wire mesh and mosquito proof netting. The floor had no jute sacks to facilitate ventilation. There were three floors each was made of wire mesh to ensure ventilation. The walls of the structure were made of wire mesh and covered with jute sacks which served as evaporating pads.

Design and construction of Jute fabric-walled Hexagonal Evaporative Cooling Barn (HexB)



GROUND PLAN

***Figure 25*: Sketch of ground plan of Jute fabric-walled hexagonal evaporative structure**

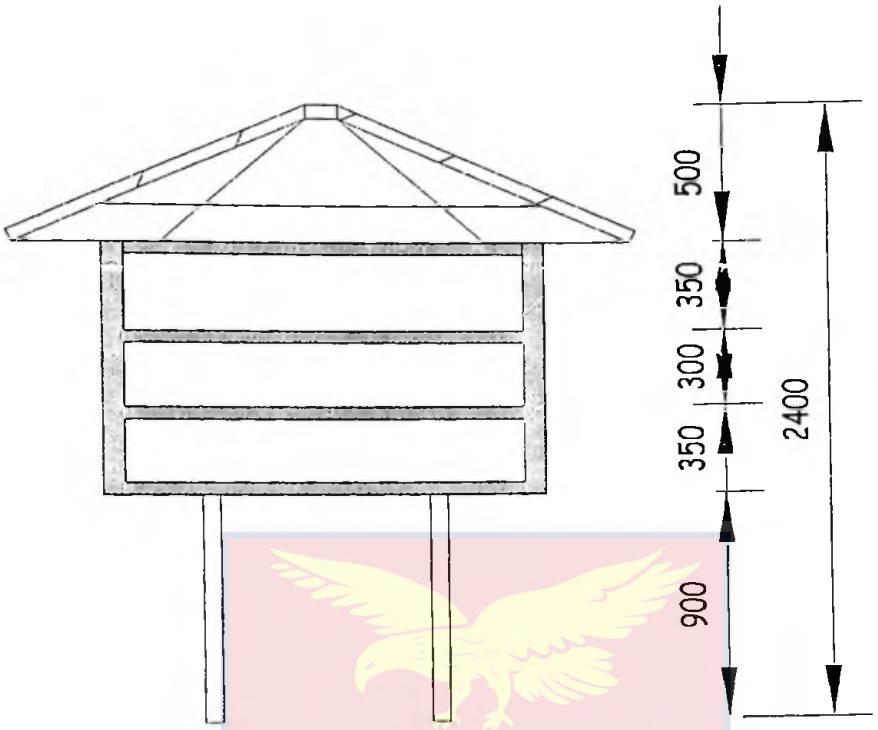


Figure 26: **Sketch of Section of Jute-walled hexagonal evaporative structure**

Figure 27: Sketch (C4) of Front elevation of hexagonal evaporative structure

Figure 28: **Construction of hexagonal evaporative structure (HexB)**

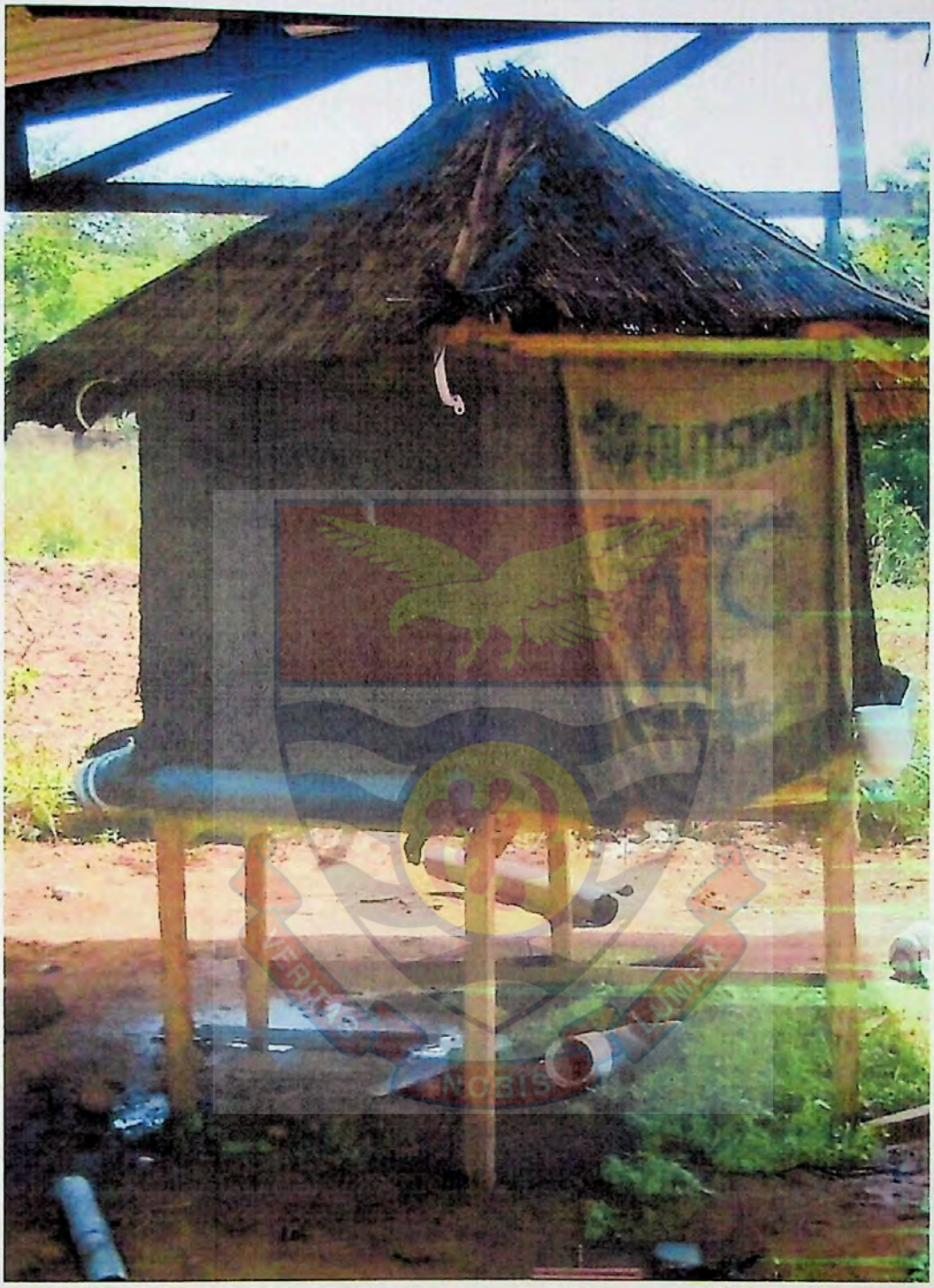


Figure 29: **Constructed jute-walled hexagonal evaporative structure (HexB)**

Room Storage

The room was cement blocks structure with corrugated asbestos sheets roof and plywood ceiling. The room was well ventilated. The roots were packed in plastic baskets and kept on the floor.

Data collection and analysis

All data collected were subjected to Analysis of Variance using Gen-stat Discovery software version 4.0. Analysis of Variance was done to determine whether there were significant differences in the parameters studied. For treatments that were significant, mean separation was done using the Least Significant Difference (Lsd) test at 5 % probability level.

The following data were collected:

1. Psychrometric Characteristics of the Storage structures and Ambient Conditions. Temperature and Relative Humidity were recorded in the storage structures, storage room, under the shed and ambient conditions with digital thermometer and relative humidity meters. Psychrometric characteristics of air such as moisture content, enthalpy, volume of air, etc. were determined with a computer based programme PsycPro version 1.1.16.

2. Weight loss

The initial weight of roots was taken before being put in storage. Percentage weight loss in storage was determined on the 4^{th}, 8^{th} and 13^{th} week of storage by finding the difference between two successive weighings. The difference was divided by the initial weight as in Equation 26.

$$Percentage\ weight\ loss = \frac{Initial\ wt\ roots - Final\ wt}{Initial\ wt\ of\ roots}\ x\ 100 \quad 26$$

3. Degree of shrinkage

Percentage shrinkage was determined by finding the difference in size reduction on monthly basis with a dial caliper. Ten roots from each treatment were measured monthly with a Dial Calipers (Opus 150 mm). For each root the greatest dimension was measured at right angles to the longitudinal axis. The diameter-measuring points were marked and served as subsequent measuring points. The difference in diameter between two successive measured diameters determined shrinkage in size. The percentage shrinkage is computed as in Equation 27.

$$Tuber\ shrinkage\ (\%) = \frac{Initial\ diameter - Final\ diameter}{Initial\ diameter\ of\ roots}\ x\ 100 \quad 27$$

4. Degree of Decay in storage

Roots from sampled plants from each plot were counted and examined for decay. Roots with decay regardless of the spread were considered rotten and percentage decay was determined as in Equation 28.

$$Percentage\ decayed\ \text{roots} = \frac{No.\ of\ decayed\ \text{roots}}{Total\ No.\ of\ \text{roots}}\ x\ 100 \quad 28$$

5. Incidence of sprouting in storage

Roots were examined at monthly intervals for sprouting and 100 % sprouting. Percentage sprouting was computed as in Equation 29.

$$Percentage\ sprouted\ roots = \frac{No.\ of\ sprouted\ roots}{Total\ No.\ of\ roots}\ x\ 100 \quad 29$$

6. Insect infestation in storage

Tubers from each plot were examined for weevil infestation. The number of insects (weevils) among each treatment was determined by counting. The level of insect infestation was determined by determining the number of weevils in each treatment sample.

Results and Discussion

Psychrometric characteristics of storage structures

Minimum and maximum temperature of air inside the storage structures, storage room, shed and outside (ambient) conditions were recorded as shown in Table 28. Temperatures increased from January to April when storage ended. The highest temperatures were recorded in March and April. In CC air temperature was reduced by 7.2 °C while in HexB and InG temperature was reduced by 5.2 °C and 4.6 °C respectively. The variation between the minimum and maximum temperature was lower inside the storage structures than that of the surrounding air because the evaporator tended to prevent high temperature build up (afternoon temperature) inside the structures (Table 28). It was also observed that minimum temperatures inside the storage structures were higher than that of the outside air. This could be attributed to respiratory heat produced by roots and the cladding of the structure walls which maintained comparatively stable air conditions inside the structures. Figure 30 shows the mean monthly temperatures recorded in the storage structures, shed and ambient. Evaporation was most effective in causing cooling in the Cool chamber (CC). Mean monthly temperature in CC ranged from 25.5 °C to 27 °

C in April while ambient mean monthly temperature ranged from 29.7 °C to 30.8 °C. The mean outside temperature was higher than the mean temperatures in the structures as shown in Figure 30.

Figure 31 shows the mean monthly air relative humidity inside the storage structures and outside. The mean air relative humidity outside was lower than relative humidity inside the evaporative structures as shown in Figure 31.

Table 28: Minimum and maximum temperature of air inside structures, shed and ambient during the storage period

Storage System	Cool chamber		HexB		InG		Room		Shed		Ambient	
	Min	Max	Min	Max	Min	Max	Min	Max	Max	Max	Min	Max
Month	T °C	T°C	T°C	T°C	T°C	T°C	T°C	T°C	T°C	T°C	T°C	T°C
Jan	24.7	26.3	24.3	29	26	29	24	29	26	30	26	33.5
Feb	25.3	27.5	24.7	29.3	26.5	29.1	25	29	26	30	26.4	34.5
March	26.2	27.4	25.7	29.6	27.4	30.1	25	30	26.2	30	26.9	34.5
April	26.5	27.8	26.1	29.8	27.6	30.4	25	30	26.1	31	26.6	35

Source: Author's Data (2015)

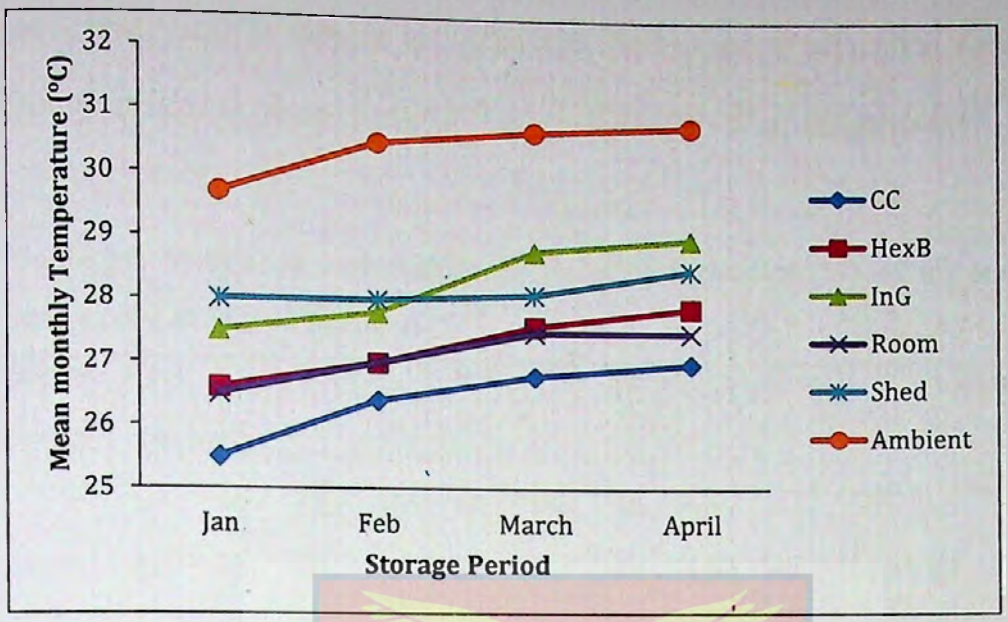


Figure 30: Mean monthly temperature of air inside structures, shed and outside during the storage period

Maximum and minimum relative humidity were recorded inside the structures and outside the structures for the entire storage period (Table 29). The relative humidity inside the structures was about 8-20 % higher than outside. Table 30 shows the mean monthly enthalpy, moisture content and specific volume of air inside the evaporative structures and outside. The enthalpy of the air inside the storage structures ranged from 64.77 kJ kg^{-1} under room conditions to 79.26 kJ kg^{-1}. The enthalpy of the outside air was 80.9 kJ kg^{-1} which was higher than that of the storage structures. This is because the cooling in the evaporative storage structures were adiabatic processes. The high ambient sensible heat blown through the wet pad was converted to latent heat of vaporization of moisture and a depression in the internal enthalpy of air in the storage structures. Furthermore, respiratory heat from the sweet potato roots was too small to raise the enthalpy to be equal to

the enthalpy of the outside air. The specific volume of air in the various storage structures ranged from 0.874 $m^3 kg^{-1}$ (CC) to 0.887 $m^3 kg^{-1}$ (ambient).

Table 29: Minimum and maximum Relative humidity (%) of air inside structures, shed and ambient

Storage System	Cool chamber		HexB		InG		Room		Shed		Ambient	
	Min	Max	Min	Max	Min	Max	Min	Max	Max	Max	Min	Max
Month	Rh	Rh	Rh	Rh	Rh	Rh	Rh	Rh	Rh	Rh	Rh	Rh
Jan	79	94	66	93	73	95	70	76	63	80	61	81
Feb	81	95	61	92	72	94	62	75	54	82	51	85
March	71	91	57	91	73	95	55	71	52	92	50	96
April	77	94	68	90	67	82	60	65	60	81	58	83

Source: Author's Data (2015)

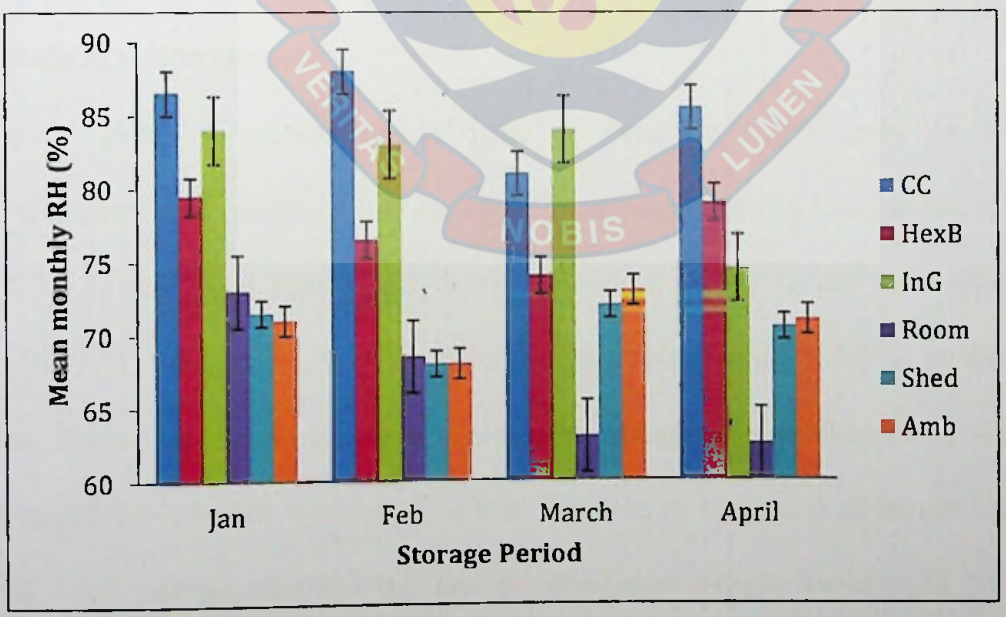


Figure 31: **Mean monthly Relative humidity of storage structures, shed and ambient (outside)**

Table 30: Mean Psychrometric properties of air inside storage structures, shed and outside

Psychrometric properties of storage structures						
Storage system						
	CC	HexB	InG	Room	Shed	Amb
Dry bulb Temp DB (° C)	27.3	27.3	28.3	27.10	28.2	30.4
Wet bulb Temp WB (° C)	24.44	24.15	25.69	22.37	23.4	25.9
Relative Humidity RH (%)	83.3	77.3	81.4	66.8	70.5	70.8
Humidity Ratio W (g/kg)	18.65	17.79	19.83	15.13	17.09	19.56
Specific volume V (m^3/kg)	0.874	0.875	0.881	0.871	0.877	0.887
Enthalpy h (kJ/kg)	74.01	72.76	79.26	65.77	71.89	80.49
Dew Point Temp DP (° C)	23.73	22.98	24.81	20.40	22.33	24.50
Density d (kg/m^3)	1.17	1.16	1.16	1.17	1.16	1.15
Vapour Pressure V (mm Hg)	22.0	21.1	23.5	18.0	20.2	23.1
Absolute humidity (g/m^3)	21.346	20.334	22.625	17.379	19.488	22.061

Source: Author's Data (2015)

Weight loss in storage

After 4 weeks storage type of structure significantly ($p<0.01$) influenced root weight loss in storage. Root weight loss in CC was the least, 5.7 6 % which was significantly lower than HexB (10.47 %) and room storage (16.07 %) but not significantly different from InG storage (7.73 %) as shown in Table 31. Similarly, type of storage structure significantly ($p<0.01$) influenced cumulative weight loss after 8 weeks of storage as shown in Table 31. CC storage recorded the lowest cumulative weight loss (11.12 %) as compared to weight loss in HexB (20.07 %) and InG (20.96 %). Room storage

recorded the highest weight loss of 28.97 % which can be attributed to lower relative humidity (62.5-73 %) (Figure 15).

Soil amendment did not significantly ($p<0.05$ influence tuber weight in storage after 4 weeks of storage. However, NPK reduced weight loss (9.88 %) as compared to roots fertilized with PM (10.58 %) and control (10.25%) as shown in Table 31. On the contrary CD application resulted in the lowest percentage root weight loss (9.31 %) after 4 weeks of storage. Similarly manure application did not significantly influence cumulative tuber weight loss after 8 weeks of storage (Table 31). However, NPK fertilized roots suffered the highest percentage weight loss in storage 22.42 %. This observation is contrary to observation by Sowley et al. (2015) that NPK application resulted in lower weight loss of roots in storage as compared to PM application and control. The control resulted in the lowest cumulative percentage root weight loss (17.86 %) after 8 weeks of storage.

After 13 weeks of storage, weight loss was highly significant ($p<0.01$) among the different treatments. PM application resulted in the lowest weight loss (40.4 %) which was significantly lower than weight loss in CD (52.2 %) and NPK (50.9 %) application (Table 31). This could be attributed to higher dry matter content of PM fertilized roots (21.59 %) as compared to roots from CD fertilized roots (19.68 %) and NPK fertilized roots (20.61 %) as shown Table 23 of Chapter 4 of this thesis.

Table 31: Effects of Structure, NPK and manure on weight loss of OFSP tubers after 4, 8 and 13 weeks in storage at Cape Coast

Treatment	Percentage weight loss		
Irr. ET_c %	Root weight loss 4 wk	Cum root weight loss 8 wk	Cum root weight loss 13wk
CC	5.76	11.12	26.8
HexB	10.47	20.07	68.6
InG	7.73	20.96	47.4
Room	16.07	28.79	47.4
F-test	**	**	**
LSD	3.275	4.687	6.20
CV (%)	46	32.5	18.3
Manure/NPK			
PM	10.58	20.84	40.4
CD	9.31	19.81	52.2
NPK	9.88	22.42	50.9
Control	10.25	17.86	46.6
F-test	NS	NS	**
LSD	1.768	4.687	6.20
CV (%)	46.0	32.5	18.3

Source: Author's Data (2015) Where NS = non-significant and ** = highly significant at $p<0.01$ probability level; CV = coefficient of variation; LSD = Least Significant Difference between means.

The interaction of storage structure and manure significantly ($p<0.05$) influenced cumulative root weight loss in storage after 8 weeks as shown in Table 32. CD fertilized roots in room storage recorded the highest weight loss (34.91 %) after 8 weeks of storage while PM fertilized roots stored in CC (cool chamber) experienced the least weight loss, 8.83 % as shown in Table 32.

Table 32: Interaction effect of storage structure and manure on sweet potato root cumulative weight loss after 8 weeks of storage

Treatments	Percentage weight loss			
	Manure			
Structure	Cont.	CD	NPK	PM
CC	11.15	10.28	14.21	8.83
Hex B	16.18	19.16	19.42	25.49
InG	17.04	14.87	24.41	27.51
Room	27.07	34.91	31.64	21.52
F-test		*		
LSD		4.687		
CV (%)		32.5		

Source: Author's Data (2015) Where * = significant at $p<0.05$ probability level; CV = coefficient of variation; LSD = Least Significant Difference between means

Similarly storage structure and manure significantly ($p<0.01$) influenced cumulative weight loss of roots after 13 weeks of storage (Table 33). The highest weight loss was recorded in NPK produced roots stored in HexB (85.2 %) while PM fertilized roots in CC recorded the lowest weight loss 20.2 %. Irrespective soil amendment CC storage recorded relatively low weight loss (20.2 % to 30.3 %) while HexB storage recorded higher weight loss (61.0 % to 85.2 %) as shown in Table 33.

Table 33: Interaction effect of storage structure and manure on cumulative weight loss of sweet potato roots after 13 weeks of storage

	Percentage root weight loss			
Treatments	Fertilization			
Structure	Cont	CD	NPK	PM
CC	27.3	30.3	29.6	20.2
Hex B	64.6	63.4	85.2	61.0
InG	48.5	52.4	48.6	40.2
Room	46.2	62.8	40.2	40.3
F-test		**		
LSD		12.40		
CV (%)		18.3		

Source: Author's Data (2015) Where ** = significant at $p<0.05$ probability level; LSD = Least Significant Difference between means.

The interaction of irrigation and storage structure significantly ($p<0.05$) influenced root weight loss in storage after 4 weeks of storage as shown in Table 34. Roots from plots irrigated with 90 % ET_c in room storage suffered the highest weight loss of 18.68 % after 4 weeks of storage while roots which received 80 % ET_c in CC recorded 2.79 % weight loss which was the least. Irrigation had no significant effect on weight loss after 4 weeks of storage as shown in Table 34. DI at 80 % CWR resulted in the lowest weight loss (8.99 %).

Table 34: Interaction effect of storage structure and irrigation on weight loss of sweet potato roots after 4 weeks

Treatments	Percentage root weight loss Irrigation % ET_c				
Structure	70 %	80 %	90 %	100 %	Mean
CC	4.54	2.79	7.50	8.22	5.76
Hex B	9.27	11.77	14.47	6.36	10.47
InG	10.80	5.49	6.99	7.62	7.73
Room	13.87	15.93	18.68	15.81	16.07
Mean	9.62	8.99	11.91	9.50	
F-test			*		
LSD			6.717		
CV (%)			47.1		

Source: Author's Data (2015) Where * = significant at $p<0.05$ probability level; LSD = Least Significant Difference between means.

Shrinkage (Loss in size)

Storage structure significantly influenced root shrinkage after four weeks of storage as shown in Table 35. Root shrinkage was significantly higher in room storage than in the evaporative structures. The ranking order of root shrinkage in storage was room storage (3.83 %) > InG (2.46 %) > HexB (2.37 %) > CC (2.04 %) as shown in Table 35. Room storage recorded the highest shrinkage (3.83 %) which was significantly higher ($p<0.01$) than shrinkage recorded in the evaporative structures CC, HexB and InG. This could be attributed to lower relative humidity in the room during the storage period as shown in Table 29 and Figure 15. However, percentage shrinkage in CC was not significantly lower than shrinkage in InG (2.47 %) and HexB

(2.37 %) evaporative structures. Additionally storage structure had significant ($p<0.01$) influence on cumulative root shrinkage after 8 weeks of storage as shown in Table 35. Room storage recorded the highest shrinkage in root size (8.63 %) among the four different storage structures. The evaporative structures were significantly better than room storage in terms of shrinkage. Differences in root shrinkage among the three evaporative structures were, however, not significant. However, CC recorded the lowest root shrinkage 3.67 % as compared to 4.08 % and 4.71 % for InG and HexB, respectively. On the contrary root shrinkage were not significantly different among the four storage structures after thirteen weeks of storage (Table 35). Cool Chamber recorded the lowest percentage root shrinkage (5.51 %) which could be attributed to lower temperatures 25.5-27 °C (Table 28), higher average relative humidity (81-88 %) and lower weevil infestation. Room storage recorded the highest percentage shrinkage (9.18 %) while InG and HexB recorded 6.33 % and 6.01 %, respectively (Table 35).

Soil amendment (PM, CD and NPK) did not significantly influence root shrinkage in storage after four weeks of storage as shown in Table 35. The interaction of manure and storage structure also had no significant influence on root shrinkage after four weeks of storage. Soil amendment had no significant influence on root shrinkage after eight weeks of storage. Similarly the interaction of manure and storage structure had no significant influence on root shrinkage after eight weeks of storage as shown in Table 35. However the highest root shrinkage were recorded in the control experiment (5.86 %) followed by NPK application (5.61 %) while CD and PM application

recorded 4.89 % and 4.74 % shrinkage, respectively (Table 35). Level of irrigation as well did not significantly influence root shrinkage after eight weeks of storage.

After thirteen weeks of storage, soil amendment had no significant influence on percentage root shrinkage. However, the control recorded the highest percentage shrinkage (6.98 %) after thirteen weeks of storage. NPK recorded 6.17 % while CD and PM recorded 5.77 % and 5.41 % respectively (Table 35). It can also be noted that irrigation and the interaction of soil amendments and irrigation had no significant influence on root shrinkage in storage.

Table 35: Effects of structure and manure on cumulative shrinkage of OFSP tubers after 4, 8 and 13 weeks of storage in Cool Chamber

Treatment	Percentage shrinkage (loss in size)		
Irr. ET_c %	Root shrinkage 4 wk	Cum. root shrinkage 8wk	Cum. root shrinkage 13wk
CC	2.04	3.67	5.51
HexB	2.37	4.71	6.01
InG	2.46	4.08	6.33
Room	3.83	8.63	9.18
F-test	**	**	NS
LSD	0.485	1.624	4.58
CV (%)	51.2	43.2	49.1
Fertilization			
PM	3.06	4.74	5.41
CD	2.50	4.89	5.77
NPK	2.76	5.61	6.17
Control	2.39	5.86	6.98
F-test	NS	NS	NS
LSD	0.485	1.624	4.58
CV (%)	51.2	43.2	49.1

Source: Author's Data (2015) NS = non-significant and ** = highly significant at $p<0.01$ probability level; CV = coefficient of variation; LSD = Least Significant Difference between means

Decay of roots in storage

Storage structure significantly influenced root decay in storage as shown in Table 36. After 4 weeks of storage roots in InG storage recorded the lowest percentage decay 12.8%, while roots in CC, HexB and Room storage recorded 16.9 %, 20.5 % and 26.1% decay, respectively. However, after eight weeks, storage structure effect on root decay was not significant (Table 36). CC storage reduced root decay even though it was not significantly better than room storage, InG and HexB storage. The ranking order of root decay was CC (29.9 %) < HexB (31.2 %) < InG (36.8 %) < Room (46.7 %). After 13 weeks, storage structure significantly influenced root decay in storage. Cool chamber recorded the lowest percentage root decay (44.5 %). InG storage, room storage and HexB storage recoded 49.0 %, 62.9 % and 84.0 % root decay, respectively.

Soil amendment significantly ($p<0.05$) influenced percentage root decay after 4 weeks of storage as shown in Table 36. PM treatment resulted in the lowest root decay (12.9 %) which is 50.57 % reduction in percentage decay as compared to 26.1 % decay for Control. This observation is supported by Sowley et al. (2015) and Data et al. (1989) who reported that OFSP produced with PM suffered much less decay as compared to unfertilized roots. The ranking order of decay as influenced by soil amendment (manure) was Control (26.1 %) > NPK (19.8 %) > CD (17.3 %)> PM (12.9 %). This observation is supported by similar findings by Sowley et al. (2015) who stated that OFSP roots amended with PM and NPK suffered much less rot than unfertilized tubers. After 13 weeks of storage soil amendments significantly

($p<0.01$) influenced root decay as shown in Table 36. The ranking order of root decay as influenced by soil amendment was NPK (73.4 %) > Control (60.1 %) > CD (58.8 %)> PM (48.1%).

Table 36: Effects of Structure, NPK and manure on percentage decay of OFSP roots after 4, 8 and 13 weeks in storage

Treatment	Percentage Root decay		
Structure	Percentage root decay 4 wk	Cumulative root decay 8 wk	Cumulative root decay 13 wk
CC	16.9	29.9	44.5
HexB	20.5	31.2	84.0
InG	12.8	36.8	49.0
Room	26.1	46.7	62.9
F-test	*	NS	**
LSD	9.43	17.5	13.24
CV (%)	69	68	30.9
Fertilization			
PM	12.9	20.84	48.1
CD	17.3	19.81	58.8
NPK	19.8	22.42	73.4
Control	26.1	17.86	60.1
F-test	*	NS	**
LSD	9.43	17.5	13.24
CV (%)	69	68	30.9

Source: Author's Data (2015) Where NS = non-significant and ** = highly significant at $p<0.01$ probability level; CV = coefficient of variation; LSD = Least Significant Difference between means

Manure and storage structure interaction significantly influenced percentage decay after 8 weeks in storage (Table 37). NPK produced roots stored in InG and PM produced roots stored in CC recorded significantly lower percentage decay 14.2 % and16.3% respectively after 8 weeks of storage. On the contrary PM produced roots stored in InG recorded the

highest percentage decay (67.5%). Similarly manure and storage structure interaction significantly ($p<0.01$) influenced percentage decay after 13 weeks in storage (Table 38).

Table 37: Interaction effect of storage structure and manure on sweet potato root cumulative percentage decay after 8 weeks of storage

Treatments	Cumulative percentage decay			
	Fertilization			
Structure	Cont.	CD	NPK	PM
CC	29.6	32.9	41.0	16.3
Hex B	42.1	33.8	14.2	34.6
InG	21.7	19.6	38.5	67.5
Room	48.7	42.3	68.3	27.6
F-test			*	
LSD			35.03	
CV (%)			68	

Source: Author's Data (2015) Where * = significant at $p<0.05$ probability level; CV = coefficient of variation; LSD = Least Significant Difference between means

PM fertilized roots in CC recorded the lowest 21.6 % decay after 13 weeks in storage. On the contrary roots produced from control plots recorded 100 % decay after 13 weeks of storage. Similar observation was reported by Sowley et al. (2015) and Data et al. (1989) that roots from unfertilized plots decayed more severely than roots from fertilized plots in storage. However Sowley et al. (2015) reported that NPK produced roots suffered less decay in storage which is contrary to current finding that NPK produced roots suffered 100 % root decay after 13 weeks in storage as shown in Table 38.

Table 38: Interaction effect of storage structure and manure on sweet potato root cumulative percentage decay after 13 weeks of storage

Treatments	Cumulative percentage decay			
	Manure			
Structure	CD	Cont.	NPK	PM
CC	47.9	54.1	54.4	21.6
Hex B	92.9	100	84.2	58.8
InG	37.0	30.8	55.1	72.9
Room	57.5	55.4	100	38.8
F-test		**		
LSD		26.49		
CV (%)		30.9		

Source: Author's Data (2015) Where ** = highly significant at $p<0.01$ probability level; CV = coefficient of variation; LSD = Least Significant Difference between means

Level of irrigation did not significantly influence root decay after 13 weeks of storage (ANOVA E4). This is contrary to the findings by Thompson et al. (1992) which indicated that sweet potato root decay is responsive to amount of water application. The ranking order of root decay after 13 weeks of storage as influenced by irrigation was 70 ET_c (67.1) > 100 % ET_c (62.8 %) > 80 % (61.2 %) > 90 % ET_c 46.6 %. Thus it can be stated that DI (90 % ET_c) resulted in lower root decay (46.6%) in storage. However further reduction of water application to 70 % ET_c increased root decay to 67.1 %.

Sprouting in storage

From Table 39 percentage sprouting of roots in storage was not influenced by manure application, level of irrigation and storage structure after

four weeks of storage. HexB recorded the highest sprouting (45.3 %). The ranking order of sprouting in storage was HexB (45.3 %) > CC (40.1 %) > InG (36.8 %) > Room (27.9 %) as shown in Table 39. Manure application did not significantly influence sprouting in storage, however, the ranking order of sprouting was CD (42.5 %) > Control (40.3 %) > NPK (34.3 %) > PM (33.0 %) as shown in Table 39. This suggestion is contrary to the findings by Data *et al.* (1989) that white-fleshed sweet potato roots fertilized with PM exhibited higher percentage of sprouting than roots fertilized with NPK and unfertilized roots.

After eight weeks of storage, cumulative sprouting of roots was significantly ($p<0.01$) influenced by storage structure as shown in Table 39. In CC sprouting was 83.5 % which was the highest while InG recorded the lowest cumulative sprouting (38.4 %). HexB and Room storage recorded 72.9 % and 61.1 % respectively. The high percentage sprouting in CC can be attributable to high relative humidity in the structure as shown in Table 29. It can thus be stated that even though CC provides relatively cooler temperatures and higher relative humidity it also promotes sprouting of roots in storage.

Manure application did not significantly influence root sprouting after 4 and 8 weeks in storage (Table 39). The ranking order of sprouting as influenced by manure was Control (68.8 %) > CD (67.1 %) > NPK (61.5 %) > PM (58.4 %). Level of irrigation had no significant influence on root sprouting. However interaction effect of manure and structure significantly ($p<0.05$) influenced sprouting after 8 weeks in storage (Table 40). PM fertilized roots in InG storage recorded the lowest sprouting (7.1 %) while

roots from control in CC storage recorded the highest sprouting (87.5 %) as shown in Table 40. At the end of 13 weeks almost all roots had sprouted in CC and HexB.

Table 39: Effects of Structure, NPK and manure on sprouting of OFSP tubers after 4 and 8 weeks in storage at Cape Coast

Structure	Root sprouting 4 wk	Cum root sprouting 8 wk
CC	40.1	83.5
HexB	45.3	72.9
InG	36.8	38.4
Room	27.9	61.1
F-test	NS	**
LSD	12.87	18.19
CV (%)	48.2	39.9
Manure/NPK		
PM	33.0	58.4
CD	42.5	67.1
NPK	34.3	61.5
Control	40.3	68.8
F-test	NS	NS
LSD	12.87	18.19
CV (%)	48.2	39.9

Source: Author's Data (2015) Where NS = non-significant and ** = highly significant at $p<0.01$ probability level; CV = coefficient of variation; LSD = Least Significant Difference between means.

Table 40: Interaction effect of storage structure and manure on cumulative root sprouting after 8 weeks of storage

Percentage root sprouting				
Treatments	Fertilization			
Structure	Cont.	CD	NPK	PM
CC	87.5	76.7	79.8	89.9
Hex B	85.4	71.1	78.8	56.2
InG	32.5	72.5	41.7	7.1
Room	69.8	48.3	45.8	80.4
F-test			*	
LSD			36.37	
CV (%)			39.9	

Source: Author's Data (2015) Where * = significant at $p<0.05$ probability level; CV = coefficient of variation; LSD = Least Significant Difference between means

Insect infestation in storage

After 4 weeks of storage, storage structure highly significantly ($p<0.01$) influenced weevils infestation among roots (Table 41). CC storage structure recorded the lowest weevil number (2.12) which could be attributed to high Relative humidity (moist conditions) in the structure. The order of number of weevils in the structures was as follows: CC (2.12) < HexB (3.12) < InG (4.68) < Room (9.32). Similarly, after 8 weeks, storage structure significantly ($p<0.01$) influenced cumulative number of weevils in structure. The ranking order of number of weevils was: CC (3.19) < HexB (9.25) < Room (23.91) < InG (26.57). The same thing can be said about the number of weevils after 13 weeks of storage. Storage structure effect on weevil infestation was highly significant ($p<0.01$). CC recorded the lowest number

(5.9) which can be attributed higher relative humidity (moist condition) in the structure. The moist condition was not conducive for the survival of the weevil. It is well known that sweet potato weevil is more prevalent in dry conditions. The order of number of weevils in the structures was: Room (32.2) > InG (27.7) > HexB (24.9) > CC (5.9) as shown in Table 41. Room conditions was conducive for weevil survival.

Soil amendment did not significantly influence weevil number in storage after 4, 8 and 13 weeks as shown in Table 41. After 4 weeks of storage, Control and NPK fertilized roots recorded 5.19 weevils each while PM and CD fertilized roots recorded 4.69 and 4.19 respectively. After 13 weeks of storage the order of number of weevils among roots as influenced by soil amendment was: NPK (24.2) > CD (24.1) > PM (22.9) > Control (19.4). Roots from control plots had few weevils (19.4) as compared to roots from amended plots. This could be attributed to high levels of organic acids such as malic acid which is an organic compound. Malic acid has been shown to reduce susceptibility of sweet potato to weevil infestation. The control plots yielded higher levels of carbohydrate.

Deficit irrigation and manure and their interactions did not significantly reduce number of weevils in storage. The number of weevils was in this order; 70 % ET_c (18.7) > 100 % ET_c (17.6) > 90 % ET_c (14.0) > 80 % ET_c (12.7).

The interaction of soil amendment and storage structure significantly influenced weevil number in storage after 8 weeks as shown in Table 42. CD fertilized roots in CC recorded the lowest weevil number (1.25) in storage

while roots from control plots in InG storage recorded the highest number of weevils (36.77).

Table 41: Effects of Structure and Fertilization on weevil numbers in OFSP roots after 4, 8 and 13 weeks in storage

Treatment	Number of weevils		
Structure	Number of weevils 4 wk	Cum number of weevils 8 wk	Cum number of weevils 13 wk
CC	2.12	3.19	5.9
HexB	3.12	9.25	24.9
InG	4.68	26.57	27.7
Room	9.32	23.91	32.2
F-test	**	**	**
LSD	3.275	4.695	6.58
CV (%)	46	41.9	40.8
Fertilization			
PM	4.69	15.82	22.9
CD	4.19	16.19	24.1
NPK	5.19	16.15	24.2
Control	5.19	14.76	19.4
F-test	NS	NS	NS
LSD	1.768	4.695	6.58
CV (%)	46.0	41.9	40.8

Source: Author's Data (2015) Where NS = non-significant and ** = highly significant at $p<0.01$ probability level; CV = coefficient of variation; LSD = Least Significant Difference between means.

Table 42: Interaction effect of storage structure and fertilization on number of weevils after 8 weeks of storage

Treatments	Number of weevils			
	Fertilization			
Structure	CD	Cont.	NPK	PM
CC	1.25	5.25	3.75	2.50
Hex B	5.75	8.00	14.25	9.00
InG	25.00	36.77	23.50	21.03
Room	32.77	9.00	23.11	30.75
F-test			**	
LSD			9.39	
CV (%)			41.9	

Source: Author's Data (2015) Where * = significant at $p<0.05$ probability level; CV = coefficient of variation; LSD = Least Significant Difference between means

Conclusions

The evaporative storage structures significantly reduced percentage root decay, shrinkage, weight loss and weevil infestation in storage as compared to room storage. However, there was increase in sprouting of OFSP roots stored in evaporative storage structures. Cool chamber evaporative structure (CC) recorded lower root shrinkage, decay, weight loss and weevil infestation in storage as compared to the other evaporative structures. However there was increased in tuber sprouting in OFSP tubers stored in cool chamber. Soil amendment significantly influenced percentage root decay. Application of PM reduced percentage root decay after 13 weeks of storage. PM and CD reduced weight loss in storage significantly. After 13 weeks in storage PM reduced percentage decay in roots in CC storage (21.6%) while roots from control

plots recorded 100 % decay. Thus roots from unfertilized plots decayed more severely than roots from fertilized plots in storage. Reduced irrigation (water stress) resulted in insignificant reduction in percentage root decay. Irrigation, manure and their interaction did not significantly influence weevil infestation in storage.

CHAPTER SIX

THE EFFECT OF IRRIGATION, MANURE AND NPK ON QUALITY AND PROXIMATE CONTENT OF ORANGE FLESHED SWEET POTATO (OFSP)

Introduction

Sweet potato is high in nutritive value and it outranks most carbohydrate based food (Onuh et al., 2004). Sweet potato serves as a staple food vegetable (fleshy roots and tender leaves), snack food, weaning food and animal feed. It also serves as raw material for the production of starch and alcohol. Sweet potatoes are a good source of minerals (Luis et al., 2013), carbohydrates, fibre, antioxidants, starch and vitamins (Anderson & Gugerty, 2013). According to Shih et al. (2007), among the other root and tuber crops, sweet potato possesses higher contents of carbohydrates, various vitamins, minerals, and protein than other vegetables. Sweet potato roots and leaves are also good sources of antioxidants (Toew et al., 2007). Sweet potato roots are good sources of fibre, vitamin C and minerals such as zinc, potassium, sodium, manganese, calcium, magnesium and iron (Antia et al., 2006). Orange Fleshed Sweet Potato (OFSP) especially is high in carotenoids, particularly βeta carotene. βeta carotene is a precursor to vitamin A and it contributes in alleviating vitamin A deficiency (Strobe et al., 2007). The importance of carotenoid in nutrition and health in the developing countries where deficiency of vitamin A remains a serious health problem cannot be over-emphasized. Vitamin A deficiency is a major public health problem in developing countries

such as Ghana. According to Hinneh (2013), statistics by the Ghana Health Service (GHS) (2012) indicate that 12,000 children in Ghana die every year due to malnutrition. It was further indicated that malnutrition contributes to about half of all child deaths beyond early infancy and one out of every thirteen children in Ghana die before their fifth birthday due to under-nutrition. Increased production and utilization of OFSP could be cost effective solution to vitamin A deficiency in children in Ghana and other developing countries.

However, the production of sweet potato is going down despite its nutritional and economic value. Average yield of 5 tonnes ha^{-1} is low as compared to 14 tonnes ha^{-1} in China and other developing regions of Asia. The reduction in production can be attributed to poor soil nutrient status and rapid growth in population leading to excessive cultivation of land (IITA, 1995). Excessive cultivation of land leads to excessive nutrient removal and thereby soil nutrient depletion which results in low yields. The causes of low yields can also be attributed to poor agronomic practices. There is therefore the need to reinvigorate over cultivated soils and improve the physical and chemical conditions of the soil. It has been stated that the application of fertilizers is one of the most important ways of increasing the productivity of crops (Ali et al., 2009). Depending on the fertility status of the soil, fertilizer may increase the yield of sweet potato by 32-83 %. Manure is an age-old source of fertilizer which modifies soil physical and chemical properties and releases nutrients for a longer period of time. Plant nutrients are essential for the production of high quality crops to provide nutrient requirement for the world's expanding

population. Therefore increased crop production largely relies on the type of fertilizer used to supplement essential nutrients for plants. An earlier study showed that increase in the levels of poultry manure applied resulted in an increase in dry matter, starch, fiber and protein contents and a decrease in fat content of *Dioscorea. bulbifera*. Dry matter, β-carotene and starch content in roots were lower in traditional system of production where no manure and fertilizer was applied (Nedunchezhiyan et al., 2010). However, they found that traditional system of production of sweet potato recorded higher sugar content in roots.

Prolonged drought condition reduces the formation and growth of roots and dry matter accumulation (Pardales et al., 2000). On the contrary Indira and Wanda (2004) stated that higher irrigation levels resulted in lower dry matter content of roots. They however indicated that the total nitrogen content of sweet potato roots was significantly responsive to irrigation and that lower water stress (higher irrigation levels) resulted in higher total nitrogen content of roots.

There is less information about the sensitivity of root carbohydrates, total nitrogen, fibre content, ash content, beta carotene, total phenols, dry matter, etc. of OFSP to irrigation and manure in the coastal savanna zone of Ghana. This study therefore examined the effect of irrigation and manure treatments on the root carbohydrates, total nitrogen, fibre content, ash content, beta carotene, total phenols, dry matter, etc. on OFSP. The specific objectives of the study were: (1) to determine the effect of the level of irrigation and manure on nutritional content of OFSP, (2) to determine the interaction effect

of irrigation and fertlization on the nutritional content of OFSP and (3) to determine the effect of evaporative storage structure on the nutritional content of OFSP.

Materials and Methods

Sample collection

A field experiment was carried out between October 2014 and January 2015 planting season at the Teaching and Research Farm of University of Cape Coast in the Central Region of Ghana as described in Chapter 3 of this thesis. Sample of OFSP roots were harvested for analysis.

Preparation of sample for analysis

Three sweet potato roots were randomly selected from each treatment at harvest. The freshly harvested sweet potato samples were washed with clean water and sliced into thin slices for drying.

The sliced samples of OFSP roots were dried in an oven at 60 °C. The dried samples (10 g) were then homogenized into powdery form ready for the analysis. Preparation of sample solution for the determination of N, K, Na, Ca, Mg, P, Zn, Cu and Fe was done following standard protocols.

The preparation of sample solutions suitable for elemental analysis involved an oxidation process which is necessary for the destruction of the organic matter, through acid oxidation before a complete elemental analysis could be carried out.

Sulphuric acid-hydrogen peroxide digestion procedure as outlined in Jones et al. (1991) is described in Appendix A1.

Determination of total Nitrogen was by the MICRO-KJEDAHL Method as described in Appendix A2.

Percentage nitrogen content was determined as in Equation 30.

Calculation:

$$N(\%) = \frac{(S.B) \text{ x solution volume}}{102 \text{ x aliquot x sample weight}} \qquad 30$$

Where,

S = Sample titre value

B = Blank titre value

Colorimetric determination of phosphorous (P) using the ascorbic acid method

Phosphorous was determined by Molybdate yellow method (Onwuka, 2005) using spectrophotometer. The procedure is as described in Apendix A3. A calibration curve was plotted using their concentrations and absorbances. The concentrations of the sample solutions were extrapolated from the standard curve. Phosphorous in the digested samples were calculated using Equation 31.

Calculation:

$$P(\mu g/g) = \frac{C \text{ x Dilution Factor}}{\text{weight of sample}} \qquad 31$$

Where C = P g ml^{-1} obtained from the graph,

(IITA, 1985)

Determination of potassium (K) and sodium (Na)

They were determined by flame photometric method (AOAC, 1984) as described in Appendix A4. Potassium and sodium in the digested samples were calculated as in Equation 32 and 33, respectively.

Calculation

$$K(\mu g/g) = \frac{\text{C x solution volume}}{\text{Sample weight}} \qquad 32$$

Where:

C = K µg/g obtained from the graph

$$Na\ (\mu g/g) = \frac{\text{C x solution volume}}{\text{Sample weight}} \qquad 33$$

C = Na µg/g obtained from the graph

(Jones et al., 1991)

Determination of calcium and magnesium by EDTA titration

Calcium and magnesium were determined using versanate complexometric titration method. The method involved chelation of the cations with ethylene diaminetetra-acetic acid (EDTA). The procedure is described in appendix A5. Percentage calcium and magnesium in the digested samples were computed using Equation 34 and 35, respectively.

Calculations:

$$\%\ Ca = \frac{0.005x40.08xT}{Sample\ weight} \qquad 34$$

$$\% Mg = \frac{0.005x39.1xT}{Sampl\ weight} \quad 35$$

Where T = titre value

(Page, Miller, & Keeney, 1982)

Determination of iron (Fe), copper (Cu) and zinc (Zn) using Atomic Absorption Spectrophotometer (Buck Model 210 UGP)

Iron, copper and zinc were determined using Atomic Absorption Spectrophotometer (AAS). The procedure is as described in Appendix A6. Iron, copper and zinc were determined using Equations 36, 37 and 38, respectively.

Calculations:

$$Fe\ (\mu g\ g^{-1}) = \frac{\text{C x solution volume}}{\text{Sample weight}} \quad 36$$

$$Cu\ (\mu g\ g^{-1}) = \frac{\text{C x solution volume}}{\text{Sample weight}} \quad 37$$

$$Zn\ (\mu g\ g^{-1}) = \frac{\text{C x solution volume}}{\text{Sample weight}} \quad 38$$

Determination of Sulphur (S)

The determination of sulphur was carried out in a di-acid digestion using nitric acid and perchloric acid (2:1) as described in Appendix A7.

The sulphur content of the samples were determined using Equation 39

Calculation:

$$S\ (\mu g\ g^{-1}) = \frac{C\ x\ solution\ volume}{Sample\ weight} \qquad 39$$

(FAO., 2008).

Total phenols

The total phenolics in sweet potato extracts were estimated by Folin-Ciocalteu colorimetric method according to Ju (1989) with slight modification. The procedure is described in Appendix A8. Results were expressed as mg of gallic acid equivalents (GAE) per gramme dry weight (mg kg^{-1} dw).

Sample preparation for proximate analysis

For each treatment or sweet potato sample, three roots were randomly taken, washed with tap water, peeled and cut into thin slices, packed into plastic bags and frozen for analysis. Samples were taken from the stem end, the mid-section, the root end and pooled for analysis.

Determination of Nutrient Composition

Starch determination

The determination of starch in sweet potato was measured by a rapid method with acid hydrolysis as described in Appendix A9. It was first extracted with perchloric acid and determined colorimetrically after it had formed a blue complex with potassium iodide (Allen et al., 1974). The percentage starch content of samples were determined with Equation 40.

$$Starch\ (\%) = \frac{C\ (mg) x\ solution\ volume\ (ml)}{10\ x\ aliquot\ (ml)\ x\ sample\ weight\ (g)} \qquad 40$$

Where:

C = miligrammes of starch from graph

Sugar determination

Sugar was determined by extraction with ethanol and determined by calorimetric means.

Protein determination

Protein was determined by finding total nitrogen by the Kjeldahl method. Protein content of sweet potato sample was calculated with conversion ratio N (%) x 6.25.

Crude fibre

Crude fibre in sweet potato was measured using modification of Moir (1971) method (Allen et al., 1974). Fibre was first extracted with diethyl ether and then the sample hydrolyzed by boiling with 1.25 % w/v sulphuric acid. This was followed by alkali extraction with 1.25 % w/v NaOH. The percentage fibre content of samples were determined using Equation 41.

$$Crude\ fibre\ (\%) = \frac{Uncorrected\ fibre(g)x\ loss\ in\ wt(g)x\ total\ extracted\ material\ x10^2}{wt\ of\ ash\ (g)x\ wt\ of\ hydrolysis\ (G)x\ sample\ wt\ (g)} \quad 41$$

Dry Matter and Ash Content Determination

Dry matter content was determined based on the oven-drying method at 105 °C for 48 hours or dried till constant weight. Dry matter content of the samples was calculated from the initial and final weight of each sample (Equation 42).

Ash content in sweet potato was measured by the standard GB/T5009.4-2010 method.

$$Dry\ matter\ content\ (\%) = \frac{Weight\ of\ sample\ after\ dring}{Weight\ of\ sample\ before\ drying}\ x\ 100 \quad 42$$

Carotenoid Analysis (Harvestplus Method)

Determination of ß-carotene in frozen and milled sweet potato roots was done by HarvestPlus method (Rodriguez-Amaya and Kimura, 2004). The procedure consisted of sample preparation, extraction, partitioning and Spectrophotometric analysis as described in Appendix A10.

Extraction

A portion of 10 g of the frozen sample was placed in a mortar and ground and 30 ml of cold acetone was mixed with the help of the pestle for 5 minutes. The sample was filtered with suction through Buckner funnel with Whatman No 1 filter paper. The extract was received in a protected suction flask. The mortar, pestle, and residue were washed with a small amount of acetone. The extraction was repeated 3 to 4 times until the residue was devoid of colour.

Partitioning to petroleum ether

Twenty millilitres (20 ml) of petroleum ether was put in a separating funnel and a small portion of the acetone extract added.

Distilled water was added slowly, letting it flow along the walls of the funnel. To avoid formation of an emulsion, the experimental setup was kept steady and devoid of shaking (once formed, an emulsion can be broken by adding acetone or sodium chloride).

The two phases were allowed to separate and the lower aqueous-acetone phase discarded. Another portion of the acetone extract was added and the operation was repeated until all of the extract has been transferred to petroleum ether, then it was washed 4 to 5 times with water to remove residual acetone.

The extract was washed with 150-200 ml of brine solution (NaCl) to break any emulsion formed.

The petroleum ether phase was collected in a 25 ml volumetric flask making the ethereal extract pass through a glass funnel containing an anhydrous sodium sulphate. The extract was transferred into amber bottle for absorbance reading.

Spectrophotometric analysis of total carotenoid

The carotenoid ethereal extract was read at 450 nm using Cecil CE 1021 spectrophotometer. The total carotenoid concentration was then calculated using the coefficient of absorption for β-carotene (2592). The total carotenoid content of samples were determined with Equation 43.

$$Total\ Carotenoid\ content = \frac{A_{total}\ x\ Vol(ml) x\ 10^4\ x\ (DF)}{A^{1\%}{}_{1cm}\ x\ sample\ weight} \qquad 43$$

Where:

A_{total} = Absorbance at 450 nm

Volume (ml) = Total volume of extract (25 mls)

$A^{1\%}{}_{A3m}$ = 2592 (absorption coefficient of beta-carotene in petroleum ether (PE)

DF = Dilution factor

Data collected

Potassium content of roots

$$K\ (\mu g\ g^{-1}) = \frac{\boldsymbol{C\ x\ solution\ volume}}{\boldsymbol{Sample\ weight}}$$

Calcium content of roots (%)

$$\%\ Ca = \frac{0.005x40.08xT}{Sample\ weight}$$

Magnesium content of roots (%)

$$\%\ Mg = \frac{0.005x39.1xT}{Sampl\ weight}$$

Zinc content of roots

$$\text{Zn}\ (\mu\text{g/g}) = \frac{\text{C x solution volume}}{\text{Sample weight}}$$

Sulphur content of roots

$$S\ (\mu g/g) = \frac{C\ x\ solution\ volume}{Sample\ weight}$$

Starch content (%)

$$Starch\ (\%) = \frac{C\ (mg)x\ solution\ volume\ (ml)}{10\ x\ aliquot\ (ml)x\ sample\ weight\ (g)}$$

Crude fibre (%)

$Crude\ fibre\ (\%)$

$$= \frac{Uncorrected\ fibre(g)x\ loss\ in\ wt(g)x\ total\ extracted\ material\ x10^2}{wt\ of\ ash\ (g)x\ wt\ of\ hydrolysis\ (G)x\ sample\ wt\ (g)}$$

Protein content (%)

Protein content of sweet potato sample was calculated with conversion ratio N (%) x 6.25.

Total carotenoid

$$Total\ Carotenoid\ content = \frac{A_{total}\ x\ Vol(ml) x\ 10^4\ x\ (DF)}{A^{1\%}{}_{1cm}\ x\ sample\ weight}$$

Statistical analysis

The data collected were subjected to statistical analysis using Analysis of Variance (ANOVA). The data obtained were analyzed using the GenStat Discovery Edition 4.0 statistical package. Least Significant Difference (LSD) was used to separate the means at 5 % level of probability.

Results and Discussion

Fibre content (%)

Fibre content of OFSP roots was significantly ($p<0.05$) responsive to level of irrigation as shown in Table 43. Fibre content of tubers increased with decreasing level of irrigation. The rank order of fibre content of tuber was 70 % ET_c (12.70 %) > 80 % ET_c (12.42 %) > 90 % ET_c (11.82 %) > 100 % ET_c (10.97 %) as shown in Table 43. Thus water stress or reduced water application resulted in higher fibre content of roots. This could be beneficial in the sense that lower application of water saves water for other uses while it produces more dietary fibre. Moreover, dietary fibre has the potential to reduce the incidence of a variety of diseases in man including colon cancer, diabetes, heart diseases and digestive disturbances (Palmer, 1982).

Soil amendment significantly influenced the level of fibre content of root (Table 43). However, CD and NPK were not significantly better than the control in influencing fiber yield. PM resulted in the lowest root fibre content

(10.01 %) and it was significantly lower than CD (12.77 %), NPK (12.68 %) and the control (12.45 %).

Irrigation and soil amendments interactions significantly influenced root fibre content (Figure 32). PM and 100 % ET_c interaction resulted in the lowest root fibre content of 5.96 %. However, fibre content increased to 11.21 %, 11.64 % and 11.09 % as water stress (DI) increased to 90 % ET_c, 80 % ET_c and 70 % ET_c, respectively. Similarly for CD treated plots root fiber content increased as irrigation level decreased. Root fibre content decreased with water stress for NPK and Control. Fibre content of roots increased by 48.9 % from 10.49 % to 15.62 % as water stress increased from 100 % ET_c to 70 % ET_c. On the contrary, fibre content of roots decreased from 14.27 % to 11.89 % for plots treated with NPK, as level of irrigation decreased from 100 % ET_c to 70 % ET_c, respectively as shown in Figure 32. Similarly, for the control experiment, fibre content of roots decreased from 13.23 % to 11.84 % as irrigation level decreased from 100 % CWR to70 % CWR. Fibre content increased with water stress for PM and CD but not for NPK and Control. Thus it can be concluded that fibre content increased with water stress for manure.

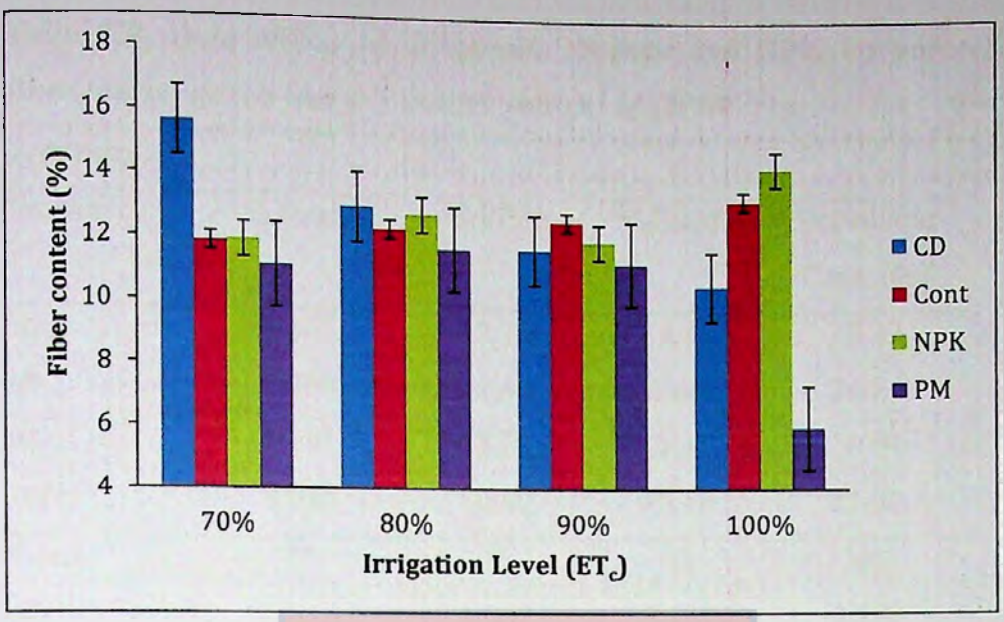


***Figure 32*: Interaction effect of Manure, NPK and irrigation on percentage fibre content of OFSP (Lsd = 2.082, p<0.01)**

Sugar content (%)

Sugar content of roots was significantly ($p<0.01$) responsive to irrigation (water stress). Table 43 shows that sugar content of roots decreased as water stress increased. Application of 100 % ET_c and 90 % ET_c resulted in 8.034 % and 8.141 % sugar content respectively which were not significantly different. However, further reduction of irrigation to 80 % ET_c and 70 % ET_c decreased sugar content to 7.791 % and 7.641 %, respectively. It can thus be stated that the sugar content of OFSP roots can be increased or decreased by regulating irrigation depending on the purpose of production.

Table 43: Main effects of irrigation, Manure and NPK on percentage fiber, sugar, starch and dry matter content of OFSP

Treatments				
Irr. % ETc	% Sugar	% Fibre	% Starch	Dry matter Cont. (%)
70	7.641	12.70	49.48	20.37
80	7.791	12.42	52.68	21.24
90	8.141	11.82	51.47	20.84
100	8.034	10.97	50.48	21.02
F-test	**	*	NS	NS
LSD	0.2641	1.042	2.775	1.188
CV (%)	3.13	8.09	5.10	6.8
Fertilization				
PM	8.267	10.01	51.60	21.59
CD	6.959	12.77	47.59	19.68
NPK	4.484	12.68	39.52	20.61
Control	11.981	12.45	65.84	21.58
F-test	**	**	**	**
LSD	0.2641	1.042	2.775	1.188
CV (%)	3.13	8.09	5.10	6.8

Source: Author's Data (2015) NS = non-significant and ** = highly significant at $p<0.01$ probability level; CV = coefficient of variation; LSD = Least Significant Difference between means

Soil amendment significantly ($p<0.01$) influenced sugar content of roots (Table 43). The ranking order of sugar content of roots was Control (11.981 %) > PM (8.267 %) > CD (6.959 %) > NPK (4.484 %). The Control resulted in higher sugar content than PM, CD and NPK which is supported by similar finding by Essilfie (2012). She observed that in the minor season *apomuden* (OFSP) from control (unfertilized plots) contained 12.1 % sugar

while roots from 10 tons ha^{-1} PM and 30-30-30 kg ha^{-1} NPK treated plots contained 11.7 % and 10.5 % respectively.

The effect of the interaction between irrigation and soil amendment on sugar content was highly significant as shown in Table 44. Sugar content of roots from control was not affected by irrigation level as there was only an insignificant reduction of sugar content as irrigation was reduced from 100 % to 70 % ET_c. Sugar content of NPK treated plots decreased significantly from 4.96 % to 4.045 % as irrigation decreased from 100 % to 70 % ET_c. There were non-significant reduction in sugar content of roots as irrigation decreased from 100 % to 70 % ET_c for CD and PM. Thus sugar content decreased with water stress for NPK but not PM, CD and control.

Table 44: Interaction effect of CD, PM NPK and irrigation level on percentage sugar content of OFSP

	Percentage Sugar			
Treatments	Fertilization			
Irri. % ETc	CD	Control	NPK	PM
70	6.820	11.891	4.045	7.909
80	6.969	11.815	4.111	8.372
90	7.049	12.209	4.877	8.565
100	7.016	12.020	4.960	8.265
F-test		**		
LSD		0.5274		
CV (%)		3.13		

Source: Author's Data (2015) Where ** = highly significant at $p<0.01$ probability level; CV = coefficient of variation; LSD = Least Significant Difference between means.

Starch content (%)

Starch content of roots was not significantly responsive to irrigation (water stress) as shown in Table 44. However, starch content of roots increased from 50.48 % to 52.68 % as irrigation decreased from 100 % to 80 % ET_c. Starch content subsequently decreased to 49.48 % when irrigation was further reduced to 70 % ET_c. Soil amendments had significant ($p<0.01$) effect on starch content of OFSP roots at harvest. The rank order of sugar content of roots was Control (65.84 %) > PM (51.60 %) > CD (47.59 %) > NPK (39.52 %). The control had the highest starch content than the application of PM and NPK which is supported by similar finding by Essilfie (2012). She noted that in the minor season *Apomuden* (OFSP) from unfertilized plots contained 16.8 % starch while roots from 10 t ha^{-1} PM and 30-30-30 kg ha^{-1} NPK treated plots contained 13.3 % and 11.9 % respectively.

Irrigation and soil amendments interaction also significantly ($p<0.01$) influenced starch contents of roots after harvest (Figure 33). From Figure 33 sugar content of roots produced from CD, PM and control plots decreased as irrigation decreased (water stress increased). For NPK produced roots sugar content increased (from 34.05 % to 41.47 %) as irrigation decreased from 100 % ET_c to 70 % ET_c.

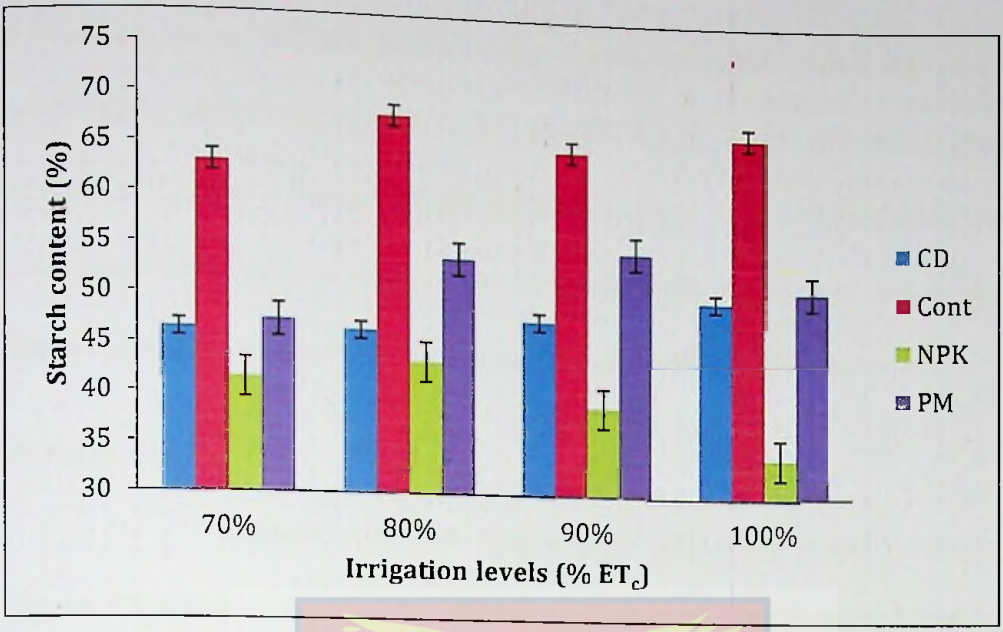


***Figure 33*: Interaction effect of CD, PM NPK and irrigation level on percentage starch content of OFSP (Lsd 5.542; p<0.01)**

Dry matter content (%)

Dry matter accumulation was not significantly influenced by level of irrigation (Table 43). However, reduced water application to 70 % ET_c resulted in the lowest dry matter content, of 20.37 % which is consistent with work done by Pardales et al. (2000) who stated that drought condition reduces the formation and growth of roots and dry matter accumulation. Manure and NPK application, however, significantly affected dry matter content of tubers (Table 43). CD treated plots produced the lowest dry matter content of roots (19.68 %) while PM gave the highest dry matter yield (21.59 %) which was not significantly different from NPK and control.

Ash content of roots

Irrigation significantly ($p<0.01$) influenced ash content of roots as shown in Table 45. Full irrigation (Irrigation at 100 % ET_c) resulted in the

lowest ash content of tubers (2.078 %). The highest ash content was recorded at 90 % ET_c (4.195 %) and 70 % ET_c (4.180 %). It can be stated that reduced irrigation resulted in increased ash content of tubers. Soil amendment had no significant influence on ash content of roots. Soil amendment and irrigation interaction also had no significant effect on ash content of roots.

Protein content

Irrigation did not significantly influence protein content of tubers. Protein content of tubers increased as water stress increased (Table 45) though differences were not significant. This observation is contrary to Indira and Wanda (2004) who indicated drought reduced total nitrogen content of roots and root yield. Though fertilization did not significantly influence protein content of roots manure and NPK application resulted in higher protein content of roots than the control.

Manure and irrigation interaction significantly ($p<0.05$) influenced protein content of roots (Figure 34). Protein content increased with water stress for NPK. NPK and 100 % ET_c interaction yielded 6.27 % protein but increased to 9.17 % and subsequently 7.76 % protein as water stress increased to 80 % CWR and 70 % CWR respectively. For CD and PM, protein content decreased as DI increased from 100 % ET_c to 80 % ET_c. However, further reduction in water application to 70 % CWR increased protein content of roots.

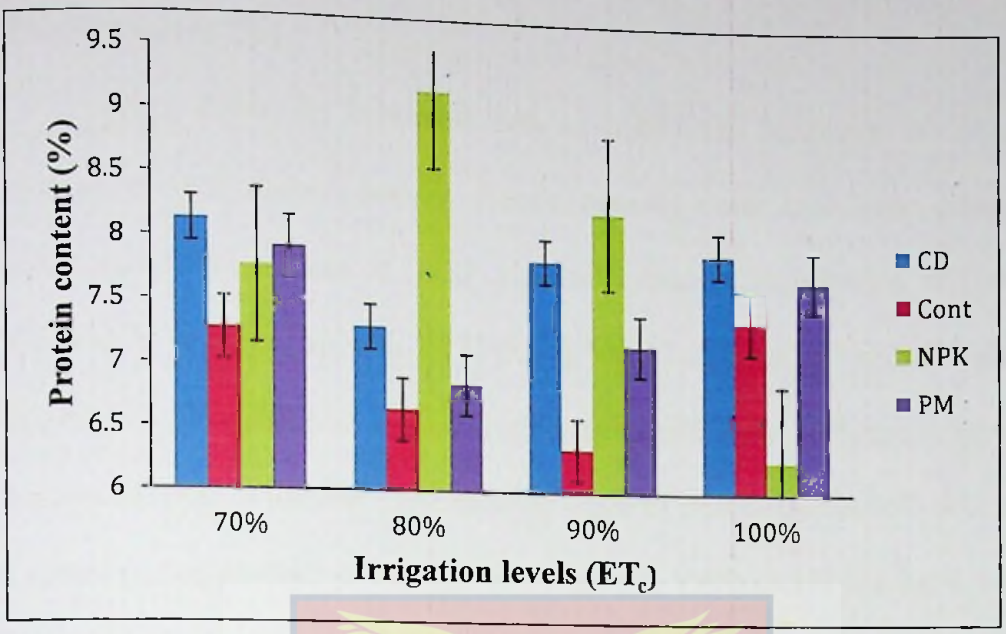


Figure 34: **Interaction effect of CD, PM NPK and irrigation level on percentage protein content of OFSP roots (Lsd = 1.606; p<0.05)**

Table 45: Main effects of irrigation, CD, PM and NPK on percentage ash, protein, phenols and fat content of OFSP

Treatments				
Irr. % ETc	% Ash	% Protein	Phenols (mg/kg)	% Fat
70	4.180	7.784	1.227	1.618
80	2.956	7.487	1.286	1.511
90	4.195	7.422	1.221	1.348
100	2.078	7.340	1.277	1.988
F-test	**	NS	NS	NS
LSD	1.488	0.804	0.07095	0.6570
CV (%)	41.19	10.02	5.31	38.24
Fertilization				
PM	2.276	7.434	0.975	1.925
CD	3.511	7.812	1.271	1.490
NPK	3.446	7.860	1.131	1.196
Control	4.259	6.923	1.628	1.871
F-test	NS	NS	**	NS
LSD	1.488	0.804	0.07095	0.6570
CV (%)	41.19	10.02	5.31	38.24

Source: Author's Data (2015) Where NS = Not significant and ** = highly significant at p<0.01 probability level; CV = coefficient of variation; LSD = Least Significant Difference between means.

Phenol content (%)

From Table 45 irrigation had no significant influence on phenol content of OFSP roots at harvest. Hence reducing water application does not affect the phenol content of OFSP roots after harvest. Application of 100 % ET_c and 70 % ET_c resulted in 1.277 mg kg^{-1} and 1.227 mg kg^{-1} phenol content respectively. However, soil amendment significantly influenced phenol content of roots at harvest. The ranking order of phenol content of roots was Control (1.628 mg kg^{-1}) > NPK (1.131 mg kg^{-1}) > CD (1.271 mg kg^{-1}) > PM (0.975 mg kg^{-1}). The Control produced significantly more phenol than NPK, CD and PM. Soil amendment and irrigation interaction significantly ($p<0.05$) influenced phenol content of roots as shown in Figure 35. Phenol content of roots increased as irrigation reduced for CD. NPK and 100 % ET_c interaction yielded 1.283 mg kg^{-1}phenol, however as irrigation decreased to 70 % ET_c phenol content decreased to 1.119 mg kg^{-1}. On the contrary for NPK and the Control, reduced irrigation (increased water stress) reduced phenol content of roots as shown in Figure 35. PM and irrigation interaction caused no significant change in phenol content as irrigation reduced from 100 % ET_c to 70 % ET_c.

Fat content (%)

Irrigation and soil amendments and their interactions had no significant influence on fat content of OFSP roots after harvest (Table 45). However, application of 100 % ET_c resulted in the highest fat content of 1.988 %.

Similarly, PM application resulted in 1.925 % fat content which was the highest among the different soil amendments.

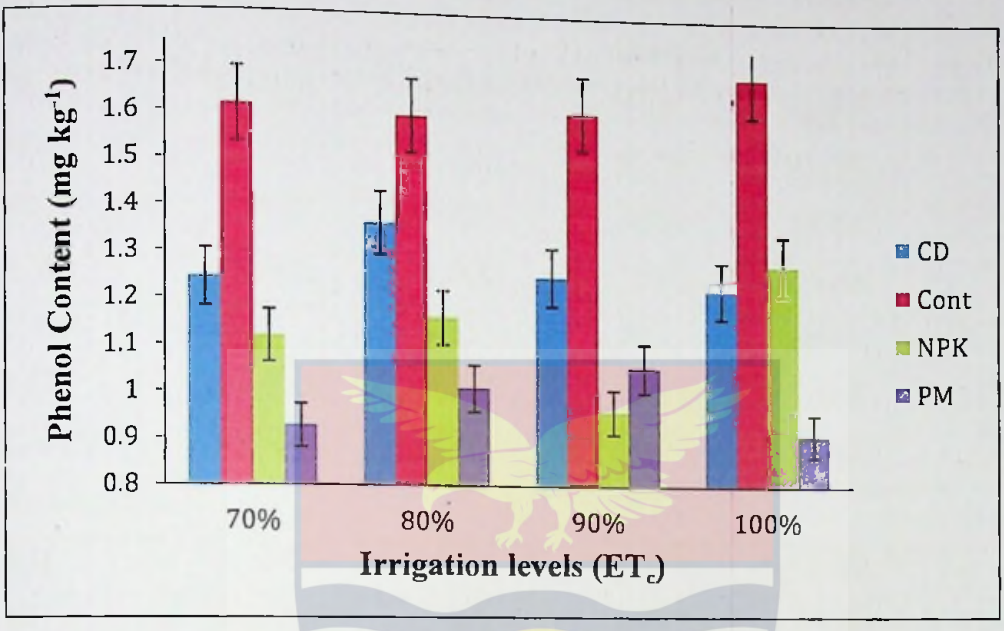


***Figure 35*: Interaction effect of CD, PM NPK and irrigation level on total phenol content (mg kg^{-1}) of OFSP roots (Lsd = 0.1417; $p<0.05$)**

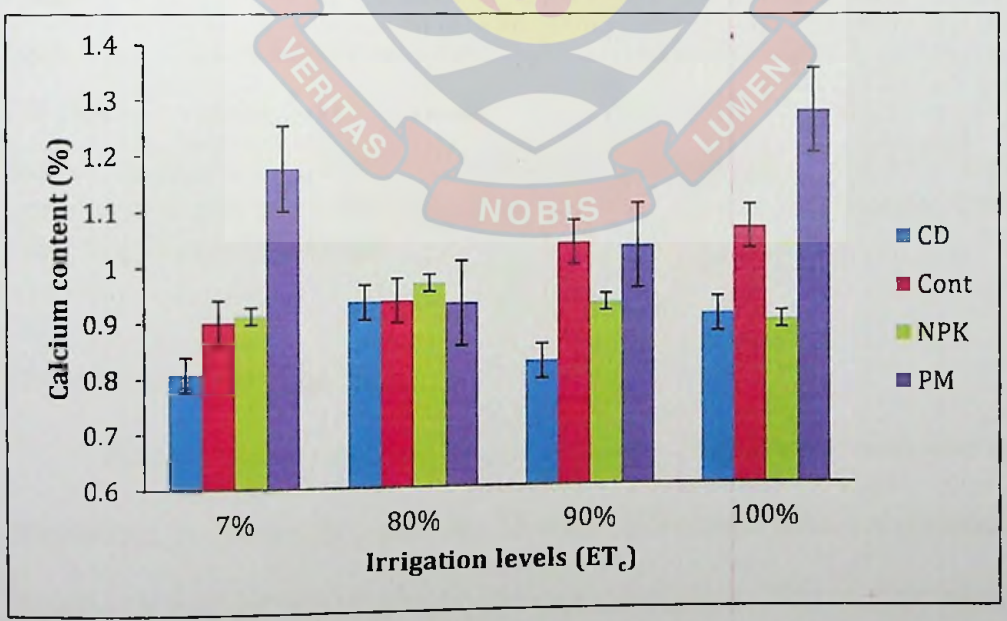


***Figure 36*: Interaction effect of CD, PM NPK and irrigation level on percentage Ca content of OFSP roots (Lsd = 0.1859)**

Table 46: Main effects of irrigation, CD, PM and NPK on percentage Ca, Mg, P and total carotenoid content of OFSP

Treatments				
Irr. % ET_c	% Ca	% Mg	Carotenoid ($\mu g\ g^{-1}$)	P(µg/g)
70	0.9452	7.784	9.94	66.63
80	0.9433	7.487	51.78	67.73
90	0.9535	7.422	37.37	68.88
100	1.0342	7.340	33.95	69.66
F-test	NS	NS	**	NS
LSD	0.09308	0.804	0.937	24.12
CV (%)	9.02	10.02	3.4	16.65
Fertilization				
PM	1.1070	7.434	19.83	67.56
CD	0.8675	7.812	40.77	75.46
NPK	0.9275	7.860	45.57	62.80
Control	0.9839	6.923	26.87	65.98
F-test	**	NS	**	NS
LSD	0.09308	0.804	0.937	24.12
CV (%)	9.02	10.02	3.4	16.65

Source: Author's Data (2015) Where NS = non-significant and ** = highly significant at $p<0.01$ probability level; CV = coefficient of variation; LSD = Least Significant Difference

Phosphorus content (µg/g)

Phosphorus content was not responsive to irrigation, manure and their interactions as shown in Table 46. Though differences were not significant, phosphorus content decreased with decreasing irrigation. The ranking order of phosphorus content as influenced by irrigation was 100 % ET_c (69.66 $\mu g\ g^{-1}$) > 90 % ET_c (68.88 $\mu g\ g^{-1}$) > 80 % ET_c (67.73 $\mu g\ g^{-1}$) > 70 % ET_c (66.63 $\mu g\ g^{-1}$).

CD and PM application produced the highest root phosphorus content of 75.46 µg g^{-1} and 67.56 µg g^{-1} respectively. NPK produced the lowest root phosphorus content (62.80 µg g^{-1}).

Calcium content (%)

Calcium content of roots was not responsive to levels of water application. Though differences were not significant water stress decreased calcium content. Fertilization, however, influenced calcium content significantly ($p<0.05$) as shown in Table 46. PM improved Ca content of roots by 12.5 % as compared to the control. However, CD and NPK application were not significantly better than the control.

Magnesium content (%)

Irrigation and manure had no significant influence on magnesium content of OFSP roots after harvest (Table 46). Though differences were not significant, water stress increased magnesium content of roots by 6.04 % from 7.34 % to 7.784 as irrigation decreased from 100 ET_c to 70 % ET_c. PM, CD and NPK increased magnesium content as compared to the control (Table 46). Though differences were not significant NPK produced the highest magnesium content of roots. The ranking order of magnesium content of roots was NPK (7.86 %) > CD (7.812 %) > PM (7.434 %) > Control (6.923 %). The interaction of manure and irrigation also did not significantly influence the magnesium content of OFSP roots. However, magnesium content of roots increased as DI increased from 100 % CWR to 70 % CWR for CD and Control (Figure 37). Magnesium content of roots increased by 89.9 % and

84.9 respectively for CD and Control as DI increased from 100 % CWR to 70 % CWR. On the contrary, magnesium content of roots from NPK treated plots decreased by 47.7 % as water stress (DI) increased from 100 % ET_c (0.01545 %) to 70 % ET_c (0.01046 %). The magnesium content of PM treated plots increased as irrigation level decreased (water stress increased) from 100 % CWR (0.01652 %) till 80 % CWR (0.02599 %) then subsequently decreased to (0.00797 %) as irrigation level decreased further to 70 % CWR. Thus PM and 80 % CWR produced the highest magnesium content of OFSP roots.

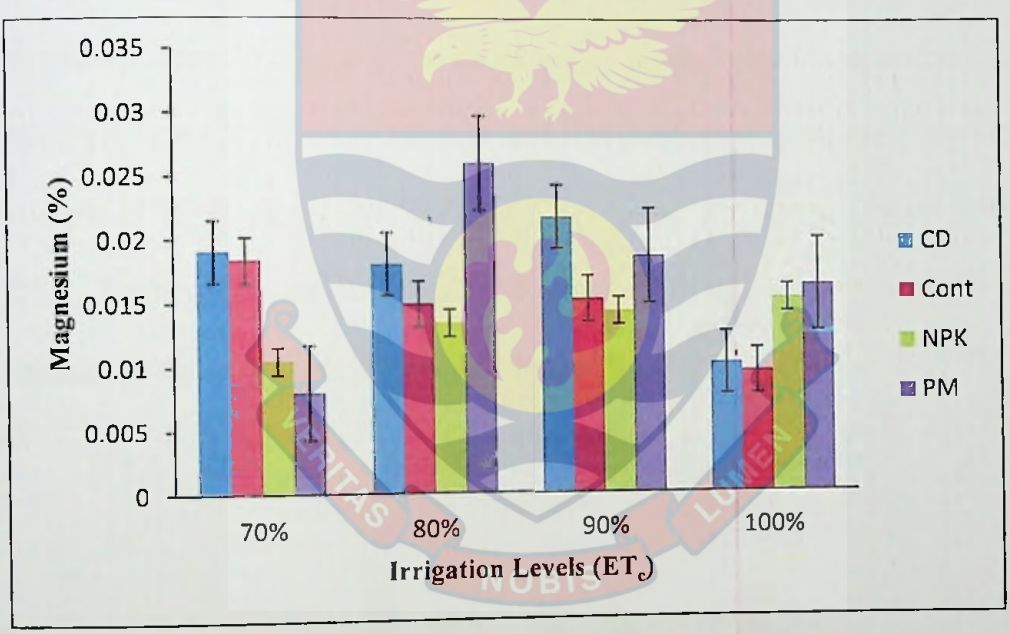


***Figure 37*: Percentage magnesium (Mg) content of tubers as influenced by interaction between irrigation and soil amendments (Lsd = 0.005178)**

Total carotenoid content (µg/g)

Irrigation significantly ($p<0.01$) influenced carotenoid content of OFSP roots after harvest (Table 46). Carotenoid content increased as irrigation decreased from 100 % ET_c (33.95 µg g^{-1}) to 80 % ET_c (51.78 µg g^{-1}).

However, further reduction of irrigation to 70 % ET_c resulted in lower carotenoid content of 9.94 µg g^{-1}. Thus, it can be suggested that DI at 80 % CWR produced the highest carotenoid content. Soil amendment also influenced carotenoid content significantly ($p<0.01$). The ranking order of carotenoid content of roots was NPK (45.57 µg g^{-1}) > CD (40.77 µg g^{-1}) > Control (26.87 µg g^{-1}) > PM (19.83 µg g^{-1}). Figure 38 shows carotenoid content of tubers was significantly ($p<0.01$) influenced by the interaction of soil amendment and irrigation. Carotenoid content decreased with increasing water stress (DI) for NPK and Control. For NPK treatment, carotenoid content decreased from 49.63 µg g^{-1} to 11.41 µg g^{-1} when irrigation decreased from 100 % ET_c to 70 % ET_c. For CD and PM treatments maximum carotenoid content of 73.91 µg g^{-1} and 55.23 µg g^{-1}, respectively, was produced at 80 % ET_c. Further increase in irrigation to 90 % ET_c or decrease to 70 % ET_c resulted in decrease in carotenoid content of roots.

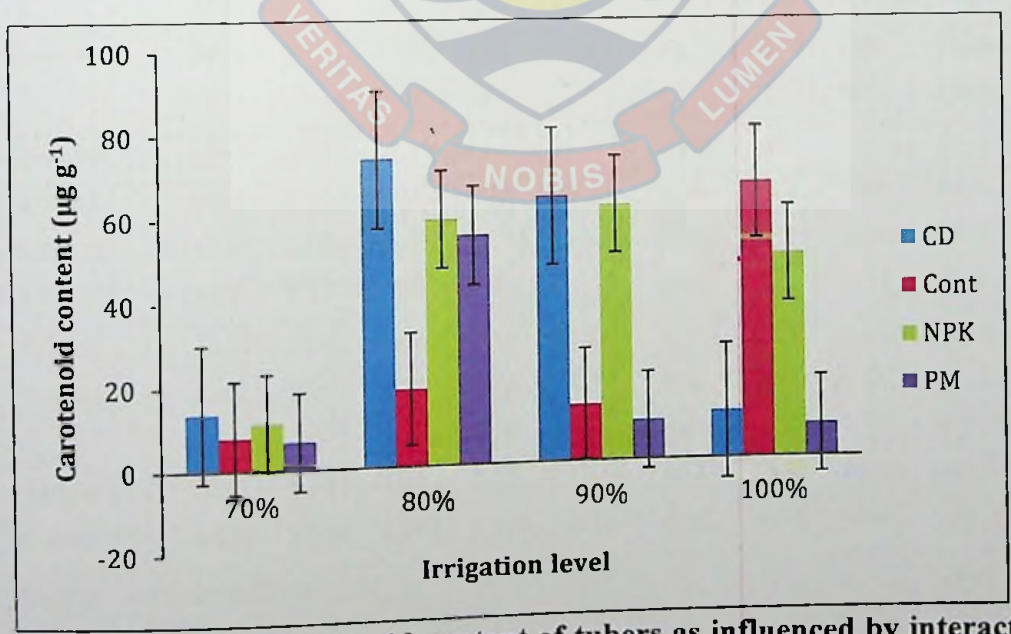


***Figure 38*: Total carotenoid content of tubers as influenced by interaction between irrigation and soil amendments (Lsd = 1.875; $p<0.01$)**

Changes in nutrient at the end of storage

Percentage mean change (mean reduction) in sugar content at the end of storage was 44.7 % as shown in Table 47. Reduction in starch content of roots at the end of storage was lower, 20.3 % while reduction in fat content was 21.8 %. The content of phenol in roots was also reduced by 8.7 % after 13 weeks of storage. On the contrary the tuber content of fibre, protein and ash increased by 14.1 %, 43.5 % and 92 %, respectively, after storage (Table 47). Table 48 shows percentage reduction in nutrient content of roots as influenced by soil amendments. There were increases in percentage content of sugar, starch, fat, and phenol while there were reduction in fibre, protein and ash content of roots after 13 weeks of storage.

Table 47: Nutrient content of OFSP tuber at harvest and after storage as influenced by irrigation

	At harvest				At end of storage (13 wks)				
Irrigation	70 %	80 %	90 %	100 %	70 %	80 %	90 %	100 %	Mean change %
Nutrients									
% Sugar	7.64	7.79	8.14	8.03	4.24	4.36	4.12	4.76	44.7
% Starch	49.48	52.68	51.47	50.48	40.56	38.58	41.15	42.38	20.3
% Fat	1.62	1.51	1.35	1.99	1.28	1.18	1.29	1.31	21.8
% Fibre	12.70	12.42	11.82	10.97	13.92	13.76	13.82	13.17	-14.1
Phenol mg g^{-1}	1.23	1.29	1.22	1.28	1.17	1.09	1.10	1.22	8.7
% Protein	7.78	7.49	7.42	7.34	10.74	10.42	11.36	10.57	-43.5
% Ash	4.180	2.956	4.195	2.078	6.21	5.86	6.70	6.98	-92

Source: Author's Data (2015)

Table 48: Nutrient content of OFSP tuber at harvest and after storage as influenced by manure and NPK application

	At harvest				At end of storage (13 wks)				
Manure	NPK	CD	Cont	PM	NPK	CD	Cont	PM	Mean change (%)
Nutrients									
% Sugar	4.48	6.95	11.98	8.26	4.83	4.49	4.04	4.12	44.8
%Starch	39.52	47.59	65.84	51.60	41.59	39.86	40.20	41.02	20.5
% Fat	1.196	1.490	1.871	1.925	1.29	1.33	1.07	1.37	21.9
% Fiber	12.68	12.77	12.45	10.01	15.00	12.44	15.07	12.15	-14.1
Phenol mg/g	1.13	1.27	1.63	0.98	1.40	1.00	1.02	1.15	8.8
% Protein	7.86	7.81	6.92	7.43	12.60	10.09	10.33	10.07	-43.5
% Ash	3.446	3.511	4.259	2.276	6.43	7.81	5.56	5.96	-90.9

Source: Author's Data (2015)

Conclusions

Fibre content increased with water stress for PM and CD but not for NPK and Control. The interaction of irrigation and soil amendments also significantly influenced fibre content of roots. Reduced water application (DI) decreased sugar content of roots. Control produced more sugar and starch than NPK, CD and PM. Irrigation and soil amendment interaction significantly influenced sugar content of roots. Sugar content of tubers from NPK amended plots decreased as irrigation decreased from 100 % to 70 % ET_c. Deficit irrigation did not influence starch and phenol content of tubers. Soil amendments significantly influenced starch and phenol content of OFSP root. Irrigation and soil amendments interaction also significantly influenced starch contents of tubers after harvest. Starch content of roots decreased as irrigation decreased for CD, PM and Control. On the contrary sugar content of

roots increased as water stress increased from 100 % CWR to 70 % CWR for NPK. Soil amendment and irrigation interaction significantly ($p<0.05$) influenced phenol content of tubers. Phenol content of roots increased as water stress increased for CD. Irrigation and soil amendments had no significant influence on fat content of OFSP roots after harvest. Irrigation and soil amendment significant ($p<0.01$) influenced carotenoid content of OFSP roots. Carotenoid content increased as irrigation decreased from 100 % to 80 % CWR. NPK treatments gave the highest carotenoid yield. Carotenoid content decreased with decreasing irrigation for NPK and Control. For CD and PM treatments maximum carotenoid yield was produced at 80 % CWR.

There were increases in percentage content of sugar, starch, fat, and phenol while there were reduction in fibre, protein and ash content of roots after 13 weeks of storage.

CHAPTER SEVEN

GENERAL CONCLUSIONS AND RECOMMENDATIONS

Introduction

A study involving deficit irrigation, organic and inorganic fertilizer practices was conducted at the Research Farm, School of Agriculture of the University of Cape Coast. Orange Fleshed Sweet potato was used in the study to determine the effect of water stress and fertilizer on growth and development of sweet potato, quality and nutritional content of the roots and shelf life in evaporative structures. There were sixteen treatments and three replications which were set up in Randomized Complete Block Design (RCBD). The crops were grown under rain shelter and water lost by the crops was computed from evapotranspiration. The plots were irrigated manually at two days intervals. Poultry manure, cow dung, NPK and no soil amendment were applied before planting. Crop growth components such as leaf number and number of branches were measured at the initial and mid-season stages. Reference evapotranspiration (ET_o) was determined from climatic data obtained from the nearby weather station. CROPWAT 8.0 which is based on FAO modified Penman-Montieth method was used to compute ET_o. Crop K_c and crop water requirement (ET_c) for the growth stages were computed. Crop water use efficiency (WUE) was determined. Soil nutrient level before planting and after harvest were determined.

After harvest crop root, vine yield, number roots per plant, sprouted tubers decayed roots, cracked roots and weevil infested roots were determined.

Sampled roots were cured for 5 days and stored in constructed evaporative structures and in an airy room for 13 weeks. Roots were examined monthly for decay, sprouting, shrinkage, weevil infestation and weight loss. Nutrient content of sampled roots were determined before and after storage. All data collected were subjected to statistical analysis using Genstat 4.0 Discovery edition.

Conclusions

On the basis of the results of field and storage study on Orange Fleshed Sweet Potato, the following conclusions were drawn:

Objective 1

The first specific objective was to compare the effectiveness of organic manure (Poultry manure and Cow dung), NPK and irrigation on growth and yield of OFSP. It was observed that:

Soil chemical properties studied were all increased by manure and NPK application. Increased water application reduced soil bulk density and particle density but increased soil pore volume. Reduced irrigation resulted in increase in bulk density, particle density and porosity. Reduced irrigation reduced growth of leaves and branches and increased root yield of OFSP. Soil amendment improved root yield better under reduced irrigation than under full irrigation. Water Use Efficiency (WUE) was highest at the minimum water application whilst full irrigation resulted in the lowest WUE.

Objective 2

The second specific objective was to determine the effect of soil amendments and irrigation on the quality of sweet potato (OFSP) roots. It was observed that:

OFSP marketable yields were significantly responsive to irrigation. Marketable yield reduced with decreasing irrigation from 100 % to 80 % ET_c. However, 70 % ET_c resulted in the highest marketable yield. Soil amendments significantly increased marketable yield. PM, CD and NPK increased marketable yields by 40.96 %, 30.34 % and 21.36 %, respectively, as compared to Control. Irrigation at 70 % ET_c resulted in the highest root number yield per plant and highest jumbo root yield per hectare. The interaction of soil amendment and irrigation levels had a significantly influenced jumbo root yield and dry matter yield. For PM and NPK treatment increased water stress (reduced irrigation) resulted in reduced dry matter yield. On the contrary, reduced irrigation increased dry matter yield for CD. DI had no significant influence on root cracking in the field, root damage during harvesting, weevil infestation and moisture content of roots. Though not significant, DI resulted in lower weevil infestation in the field. Soil amendment also had no significant effect on root cracking in the field, tuber damage during harvesting and weevil infestation. CD application resulted in significantly higher moisture content of roots than PM and Control. NPK application resulted in the highest weevil infestation. Reduced water application resulted in lower root sprouting while soil amendment promoted root sprouting in the field. Reduced water application (70 % CWR and 80 %

CWR) resulted in the lowest percentage root decay. The results of the study suggest soil amendments reduced root decay in the field.

Objective 3

The third specific objective was to compare the effectiveness of three evaporative structures of Cool chamber (CC), Hexagonal barn (HexB) and In-Ground structure (InG)) for the storage of sweet potato roots in terms of: The rate of size loss (shrinkage), weight loss, root sprouting, rate of root decay and pest infestation of roots. It was observed that:

Relative humidity was higher in the evaporative structures as compared to ambient conditions. The increase in relative humidity between evaporative structures and ambient conditions ranged from 19 - 21 %. Evaporative cooling structures reduced average outside temperature to 4.6 - 7.2 °C. The evaporative storage structures significantly reduced percentage root decay, shrinkage, weight loss and weevil infestation in storage as compared to room storage. However, there was increase in sprouting of OFSP roots stored in evaporative storage structures. Cool chamber recorded the lowest root shrinkage, root decay and weevil infestation as compared to InG, HexB and room storage. Hence Cool chamber is more effective storage structure or method than HexB, InG and Room storage. However, there was increase in root sprouting in OFSP roots stored in cool chamber due to the higher relative humidity in the structure. Soil amendment significantly influenced percentage root decay. PM reduced percentage root decay after 13 weeks of storage. PM and CD reduced weight loss in storage significantly. After 13 weeks in storage PM reduced percentage decay in tubers in CC storage (21.6 %) while

roots from control plots recorded 100 % decay. Thus roots from unfertilized plots decayed more severely than roots from fertilized plots in storage. Reduced irrigation (water stress) resulted in insignificant reduction in percentage root decay. Irrigation, manure and their interaction did not significantly influence weevil infestation in storage. Though not significant, weevil infestation decreased as irrigation level decreased.

Objective 4

The fourth specific objective was to determine the effect of soil amendment and irrigation on nutrient levels of sweet potato roots. It was observed that: Water stress (deficit irrigation) increased fibre content of OFSP roots. The interaction of irrigation and soil amendments also significantly influenced fibre content of roots. DI decreased sugar content of roots. Control produced more sugar and starch than NPK, CD and PM. Irrigation and soil amendment interaction significantly influenced sugar content of roots. NPK decreased sugar content as irrigation decreased from 100 % to 70 % ET_c. Reduced irrigation (DI) decreased starch content of roots for CD, PM and Control. On the contrary, DI increased sugar content of roots for NPK. NPK increased protein content of roots as water application reduced. Protein content of roots decreased with reduced irrigation for CD and PM. Phenol and protein content of roots were responsive to the interaction of soil amendment and irrigation levels. CD increased phenol content of roots as DI increased. On the contrary, phenol content decreased with DI for NPK and the Control. PM improved Ca content of roots by 12.5 % as compared to Control. CD and Control increased magnesium content of roots as irrigation level decreased though differences

were not significant. Application of NPK decreased magnesium content of roots with decreasing irrigation level. Phosphorus content decreased with decreasing irrigation though not significantly. Reducing water application did not reduce phenol content of OFSP roots after harvest. Protein content of roots increased as water stress increased though not significantly. Water stress decreased calcium and phosphorous content while magnesium content was increased, even though differences were not significant. There were increases in percentage content of sugar, starch, fat, and phenol while there were reduction in fibre, protein and ash content of roots after 13 weeks of storage. Generally, DI irrigation (70 % ET_c) and PM and NPK improved root yield better than under full irrigation. Water use efficiency was highest at DI 70 % CWR and lowest at full irrigation. DI (70% CWR) and PM produced the best marketable yield. DI (70 % ET_c) resulted in the highest jumbo root and marketable yield.

Recommendations

Objective 1

For maximum root yield and improve Water Use Efficiency (WUE) by the crop, poultry manure, cow dung and NPK should be applied and water application should be reduced to 70 % ET_c.

Objective 2

To increase marketable yield and to reduce root decay and sprouting in the field of Orange Fleshed Sweet potato roots irrigation should be reduced to 70 % ET_c.

Objective 3

Cool chamber storage is recommended for the storage of OFSP roots as against Hexagonal barn, In-Ground structure and Room storage.

For effective control of root decay, root shrinkage and weevil infestation, Orange Fleshed Sweet potato root s may be stored in Cool chamber.

Roots in Cool chamber should be treated with sprout suppressant to control sprouting in storage.

Objective 4

To produce OFSP roots with higher protein and sugar content from NPK treated plots irrigation should be reduced. On the contrary to produce OFSP roots with high protein and sugar content from PM and CD amended plots 100 % irrigation should be applied.

Generally OFSP roots with high dietary fiber content, total carotenoid and ash content can be produced with reduced irrigation.

Suggestions for further research

Other varieties of sweet potato known to respond to irrigation should be studied in order to determine which variety is best for a particular percentage of crop water requirements for best results.

The study should be carried out in other agro ecological areas since environmental conditions such as climate influence the results.

Further studies should be carried out to determine what happens beyond 70 % CWR and 60 % CWR.

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APPENDICES

APPENDIX A: PROCEDURE FOR NUTRITIONAL ANALYSIS OF SWEET POTATO ROOTS

A1: Sulphuric acid-hydrogen peroxide digestion procedure as outlined in Jones et al. (1991)

The digestion mixture comprises 350 ml of hydrogen peroxide, 0.42 g of selenium powder, 14 g Lithium Sulphate and 420 ml sulphuric acid. The digestion procedure as outlined in Jones et al. (1991) states that between 0.10 to 0.4 g of the oven-dried ground sample was weighed into a 100 ml Kjeldahl flask and 4.4 ml of the mixed digestion reagent was added and the samples digested at 360 °C for two hours. Blank digestions (digestion of the digestion mixture without sample) were carried out in the same way. After the digestion, the digests were transferred quantitatively into 100 ml volumetric flasks and made up to volume.

A2: Determination of total Nitrogen (MICRO-KJEDAHL Method)

Distillation

A steam distillation apparatus was set up and steam passed through it for about 20 minutes. After flushing out the apparatus, a 100 ml conical flask containing 5 mL of boric acid indicator solution was placed under the condenser of the distillation apparatus. An aliquot of the sample digest was transferred to the reaction chamber through the trap funnel. 10 ml of alkali mixture was added and distillation commenced immediately and about 40 ml of distillate collected. The distillate was titrated against M/140 HCI from green to the

initial colour of the indicator (wine red). Digestion blanks were treated the same way and subtracted from the sample titre value.

Calculation of percentage nitrogen content by Equation 30:

$$N(\%) = \frac{(S.B) \text{ x solution volume}}{102 \text{ x aliquot x sample weight}} \qquad 30$$

Where

S = Sample titre value

B = Blank titre value

A3: Colorimetric determination of phosphorous (P) using the ascorbic acid method

Phosphorous was determined by Molybdate yellow method (Onwuka, 2005) using spectrophotometer. The procedure required the preparation of colour forming reagent and P standard solutions. The colour forming reagent was made up of reagents A and B. Reagent A is made up of 12 g ammonium molybdate in 20 ml distilled water 0.2908 g of potassium antimony tartarate in 100 ml distilled water and 1l of 2.5M H_2SO_4. The three solutions were mixed together in a 2 l volumetric flask and made up to volume with distilled water. Reagent B was prepared by dissolving 1.56 g of ascorbic acid to every 200 ml of reagent A. A stock solution of 100 g P/mL solution was prepared from which E7P/mL solution a set of working standards of P with concentrations 0, 0.1, 0.2, 0.4, 0.6, 0.8 and 1.0 gP/ml in 25 ml volumetric flasks.

2 ml aliquot of the digested samples were pipetted into 25 ml volumetric flasks 2 ml aliquot of the blank digest were pipetted into each of the working standards to give the samples and the standards the same

background solution. 10 ml of distilled water was added to the standards as well as the samples after which 4 ml of reagent B was added and their volumes made up to 25 ml with distilled water and mixed thoroughly. The flasks were allowed to stand for 15minutes for colour development after which the absorbances of the standards and samples were determined using a spectrophotometer at a wavelength of 882 nm.

A calibration curve was plotted using their concentrations and absorbances. The concentrations of the sample solutions were extrapolated from the standard curve. Phosphorous in the digested samples were calculated using the following formula:

Calculation

$$P(\mu g/g) = \frac{\text{C x Dilution Factor}}{\text{weight of sample}} \qquad 31$$

Where C = P g/mL obtained from the graph,

(IITA, 1985)

A4: Determination of potassium (K) and sodium (Na)

The flame photometric method (AOAC, 1984) for determining potassium and sodium in the digested samples using Jenway PFP 7 flame phometer. In the determination the following working standards of both K and Na were prepared: 0, 2,4,6,8 and 10 g/ml. The working standards as well as the sample solutions were aspirated individually into the flame photometer and their emissions (readings) recorded. A calibration curve was plotted using the concentrations and emissions of the working standards.

The concentrations of the sample solutions were extrapolated from the standard curve using their emissions. Potassium and sodium in the digested samples were calculated as in Equation 32 and 33 respectively.

Calculation

$$K(\mu g/g) = \frac{\text{C x solution volume}}{\text{Sample weight}} \qquad 32$$

Where:

C = K µg/g obtained from the graph

$$Na(\mu g/g) = \frac{\text{C x solution volume}}{\text{Sample weight}} \qquad 33$$

C = Na µg/g obtained from the graph

A5: Determination of calcium and magnesium by EDTA titration

Calcium and magnesium were determined using versanate complexometric titration method. The method involved chelation of the cations with ethylene diaminetetra-acetic acid (EDTA). The procedure involved the determination of calcium and magnesium together and the determination of calcium alone and magnesium found by difference.

Calcium and magnesium together were determined by placing an aliquot of 10 ml of the sample solution in a 250 ml conical flask and the solution was diluted to 150 ml with distilled water 15 ml of buffer solution and 1 ml each of potassium cyanide, hydroxylamine hydrochloride, potassium ferro-cyanide and triethanolamine (TEA). Five drops of evichrom Black T (EBT) were added and the solution was titrated against 0.005 M EDTA. Calcium was

determined by pipetting 10 ml of the sample solution into 250 ml conical flask and diluted to 150 ml with distilled water. 1 ml each of potassium cyanide, hydroxyl-amine-hydrocloride potassium ferro-cyanide and TEA five drops of calcon indicator were added and the solution was titrated with 0.005 M EDTA. Percentage calcium and magnesium in the digested samples were determined using Equation 34 and 35 respectively.

Calculations

$$\% Ca = \frac{0.005x40.08xT}{Sample\ weight} \quad 34$$

$$\% Mg = \frac{0.005x39.1xT}{Sampl\ weight} \quad 35$$

Where T = titre value

(Page et al., 1992)

A6: Determination of iron (Fe), copper (Cu) and zinc (Zn) using Atomic Absorption Spectrophotometer (Buck Model 210 UGP)

Iron, copper and zinc were determined using atomic absorption spectrophotometer (AAS). Standard solutions of 1, 2 and E7/mL solutions of Fe, Cu and Zn were prepared. The standard solutions were aspirated into the atomic absorption spectrophotometer (AAS) and the respective calibration curves were plotted on the AAS. As the sample solutions were aspirated their respective concentrations were provided. Iron, copper and zinc were determined using Equation 36, 37 and 38 respectively.

Calculations

$$Fe\left(\mu\frac{g}{g}\right) = \frac{C \text{ x solution volume}}{\text{Sample weight}} \quad 36$$

$$Cu\left(\mu\frac{g}{g}\right) = \frac{C \text{ x solution volume}}{\text{Sample weight}} \quad 37$$

$$Zn\left(\mu\frac{g}{g}\right) = \frac{C \text{ x solution volume}}{\text{Sample weight}} \quad 38$$

A7: Determination of Sulphur (S)

The determination of sulphur was carried out in a di-acid digestion using nitric acid and perchloric acid (2:1). An amount of the sample (0.5 g) was weighed into a digestion flask and 5 ml of the di-acid mixture was added and the contents mixed by swirling. The flasks were placed in a digester in a fume hood and heated, starting at 90 °C and then the temperature raised to 200 °C. Heating was continued until the production of red NO_2 fumes ceased. The contents were further heated till they became colourless. After cooling the digest was diluted with 100 ml distilled water. Sulphur in the digest is determined by turbidi-metric method.

A 10 ml aliquot of the digest was pipette into a 25 ml volumetric flask and 10 ml of distilled water was added. 1 ml of gelatin-$BaCl_2$ reagent was added and mixed thoroughly and allowed to stand for 30minutes. Standard sulphur solutions of 0, 1, 2, 3, 4 and 5 g/ml were prepared to which were added 1 ml

gelatin-$BaCl_2$ reagent and 10 ml of blank digest and made up to volume with distilled water.

The absorbance of the standard and sample solutions were determined on a spectrophotometer at a wavelength of 420 nm. A standard graph was plotted from which the concentrations, C, of the sample solutions were extrapolated. The sulphur content of the samples were determined using Equation 39.

Calculation

$$S\ (\mu g/g) = \frac{C\ x\ solution\ volume}{Sample\ weight} \qquad 39$$

(F.A.O., 2008)

A8: Estimation of Total phenols

The total phenolics in sweet potato extracts were estimated by Folin-Ciocalteu colorimetric method according to Ju (1989) with slight modification. Briefly, appropriately diluted sample extract (1 ml) was added 3.0 ml of 20 fold diluted Folin-Ciocalteu reagent and 1.0 ml 0.5 M NaOH containing 10 % (w/v) Na_2CO_3. The mixture was incubated in a water bath at 50 °C for 15 min, then placed in an ice-water bath for 5 min. The absorbance was measured at 650 nm and used to calculate total phenolics content using a standard curve based on gallic acid. Results were expressed as milligram of gallic acid equivalents (GAE) per gram dry weight (mg/kg dw).

A9: Procedure for Starch determination

The determination of starch in sweet potato was measured by a rapid method with acid hydrolysis. It was first extracted with perchloric acid and the determined colorimetrically after it had formed a blue complex with potassium iodide (Allen et al., 1974). The percentage starch content of samples were determined with equation 40.

$$Starch\ (\%) = \frac{C\ (mg) x\ solution\ volume\ (ml)}{10\ x\ aliquot\ (ml)\ x\ sample\ weight\ (g)} \qquad 40$$

Where:

C = miligrams of starch from graph

A10: Carotenoid Analysis (Harvestplus Method)

Determination of ß-carotene in frozen and milled sweet potato roots was done by HarvestPlus method (Rodriguez-Amaya and Kimura, 2004). The procedure consisted of sample preparation, extraction, partitioning and spectrophotometric analysis.

Sampling and sample preparation

Extraction

A portion of 10 g of the frozen sample was placed a mortar ground and 30 ml of cold acetone, mixed with the help of the pestle for 5 minutes. The sample was filtered with suction through Buckner funnel with Whatman No 1 filter paper. The extract was received in a protected suction flask. The mortar,

pestle, and residue were washed with a small amount of acetone. The extraction was repeated 3 to 4 times until the residue was devoid of color.

Partitioning to petroleum ether

Twenty milliliters (20 ml) of petroleum ether was put in a separating funnel and a small portion of the acetone extract added.

Distilled water was added slowly, letting it flow along the walls of the funnel. To avoid formation of an emulsion, do not shake (once formed, an emulsion can be broken by adding acetone or sodium chloride).

The two phases were allowed to separate and the lower aqueous-acetone phase discarded. Another portion of the acetone extract was added and the operation was repeated until all of the extract has been transferred to petroleum ether, then it was washed 4 to 5 times with water to remove residual acetone.

The extract was washed with 150-200 ml of brine solution (NaCl) to break any emulsion formed.

The petroleum ether phase was collected in a 25 ml volumetric flask making the ethereal extract pass through a glass funnel containing an anhydrous sodium sulfate. The extract was transferred into amber bottle for absorbance reading.

Spectrophotometric analysis of total carotenoid

The carotenoid ethereal extract was read at 450 nm using Cecil CE 1021 spectrophotometer. The total carotenoid concentration was then calculated using the coefficient of absorption for β-carotene (2592). The total carotenoid content of samples were determined with Equation 43:

$$Total\ Carotenoid\ content = \frac{A_{total}\ x\ Vol(ml) x\ 10^4\ x\ (DF)}{A^{1\%}{}_{1cm}\ x\ sample\ weight} \quad 43$$

Where:

A_{total} = Absorbance at 450 nm

Volume (ml) = Total volume of extract (25 ml)

$A^{1\%}{}_{A3m}$ = 2592 (absorption coefficient of beta-carotene in petroleum ether (PE)

DF = Dilution factor

APPENDIX B: ANOVA TABLES FOR SOIL ANALYSIS

B1: Effect of treatment on soil Bulk Density

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	
Rep stratum	1	0.0022111	0.0022111	3.74		
DI	3	0.0056500	0.0018833	3.19	0.054	
Fert	3	0.0035750	0.0011917	2.02	0.155	
DI.Fert	9	0.0075250	0.0008361	1.41	0.266	
Residual	15	0.0088669	0.0005911			
Total	31	0.0278280				

Source: Author's Data (2015)

B2: Percentage pore volume of soil

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	1	0.143	0.143	0.08	
DI	3	21.375	7.125	4.13	0.025
Fert	3	20.375	6.792	3.94	0.030
DI.Fert	9	20.125	2.236	1.30	0.315
Residual	15	25.867	1.724		
Total	31	87.885			

Source: Author's Data (2015)

APPENDIX C: ANOVA TABLES FOR GROWTH AND YIELD

C1: Number of leaves per plant 4th week

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	29.27	14.64	0.52	
DI	3	61.87	20.62	0.73	0.542
Fert	3	201.92	67.31	2.38	0.089
DI.Fert	9	348.04	38.67	1.37	0.245
Residual	30	846.72	28.22		
Total	47	1487.83			

Source: Author's Data (2015)

C2: Number of Leaves per plant at mid-season stage (5th week)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	12.57	6.28	0.23	
DI	3	182.57	60.86	2.20	0.108
Fert	3	425.69	141.90	5.14	0.005
DI.Fert	9	793.60	88.18	3.19	0.008
Residual	30	828.45	27.62		
Total	47	2242.88			

Source: Author's Data (2015)

C3: Leaf Area at Mid-Season

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1282.47	641.24	8.26	
DI	3	176.25	58.75	0.76	0.527
Fert	3	703.96	234.65	3.02	0.045
DI.Fert	9	4345.41	482.82	6.22	<.001
Residual	30	2328.30	77.61		

Source: Author's Data (2015)

C4: Number of leaves 2nd reading

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	29.27	14.64	0.52	
DI	3	61.87	20.62	0.73	0.542
Fert	3	201.92	67.31	2.38	0.089
DI.Fert	9	348.04	38.67	1.37	0.245
Residual	30	846.72	28.22		
Total	47	1487.83			

Source: Author's Data (2015)

C5: Number of leaves per plant initial stage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	63.26	31.63	1.18	
DI	3	53.97	17.99	0.67	0.576
Fert	3	146.94	48.98	1.83	0.163
DI.Fert	9	328.99	36.55	1.37	0.247
Residual	30	802.75	26.76		
Total	47	1395.91			

Source: Author's Data (2015)

C6: Number of branches per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	13.4384	6.7192	31.40	
DI	3	7.7023	2.5674	12.00	<.001
Fert	3	1.9106	0.6369	2.98	0.047
DI.Fert	9	12.7410	1.4157	6.62	<.001
Residual	30	6.4190	0.2140		
Total	47	42.2113			

Source: Author's Data (2015)

C7: Leaf Area Index of sweet potato

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.29309	0.14654	1.66	
DI	3	0.10391	0.03464	0.39	0.759
Fert	3	0.04152	0.01384	0.16	0.924
DI.Fert	9	0.98883	0.10987	1.24	0.306
Residual	30	2.64828	0.08828		
Total	47	4.07563			

Source: Author's Data (2015)

APPENDIX D: ANOVA TABLES TUBER YIELD AND QUALITY

D1: Tuber yield per hectare

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	88.822	44.411	11.04	
DI	3	138.294	46.098	11.46	<.001
Fert	3	119.433	39.811	9.90	<.001
DI.Fert	9	117.660	13.073	3.25	0.007
Residual	30	120.641	4.021		
Total	47	584.851			

Source: Author's Data (2015)

D2: Economic tuber yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	18.011	9.006	1.99	
DI	3	124.506	41.502	9.18	<.001
Fert	3	78.314	26.105	5.78	0.003
DI.Fert	9	120.654	13.406	2.97	0.012
Residual	30	135.585	4.520		
Total	47	477.070			

Source: Author's Data (2015)

D3: Percentage small tuber yield.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1121.07	560.54	17.86	
DI	3	471.67	157.22	5.01	0.006
Fert	3	550.53	183.51	5.85	0.003
DI.Fert	9	1589.84	176.65	5.63	<.001
Residual	30	941.49	31.38		
Total	47	4674.60			

Source: Author's Data (2015)

D4: Vine Yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
DI	3	40.47	13.49	0.62	0.607
Fert	3	257.69	85.90	3.95	0.017
DI.Fert	9	675.20	75.02	3.45	0.005
Residual	30	652.03	21.73		
Total	47	3347.05			

Source: Author's Data (2015)

D5: Total Yld (Tuber and Vine)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
DI	3	103.39	34.46	0.79	0.507
Fert	3	573.76	191.25	4.41	0.011
DI.Fert	9	1315.07	146.12	3.37	0.006
Residual	30	1301.74	43.39		
Total	47	5280.88			

Source: Author's Data (2015)

APPENDIX E: ANOVA SWEET POTATO SHELF LIFE

E1: Percentage decay after 4 weeks of storage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	479.9	160.0	0.91	
Struct	3	1543.3	514.4	2.93	0.043
Fert	3	1467.6	489.2	2.79	0.050
Struct.Fert	9	2528.8	281.0	1.60	0.144
Residual	45	7890.6	175.3		
Total	63	13910.3			

Source: Author's Data (2015)

E2: Cumulative decay of tubers after 8 weeks of storage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	1030.5	343.5	0.57	
Struct	3	2811.7	937.2	1.55	0.215
Fert	3	570.9	190.3	0.31	0.815
Struct.Fert	9	11716.7	1301.9	2.15	0.044
Residual	45	27228.7	605.1		
Total	63	43358.5			

Source: Author's Data (2015)

E3: Cumulative percentage tuber decay after 13 weeks of storage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	2760.9	920.3	2.66	
Struct	3	15091.0	5030.3	14.54	<.001
Fert	3	5171.7	1723.9	4.98	0.005
Struct.Fert	9	14088.1	1565.3	4.53	<.001
Residual	45	15563.4	345.9		
Total	63	52675.0			

Source: Author's Data (2015)

E4: Percentage decay influenced by irrigation and manure after 13 weeks of storage.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Fert	3	6307.4	2102.5	3.58	0.021
DI	3	3786.5	1262.2	2.15	0.107
Fert.DI	9	2505.8	278.4	0.47	0.884
Residual	45	26412.5	586.9		
Total	63	55549.1			

Source: Author's Data (2015)

E5: Weevil infestation after 4 weeks of storage (Irrigation Effect)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
DI	3	86.60	28.87	2.86	0.047
Struct	3	486.59	162.20	16.06	<.001
DI.Struct	9	45.63	5.07	0.50	0.865
Residual	45	454.42	10.10		
Total	63	1084.28			

Source: Author's Data (2015)

E6: Weevil number after 8 weeks of storage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	179.21	59.74	1.96	
Struct	3	3675.79	1225.26	40.22	<.001
Fert	3	58.84	19.61	0.64	0.591
Struct.Fert	9	445.96	49.55	1.63	0.137
Residual	45	1370.77	30.46		
Total	63	5730.57			

Source: Author's Data (2015)

E7: Number of weevils after 13 weeks of storage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	32.875	10.958	1.13	
Struct	3	1665.625	555.208	57.29	<.001
Fert	3	118.375	39.458	4.07	0.012
Struct.Fert	9	790.750	87.861	9.07	<.001
Residual	45	436.125	9.692		
Total	63	3043.750			

Source: Author's Data (2015)

APPENDIX F: ANOVA TABLES NUTRITIONAL CONTENT OF TUBERS

F1: Absorbance

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
DI	3	0.18252	0.06084	3.40	0.029
Fert	3	0.29592	0.09864	5.51	0.004
DI.Fert	9	1.33801	0.14867	8.31	<.001
Residual	32	0.57249	0.01789		
Total	47	2.38894			

Source: Author's Data (2015)

F2: Percentage Sugar content of tubers

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Rep	2	0.14792	0.07396	1.21	0.326
DI	3	1.28628	0.42876	7.00	0.004
Fert	3	234.14165	78.04722	1274.62	< 0.001
DI.Fert	9	0.83318	0.09258	1.51	0.230
Residual	15	0.91848	0.06123		
Total	32	237.32751	7.41648		

Source: Author's Data (2015)

F3: Percentage Starch content of tubers

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Rep	2	3.472	1.736	0.26	0.777
DI	3	48.865	16.288	2.41	0.108
Fert	3	2894.582	964.861	142.70	< 0.001
DI.Fert	9	161.444	17.938	2.65	0.046
Residual	15	101.419	6.761		
Total	32	3209.782	100.306		

Source: Author's Data (2015)

F4: Percentage Fiber content of roots

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Rep	2	0.1464	0.0732	0.08	0.926
DI	3	12.5984	4.1995	4.40	0.021
Fert	3	42.0939	14.0313	14.71	< 0.001
DI.Fert	9	69.3553	7.7061	8.08	< 0.001
Residual	15	14.3054	0.9537		
Total	32	138.4995	4.3281		

Source: Author's Data (2015)

F5: Ash content of tubers

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Rep	2	5.613	2.807	1.44	0.267
DI	3	25.356	8.452	4.34	0.022
Fert	3	16.460	5.487	2.82	0.075
DI.Fert	9	21.897	2.433	1.25	0.337
Residual	15	29.179	1.945		
Total	32	98.505	3.078		

Source: Author's Data (2015)

F6: Percentage protein content of tubers

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Rep	2	1.3370	0.6685	1.18	0.335
DI	3	0.9179	0.3060	0.54	0.663
Fert	3	4.6006	1.5335	2.70	0.083
DI.Fert	9	11.6438	1.2938	2.28	0.076
Residual	15	8.5159	0.5677		
Total	32	27.0152	0.8442		

Source: Author's Data (2015)

F7: Test for Phenol content (mg/g) of tubers

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Rep	2	0.153440	0.076720	17.36	< 0.001
DI	3	0.026781	0.008927	2.02	0.154
Fert	3	1.858717	0.619572	140.18	< 0.001
DI.Fert	9	0.142218	0.015802	3.58	0.014
Residual	15	0.066297	0.004420		
Total	32	2.247454	0.070233		

Source: Author's Data (2015)

F8: Test for Percentage fat content of tubers

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Rep	2	0.2642	0.1321	0.35	0.711
DI	3	1.6410	0.5470	1.44	0.270
Fert	3	2.6758	0.8919	2.35	0.113
DI.Fert	9	7.6884	0.8543	2.25	0.079
Residual	15	5.6849	0.3790		
Total	32	17.9543	0.5611		

Source: Field data (2015)

F9: Test for Percentage Calcium content of tubers

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Rep	2	0.018086	0.009043	1.19	0.332
DI	3	0.047197	0.015732	2.07	0.147
Fert	3	0.242679	0.080893	10.63	< 0.001
DI.Fert	9	0.159408	0.017712	2.33	0.071
Residual	15	0.114097	0.007606		
Total	32	0.581468	0.018171		

Source: Field data (2015)

F10: Beta carotene content

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
DI	3	10848.599	3616.200	2845.55	<.001
Fert	3	5149.074	1716.358	1350.59	<.001
DI.Fert	9	15467.713	1718.635	1352.38	<.001
Residual	32	40.666	1.271		
Total	47	31506.052			

Source: Field data (2015)

F11: Phosphorus content of tubers

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	1	207.60	207.60	6.92	
DI	3	182.68	60.89	2.03	0.153
Fert	3	3297.57	1099.19	36.64	<.001
DI.Fert	9	1005.55	111.73	3.72	0.012
Residual	15	449.96	30.00		
Total	31	5143.35			

Source: Author's Data (2015)

F12: Percentage Nitrogen content of tubers

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	1	0.00000000	0.00000000	0.00	
DI	3	0.00032500	0.00010833	1.35	0.295
Fert	3	0.00587500	0.00195833	24.48	<.001
DI.Fert	9	0.00215000	0.00023889	2.99	0.030
Residual	15	0.00120000	0.00008000		

Source: Author's Data (2015))

F13: Potasium content of tubers

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	1	0.012013	0.012013	2.09	
DI	3	0.024525	0.008175	1.42	0.276
Fert	3	0.709825	0.236608	41.13	<.001
DI.Fert	9	0.090550	0.010061	1.75	0.163
Residual	15	0.086287	0.005752		
Total	31	0.923200			

Source: Author's Data (2015)

F14: Calcium content of tubers (Ca_cmol_kg^{-1})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	1	1.4154	1.4154	8.08	
DI	3	0.7590	0.2530	1.45	0.269
Fert	3	5.9102	1.9701	11.25	<.001
DI.Fert	9	1.1081	0.1231	0.70	0.698
Residual	15	2.6262	0.1751		
Total	31	11.8189			

Source: Author's Data (2015))

F15: Magnesium content of tubers (cmol_kg^{-1})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	1	0.7381	0.7381	1.87	
DI	3	0.3164	0.1055	0.27	0.848
Fert	3	4.6549	1.5516	3.92	0.030
DI.Fert	9	3.3230	0.3692	0.93	0.525
Residual	15	5.9357	0.3957		
Total	31	14.9681			

Source: Author's Data (2015)