PHYSIOLOGY, GROWTH, YIELD AND FRUIT QUALITY OF SELECTED GREENHOUSE TOMATOES (*Solanum lycopersicum*) VARIETIES AS AFFECTED BY DIFFERENT GROWING MEDIA AND POTTING BAG SIZES.

BY

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THIS THESIS IS SUBMITTED TO THE UNIVERSITY OF GHANA BOARD OF GRADUATE STUDIES, IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF PHILOSOPHY IN CROP SCIENCE (AGRONOMY).

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DECLARATION

I, Jeannette Aduhene-Chinbuah, hereby certify that with the exception of the references to other people's work which have been duly cited, this thesis is the result of my original findings and that this thesis has neither in part nor in whole been presented for a degree in Ghana or elsewhere.

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DEDICATION

This thesis is dedicated to my mother Mrs Betty Aduhene-Chinbuah and my brother Kwasi Aduhene-Chinbuah for their prayers, support and love in completing this course of study and also to my father Mr Augustus Aduhene Chinbuah, of blessed memory.

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ABSTRACT

Tomato is one of the most important vegetable crops cultivated in Ghana and constitutes part of the daily diet of most of the populace. Ghana produces 366,772t/ha annually, yet imports 25,000t/ha of tomato paste and $9.9million worth of fresh tomatoes from Burkina Faso and Europe annually to fill the supply gap which puts a lot of pressure on the country's GDP. To help minimize importation and bridge the demand gap, several interventions have been proposed including greenhouse production. Thus an investigation into the effects of growing bag sizes and substrates on growth, yield and fruit quality of two tomato varieties was conducted under greenhouse conditions. The treatments comprised of three growing bag sizes (5 Litre, 10 Litre and 15 Litre), three substrates (palm fibre, cocopeat and carbonated rice husk) and two tomato cultivars (Rodeo and Limbobo) laid out in a factorial experiment using the Randomized Complete Block Design with three replications. Vegetative, reproductive, yield and yield components, as well as fruit quality parameters were measured. Results obtained indicated that, carbonated rice husk provided high plant growth indices followed by palm fibre and cocopeat. For the growing bag sizes, the 15Litre bag supported extensive growth in plant biomass and high growth indices followed by 10Litre and 5Litre bags. Palm fibre substrate provided the highest dry matter weights, yield and yield component, fruit quality and net returns whiles cocopeat was the second best in yield and yield components, and fruit quality. However, carbonated rice husk gave the second best overall net returns. 10 Litre growing bag gave the highest yield and yield component, as well as fruit quality. Rodeo tomato plants were superior to Limbobo plants. Overall, Rodeo plants in 10 Litre of palm fibre gave the highest yield and fruit quality and is recommended to farmers to use under greenhouse production systems to obtain higher yields, quality fruit and higher net returns.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
C	Cocopeat
CRH	Carbonated Rice Husk
^{o}C	Degree Celsius
cm	Centimetre
CSIR	Council for Scientific and Industrial Research
CV (%)	Coefficient of variation expressed as percentage
EC	Electrical Conductivity
et al.	and others
EX1	Experiment 1
EX2	Experiment 2
FAO	Food and Agricultural Organisation
FAOSTAT	Food and Agricultural Organisation Statistical Databases
FOHCREC	Forest and Horticultural Crop Research Centre
G	Growing bag
g	gram
GDP	Gross Domestic Product
kg	Kilogram

LB	Limbobo
LSD	Least Significant Difference
mm	millimetre
ml	millilitre
MoFA	Ministry of Food and Agriculture
Mt	Metric tonnes
N.K.P	Nitrogen, Phosphorus and Potassium
NaOH	Sodium hydroxide
PH	Power of hydrogen
PF	Palm Fibre
RCBD	Randomized Complete Block Design
RD	Rodeo
S x G	Interaction of substrate and growing bag
V x S	Interaction between substrate and variety
S	Substrate
t/ha	Tonnes per hectare
TA	Terrible acidity
TSS (%)	Total Soluble Solids Content
V	Variety

WAT	Weeks after Transplanting
WHO	World Health Organisation

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CHAPTER ONE

1.0. INTRODUCTION

1.1 Background to the study

Tomato (*Solanum lycopersicum*) is part of the family Solanaceae and produces edible fruits for consumption. It is native to South and Central America, specifically between Peru and Mexico, but is distributed in all continents and is adapted to a wide range of climates (Worlds Crop Database, 2012). Tomato is an annual, biennial, or tender perennial; but it's often times grown as an annual crop. Presently, tomato is cultivated around the world in greenhouses to facilitate growth in all climates and year round production (Matthew, 2001).

Apart from potato, tomato is the second vegetable crop of utmost importance in the world, producing nearly 164 million tonnes of fresh tomato fruit which is harvested from 4.7 million hectares (ha) of land globally. In Ghana tomato is an important crop forming a major part of the diet of Ghanaians and is one of the commodities in high demand on the market. However, tomato production in Ghana has not reached its potential, in terms of realizing yields comparable to other countries (FAOSTAT Database, 2015).FAOSTAT Database (2004) reported tomato production for 144 countries with China leading the world in tomato production both in hectares of harvested production of 1,255,100 hectares and fruit weight production of 30,102,040 Mt. Belgium and the Netherlands are also the other two major tomato producing countries in terms of yield of fruit per hectare of 4,961,539 Hg/ha and 4,166,667Hg/ha respectively (FAOSTAT Database, 2014). Ghana ranks 48th in the production of tomatoes worldwide, producing 366,772 Mt annually (FAOSTAT, 2016).

Ghana, a major net exporter of food items some few years back, is now one of the major net importers of most daily consumables including tomatoes (Trade statistics, 2014). Ironically, some of the countries that Ghana imports from have near- deserts conditions and some are very cold regions. This importation has become so ubiquitous that, data obtained from external trade statistics of Ghana indicates large sums of money spent annually on the importation of vegetable crops (External Trade Statistics, 2016).

The reason accounting for the high importation of tomatoes to Ghana is because the tomatoes imported are bigger, firmer, far superior in quality and last longer in storage compared to the locally grown tomatoes that have high water content, a lot of seeds, poor colouration, and low total soluble solids.

Tomato has many health benefits including improving the skin, inhibiting several types of cancers, strengthening bones, providing the body with special antioxidants, among several others.

Soil-nutrient capital is steadily depleting and the population of Ghana is increasing with farmers incapable of adequately improving the soils due to limitation of accessible productive lands preventing fallowing. Thus, the main strategies employed for improving agricultural productivity in Ghana is the application of inorganic fertilizers. However, the potential of success of this strategy is low, due to problems of accessibility and affordability by smallholder farmers (Yeboah *et al.*, 2009). Despite government interventions including fertilizer subsidies, training to improve agronomic practices and introduction of quality varieties of tomatoes. Tomato farmers are still unable to grow the crop adequately to meet national demand with severe postharvest losses during the major growing season and severe shortages off season. (Elizabeth and Kolavali, 2010).

Several constraints have emerged to explain the poor quality of tomatoes produced in Ghana. These constraints are choice of variety grown, production cost, poor agronomic practices, disease and pest incidence and the decline in the soil productivity.

Hence, the need to adopt a strategy that is effective and easily accessible to Ghanaian farmers for improved tomato production is eminent.

In recent years greenhouses technologies (i.e. ENVIRODOME) have been introduced into the country and are now in use for vegetable production. The most common vegetable currently cultivated in these greenhouses is tomatoes with the objective to minimize tomato imports (Nkansah, 2015; CSIR, 2016).

Under the new government planting for Food Policy use of greenhouse technology is being encouraged (Planting for Food Policy Session Report, 2017).

Extensive studies conducted on field and greenhouse tomatoes has shown the greenhouses producing higher yields and improved tomatoes over the field plants (Nkansah, 2015; CSIR, 2016). This has been attributed to the controlled environment within the greenhouses which provides optimum growing conditions for the tomato crops (Nkansah, 2014; CSIR, 2016). Based on crop specification, greenhouses may permit the regulation of key environmental factors such as amount of light and shade, temperature, fertilizer application, irrigation and atmospheric humidity, which are the major shortcomings of field cultivation. Greenhouses also facilitate year round production allowing for crop production even under adverse weather conditions.

In producing crops in the greenhouse a number of cultural inputs and factors are involved. These include physio-chemical properties of the media, irrigation frequency, crop type, container type, as well as size and climatic conditions (Falahi Ardakani *et al.*, 1987; Fonteno, 1996; Bielinski and Teresa, 2012). Varying substrates components have different

effects on crop production, hence, choice of the growing medium to use is critical to achieving optimum crop production. As a result of the somewhat shallow depth and restricted volume of container, there is also the need to amend growing media to provide the suitable physical and chemical properties essential for plant growth.

According to Trainor (2009), the use of field soils is usually unsatisfactory for producing plants in containers predominantly because the needed drainage, aeration and water holding capacity required are not attainable in containers. Furthermore, the use of bulk soil media increases cost of transportation and impedes easy transplanting of seedlings. To address this challenge several organic "soilless" growing media or substrates have been developed. These organic materials are primarily obtained from once-living organism and mainly characterized by decay.

One of the greatest challenges in crop production using organic soilless media is sourcing inexpensive, readily available and environmentally friendly material of superior quality. Some of these soilless growing media developed as alternative to natural soil for crop production are peat moss, perlite, cocopeat, carbonated rice husk, palm fibre, sawdust and many others (Bielinski and Teresa, 2012).

Cocopeat is a multi-purpose soilless growing medium manufactured from coconut husk.It is well aerated, has high water holding capacity, and contains no soil borne pathogen and weed, with an ideal pH of 5.7- 6.5and eco-friendly.

Since it is the only substrate commercially available, it is very costly. Thus, demand for alternate growth media is of paramount interest in the sustainability of the greenhouse technology in Ghana.

Biochar is a soilless growing media that is valuable for soil amendments. The practice of converting agricultural waste (i.e. wood, manure, leaves, rice husk, etc.) to serve as a soil enhancer has been in use for about 2000 years (Lehman and Sohi, 2008). The thermal heating process of organic material in a closed perforated container with little air or no air (pyrolysis) at a temperature < 700 °C results in a fine-grained, highly porous charcoal-like material called biochar which enables soils to retain water and nutrients when added (Singhal *et al.,* 2011). Recent studies have shown how effective biochar is as a growing medium, it is known to have a good CEC, pH of 5.5-6.5, good drainage, good aeration, adequate amounts of potassium and phosphorus, low acidity and the ability to induce responses to fight against fungal diseases and pathogens in the substrate.

Palm fibre is a cheap growing media which is obtained from oil palm fruit by pounding the vegetative component of the oil palm tree after the oil has been tapped or by allowing the felled palm tree to decompose for some years and collecting the decayed vegetative part of the oil palm. It is preferred as a substrate for cultivation of vegetables because of its low cost, availability and ability to retain water (Rozman *et al*., 2000).

Earlier studies have shown that most greenhouse farmers in Ghana use varying size /volumes of growing bag, notwithstanding the effect of the volume or growing bag size of the growing medium on the growth, yield, and physiological characteristics and tomato fruit quality among other factors. In Ghana this has not been well researched and documented; hence, the performance and production of tomatoes under greenhouse technologies keep fluctuating.

There is therefore the need to evaluate various materials (i.e. biochar, cocopeat and palm fibre) and growing bag sizes (i.e. 5 Litre, 10 Litre and 15 Litre) which can enhance

production and make effective and efficient use of the greenhouse technology especially in the tomato value chain.

General Objectives

To assess the impact of growing media and potting bag sizes on the physiology, growth, yield and fruit quality of two greenhouse tomatoes varieties.

Specific Objectives are to:

1. Determine the most suitable soilless growing media from selected agricultural waste for greenhouse tomato production.
2. Determine the ideal bag size for greenhouse tomato production.
3. Evaluate the responses of the two tomato varieties to the different growing media and bag sizes.
4. Ascertain the cost effectiveness of use of different growing media
5. Formulate a standard growing system in relation to the substrate and growing bag sizes for greenhouse tomato production.

CHAPTER TWO

2.0. LITERATURE REVIEW

2.1. Origin, History and Distribution of tomatoes.

Western South America is the native land of wild tomatoes (*Solanum lycopersicum*) and was first observed in 1544 (Naika *et al*., 2005). It is part of the solanaceae family (Darwin *et al.*, 2003). For many years after its discovery it was grown as an ornamental, it was not until the 16th Century that it was first accepted as a vegetable crop in the southern part of Europe (Peralta and Spooner, 2007).

Tomato is usually termed a widespread crop as it has the tendency to grow in diverse habitats; it is therefore distributed throughout Columbia, Mexico, Bolivia, other South American countries, Asia and many parts of Africa.

Tomato is one of the major vegetable crops on the world market and forms an essential part of human diet (Peralta and Spooner, 2007). It is mostly cultivated on large scale under greenhouse and open field conditions (Kaloo, 1986). Some people believed that the origin of domestication of tomato originated from Peru, while others believe that it originated from Mexico (Peralta and Spooner, 2007).

Larry and Joanne (2007) indicated that it was in Peru that tomato became diversified, but domestication of tomato was in Mexico. New tomato varieties are being identified and conserved by plant breeders' worldwide (Peralta *et al.*, 2007). Tomato plant was first introduced into West Africa, Eastern Africa, and Central Africa during the 16th and 17th centuries (Norman, 1992). It is extensively cultivated in Burkina Faso, Nigeria and Ghana (De Lannoy, 2001).

2.2. Tomato Varieties

There are over 7,500 varieties of tomatoes discovered and cultivated for various purposes (World Crop Database, 2010). They are therefore classified by the shape, size and use. These classifications are the cherry, beefsteak, plum, globe and grape (Bielinski *et al.*, 2014).

Globe or slice tomatoes are also known as round tomatoes and are mostly used in the preparation of dishes and for processing. Beefsteak tomatoes are very large and juicy, have thicker skins, shorter shelf life and are kidney-bean shaped, and mostly used for sandwiches and burgers. For tomato paste and sauces, plum varieties are the best type as they contain lower water content and high solid contents. Cherry or cocktail tomatoes are used whole and often time used for salads because of their sweet taste; they are characteristically small and round. The grape type which is slightly smaller than the plum type was recently discovered and is also used in salads. Pear shaped tomatoes are also sometimes grown. Other relevant types are the Campari, Tomberries, Oxheart, and Marzano.

Tomato varieties can be also classified as either determinate or indeterminate. With the indeterminate type it forms vines. However, this vine does not fall off if proper conditions necessary for growth are provided to the tomato plant. It is capable of fruit set throughout a growing season. It is therefore mostly preferred by people who grow at home and commercial growers that serve the fresh market. The determinate types are bushy and harvesting is done at once. It is thus preferred by commercial farmers who wish to harvest once for tomato processing into pastes and purees (Benton, 2012). Topping off occurs at specific plant height during the growth of the plant. They are also mostly used when growing in pots or bags. Majority heirloom types are indeterminate, although few are determinate. Semi determinate tomato variety is also known as vigorous determinate. It forms one more fruit set after the first fruit set and yet tops off like the determinate varieties.

2.3. Botany of tomato

Tomato plants have several botanical descriptions and are broadly classified as reproductive and vegetative.

2.3.1. Vegetative description

Tomato is a dicotyledonous crop with a tap root system. It grows to a height of 50cm, its stem girth can grow to about 2 to 4cm long (Shankara *et al*., 2005) and has dense lateral and adventitious root (Akinfasoye, 2011).

Tomato plants have fragile, hairy and woody stem. Attached to this stem is its compound leaves made of spirally arranged leaflets which are oblong or ovate (Yeboah, 2011).

Based on its growing habits tomato plant can be classified as determinate, semi- determinate and indeterminate. The indeterminate plants grow very high and mostly need staking. Whereas, the determinate type needs no support and stop growing at 1.5m when the flowers form at the terminal growing point (Shankara *et al.*, 2005).

2.3.2. Reproductive description

Tomato plant is characterized by its yellow flowers. Its flowers are less than an inch in diameter and can occur in either a simple or complex inflorescence of about 6 to 12 bisexual flower (Rost, 1996). Temperature is one environmental factor that influences the formation of the inflorescence (MoEFandCC –India, 2015).

Agong *et al.* (2001), as well as Shankara *et al.* (2005) indicate that tomato flowers are self-pollinated (autogamous). In some cases cross pollination may occur with the aid of pollinators such as wind, insect or animals (Agong *et al.*, 2001; Shankara *et al.*, 2005). The style has a sterile tip which is elongated and around the style are six (6) stamen and anthers that are also yellow. The stamen and carpals are involved in the reproduction process of the

tomato plant. The pollen produced in the stamen fertilizes the carpals. The fertilized ovule then develops into an embryo which consequently matures to form a seed. The seed is wrapped with flesh within a mature fruit.

Tomato has a fleshy fruit and is variable in length, shape and diameter. The fruits are formed from superior ovaries with 2-9 locules. At the mature stage the colouration of the fruit changes from green to red, orange or yellow depending on the variety of tomatoes.

Determinate tomato fruits ripen faster than the indeterminate types. Agong *et al.* (2001) states that coupled with the high leaf to fruit ratio and the slow rate of ripening, indeterminate tomato fruits taste better than that of the determinate.

2.4. Quality characteristics of tomatoes

Consumers and producers preferences are very significant in the varieties farmers choose to cultivate as these qualities must be satisfied by the farmers to be able to have very competitive goods on the market. Lecomte *et al.* (2003) suggests that since consumer preference is key in tomato production there is the need to evaluate the cultivars on the market to find superior varieties. Also, there was the need to develop new tomato varieties that will meet consumer preference. Aoun *et al.* (2013) pointed out that to be able to evaluate tomato fruit quality its physical and chemical characteristics must be determined.

Fruit flavour, firmness, uniform colouration, sweet taste (i.e. high sugars and low acids) is a major determinant of fruit quality that influences consumers. For the processing companies traits they look for are pH of fruit, total soluble solids and taste of fruit (Rocha *et al*., 2012; Carli *et al.*, 2009). The qualities outlined above also dictate a number of other quality traits including beta-carotene, lycopene, flavonoids, phenolic acids, ascorbic acids and sugars. Not only genetic factors affect the production of these components, the environment the

crop grows in and the interaction effect between genetic factors and environmental interactions (Chattopadhyay *et al*., 2013).

Currently lots of research is focused on growth, yield, development and improvement of tomato plant (Harrigan *et al.*, 2007).

2.5. Nutritional Benefits tomatoes

Tomato is one of the very important vegetable and its fruit forms a vital part of the diet of a number of people in the world as its total contribution to human nutrition far outranks other vegetables (Grandillo *et al.*, 1999). High content of minerals, vitamins(i.e. A and C), antioxidants(i.e. lycopene, beta-carotene,flavonoid, phenolic acid), folate, potassium, oxalic acids(i.e. ascorbic,citric,malic, niacin and fumeric) and certain types of hormones precursors are found in tomatoes which are vital to the health of humans(Willcox *et al*., 2003;Borguini and Torres, 2009; Mertenz *et al*.,2003).

A number of diseases(i.e. type II diabetes, 80% of cardiovascular diseases, neurodegenerative diseases and certain types of cancers are reported to be managed with these phytochemicals and organic acids which tomato fruit have (World Health Organisation report, 2003; Rao and Balachandran,2002)

Obesity can be checked by consuming the tomato fruits (Abdul Hammed *et al.*, 2009). Yu and Sacco (2005) reported that excretion of certain cancerous cells can be inhibited by flavonoids and lycopene, which is contained in large amount in tomatoes. While, Hounsome *et al.* (2008) indicates that the antioxidants in tomatoes protects the human cells from oxidants that destroy the cells and causes cancer of the stomach, lungs, endometrium, pancreas oesophagus, pharynx and colon (Polivkova *et al.*,2010).

Tomato can also protect the skin from skin diseases and sun burns (Maccrae, 2008).

It can be eaten raw in the salads, as an ingredient or for cooking many dishes and in making juices (Alam *et al.* 2007).

Tomatoes are best preserved by washing thoroughly and keeping out of sunlight in a basket at room temperature. It can also be processed into purees and paste. It must not be placed in the refrigerator or fridge as it absorbs water and loses its flavour (Shidfar *et al.*, 2011).

2.6. Economic Benefits of tomatoes

Tomato plant has great economic relevance all over the world. In Ghana it is the second most relevant vegetable after garden egg plants (MoFA, 2010). Since tomatoes forms a part of most of the diets of people in the world, it has high value on both local and foreign markets. Its high value gives a lot of income to countries both on the domestic front and the foreign market (Hayley and Henrich, 2005). In Ghana, per capita consumption of tomatoes is a little over excess of 100,000 metric tonnes annually (Asare-Bediako *et al.,* 2007). FAOSTAT reported in2005 that in the year 2003, Ghana accrued US$47,000 as foreign exchange from production of 4,368MT of tomatoes. However, Ghana Export Promotion Council also in 2009 reported a decrease in export amount by approximately 18.5Mt.

Tomato plants are well suited for different cropping systems and can be intercropped with many crops. Tomato also provides the rural and urban dwellers of many countries with employment opportunity. Trade Aid Integrated in a survey conducted in 2007 indicated that the Upper East Region of Ghana is one of the leading tomato producers in the country and provides employment for approximately 11,728 families. Glover (2007) also reported roughly about 58,640 person employed in the tomato production chain in Ghana.

2.7. Cultivation of tomatoes.

4.8 million hectares of land of tomatoes plant are cultivated globally, with 162 million tonnes of fruit harvested (FAOSTAT, 2014).

2.7.1. Ecology

Tomato is a warm season crop, it is very tender crop. Though it can grow in a wide geographical area, it is cannot withstand frost and shows the appearance of minimal chilling at the fruit ripening stage (FAOSTAT, 2014).

The optimum temperature required for high quality growth of tomatoes is cool dry temperature at 20ºC to 27ºC. For tomatoes to mature early it has to have periods of warm nights with high soil temperatures (FAOSTAT, 2014).

2.7.2. Propagation and Harvesting

Tomato is propagated by seed either directly or by seedlings. In order for the tomato plants to grow erect there is the need to stake the plants whether in open field or greenhouse production. Staking is usually done with a trellis or stake.

Indeterminate plants are pruned to one to stems before fruit set, but for determinate plant it is pruned to more than three stems. Lateral branches are removed when necessary.

Tomato fruits can be harvested 3months after sowing and at different stages. Tomatoes are harvested by hand and detached from the plant at the stem region. Harvesting is mostly also done sequentially and is packed in cartoons and boxes.

For shipping the green mature tomatoes or breakers are harvested, the slightly red tomatoes are usually harvested for the local market and the fully redden tomatoes is reserved for use in the home.

2.8. Constraints of Tomato production in Ghana.

Tomato yields in Ghana (7.5 tons/ha) does not reach its potential (15 tons/ha) and yet other neighbouring countries such as Burkina Faso produce about 12.5 tons/ha it results in Ghana importing from Burkina Faso to make up for the short fall in production (Bortey *et al.*, 2016). The low yield in tomato production is due to a number of constraints:

- High post-harvest losses during the peak production season due to lack of processing facilities.
- Poor seed sources- most tomato farmers in Ghana obtain their seeds from their personal stored seeds, some also obtain seeds from the local markets, and others obtain seeds from friends and family. These informal seeds sources are usually not of high quality and affect high production. Farmers must be encouraged to purchase high quality seeds from certified seed companies and government must subsidise the cost of high quality seeds to allow farmers to have access to them.
- Pest and diseases, high cost of agricultural inputs (i.e. fertilizers, pesticides, seeds, water charges, tractor services, etc.), high rent charges, no land for expansion, no places to relocate nurseries, no storage facilities, difficulty in accessing credit, lack of capital to invest in the production, among others are some other constraints farmers face (Bortey *et al.*, 2016).

2.9. Soilless media/culture

Hydroponics, sand culture, gravel culture and other methods have been explored for use as a media in the greenhouse technology. There have been a number of studies in soilless culture for greenhouse tomato production (Bauerle, 1984).

2.9.1. Soil versus Soilless culture

By the year 1974, about 70% of greenhouse production used soil culture and 30% used other soilless systems. Soil-borne diseases such as Fusarium, Verticillium, mosaic virus and bacterial wilts became persistent and there was the need to sterilize the soil by either chemical or steam sterilization at least once a year, which increased the cost of soil for crop production (Bauerle, 1984).Bauerle (1984) claimed that inefficient water and fertilizer use; variability in soil types, difficulty in controlling the temperature of the soil and the labour intensive nature of preparing the soil for cropping were the issues that led to the development of the soilless cropping system and the increase in use of the system. The process of cultivation of crops without soil is known as soilless culture (Spomer, 1974). Gullino and Garibaldi (1994) indicated that to prevent the economic loss of crop production as a result of activities of soil pathogen, the use of soilless growing media in greenhouses was developed. By the year 1978, however, 60% of the greenhouses used soilless systems (Hickman, 1992).

2.9.2. Soilless growing media as an alternative culture for crop production

Pardossi *et al.* (2002) stated that greenhouse production system was an alternative to field production of high value crops. Premium price for high value crops influenced the need to cultivate these crops in higher quantities and of utmost quality opening the market for greenhouse growers (Cantliffe *et al.*, 2001).

The adoption of soilless culture as a means of crop production in these greenhouses has mainly increased in recent past years (Garzo *et al.*, 2002).

Cantiffe *et al.* (2002) also added that, soilless culture helped reduce the use of chemicals (i.e. methyl bromide) which consequently lengthens the time to harvest and results in a three to ten times increase in the yields of crops produced.

Soilless culture is able to increase water use and fertilizer use efficiency compared to the field production of crops (Schwarz, 1995; Jensen, 1997). With soilless media growers are able to produce crops in areas where they otherwise could not have grown the crops and also have the ability to reduce the occurrence of root diseases (Reed, 1996).

There are two main groups of soilless media which are substrate culture and water culture (Spomer, 1974).

The process of cultivation of crops in a solid material which could be either inert or non-inert material as a substitute for soil is what is known as substrate culture. This can further be grouped into two more categories, which are organic and inorganic substrates.

Sand, vermiculite, perlite, calcined clay, rockwool, pumice, among others are some inorganic substrates. Some examples of organic substrates are sawdust, peat moss, palm fibre, cocopeat, rice husk, wood residues, barks of trees, leaves, aerial parts of plants,etc.

In order for a substrate to optimally support crop growth it should be able to provide the crops with water and gases simultaneously, it must be able to make water contained in it available to plants, it should be able to hold the plant and it should be able to hold nutrients placed in it for plant, as well as make it available to plants(Jensen, 1999; Nelson, 1991).

Substrates used for growth of horticultural crops are made of organic and inorganic components with different properties. There is the decrease in the spaces between the pores of substrates and a decrease in aeration caused by the ability of the organic component of the substrate to oxidize and compact easily. Also, the organic component of the substrates causes nutritional difficulties of propagules as it has very high carbon portion compared to low nitrogen portions (i.e. high C:N ratio) (Macdonaldo,1993; Hartman *et al.*, 2018).

Materials such as vermiculite, sand, rockwool, and perlite and clay granules can be mixed with the soilless media to increase pore spares and consequently improve aeration and drainage. These mixes are usually produced differently depending on the cost and availability of the components for the media mix, the type of crop to be grown, the production requirements of the crop, production system and the season the media is to be used for cultivation (Acquaye, 2011).

2.9.3. Characteristics of substrates

Argo (1997) pointed out that the quality of the substrate is one of the important factors to consider when selecting a substrate for cultivation. The substrate chosen should be able to enhance shoot and root growth(Nelson, 1991). To be able to determine the quality of the substrate the chemical and physical properties must be evaluated. Since, not one substrate provides the crop all that is needed, when the chemical and physical characteristics are checked, the shortfall can be supplemented by the growers(Argo, 1997).

2.9.3.1. Physical characteristics of substrates.

Soilless substrates physical component is made up of four parts, which is 20-30% solids, 10-25% available water, 20-30% airspaces and 15-45% residual water (Spiers and Percy, 2007).

Acquaye (2011) noted that of all the parts of the soilless substrates the most relevant is the airspaces and available water which depends on the shape and particle size of the substrates. Spiers and Percy (2007) reported that when the substrate is dense with airspaces of less than 10%, aeration of the roots becomes a problem for plant growth. They further stated that the plant can take up more water than is available in the substrate, but would need to use up more energy to achieve this. Coarse particles usually have large pore spaces of about 0.5mm or larger, which facilitates proper aeration in the substrate. However, when the substrate is

of medium texture, it has a pore space of 0.1-0.5mm which also facilitates water availability. With fine particles, pore spaces are about 0.1m will be able to hold some water, but this will not be available to the plant. In selection of substrate there should be a fine mix of both ¾ coarse and 2/4 medium sized particle, with little fine particle (i.e. 5% of the total substrate) (Spiers and Percy, 2007).

Bunt (1983) explained that the bulk density of substrates is inversely proportional the pore spaces in the substrate. Richard, (2006) also explained that the movement of water in the medium is controlled by the total porosity of the medium. Root settling of substrate can affect the physical properties of the substrates (Nash and Pokorny,1990).

Physical characteristics of substrates are bulk density and water holding capacity (Schafer *et al.*, 2015).

2.9.3.2. Chemical characteristics of substrates

The pH, Electrical conductivity (EC) and CEC(Cation Exchange Capacity) are the chemical characteristics mostly determined for substrates (Schafer *et al.*, 2015).

The salt content of water as a result of flow of electrical current is what is referred to as Electrical Conductivity (EC) (Richard, 2006). According to Pettinelli and McAvoy (1995) the salt content of the substrate is what determines the electrical conductivity. The amount of ions from fertilizer salt that dissolves in substrate solution is Electrical Conductivity. Thus, an increase in the amount of fertilizer applied causes high levels of salt in the substrate or soil. When the EC of the soil or substrate is high it decreases the supply of water to the plant root and can cause some problems to the plant (Richard, 2006; Spiers and Percy, 2007).

Lang(1996) found out that the recommended EC for seedlings and established plants is 1.0-2.0mS/cm and 2.0-3.0mS/cm respectively. When these figures are exceeded it weakens the rate of growth of plants (Acquaye, 2011).

There are other factors that cause the increase of salt content of a growing medium; such as leaching, inadequate watering and poor drainage. An increase in the salt content in the soil is characterised by chlorosis of leaves, necrosis, root injury and burning of leaf margins.

The power of hydrogen is what is referred to as pH. The pH of a growing medium denotes the acidity or alkalinity level of the growing medium. Hartman *et al*. (2018), indicated that the pH level of a growing medium affects the uptake of nutrients by the root.

Container size, pH of irrigation water, plant species, fertilizer and water alkalinity; plant uptake of nutrients and lime concentration and activity are some of the factors that affect the pH level of a medium. When a growing medium has optimum pH levels it facilitates gaseous exchange which consequently facilitates aerations and permits water infiltration and movement of roots for healthy plant growth (Larson, 1980). Hartman *et al.* (2018) reported the optimum pH of soil for plant growth between 6.3 to 6.8, for soilless medium a pH range of 5.4 to 6.0 and a pH range of 5.2 to 6.3 for organic substrates.

2.9.4. Agro-waste in Ghana

Many of the agricultural activities carried out produce waste materials and products Sase and Christianson (1990) indicated that agricultural waste are usually gotten from food, crop residue, fibre, feedlots, forests, grasses , ranches or ranges, animal manure, dead carcass,etc. In some cases the containers used for growing and agricultural chemical residue are included to agricultural waste.

In Ghana, most agricultural waste is obtained from crop residue. Some are converted into manure and compost for fertilizing crops, some are used for animal fodder, some are used in the household (i.e. firewood for cooking) and yet some are left unused or burnt causing environment problems. Aside the fact that burning the waste is hazardous, it also wastes material that could be used for energy production or other purposes (Quartey, 2011).

Quartey(2011) estimated that over 4.2 million tonnes of agricultural waste is produced in Ghana annually and this could be used as for many purposes and a very important resource for the country. They are renewable, virtually free and available (Quartey, 2011).

Industrial wastes from oil palm, rice, coconut, as well as wood shavings over the years have become some major sources of environmental pollution. Zanin (2011) indicated that United States of America generates approximately 100,000 Mt rice hulls annually from rice mills in the country. However, they manage these large volumes of waste by charring these materials and used for growing of crops (Taguinod, 2002). Most varieties of rice are composed of approximately 20% rice husk or hull, 69% starchy endosperm commonly referred to as the total of the rice milled, and 11% bran layers (International Rice Research Institute (IRRI), 2016; Rice Knowledge Bank, 2016). Ghana produces about 1,025,180 Mt annually (Ghana Live,2017).

This translates to Ghana generating about 205,036 Mt rice hulls annually from rice mills in the country using the formula below:

Total Rice hulls = (20/ 100) x Total Rice grown

Total Rice hull = (20/100) x 1,025,180 = 205, 036.

2.10. Biochar

Plant biomass such as wood, leaves, among others can be heated in a container with little air or no air at all to obtain a carbon rich product. This product is what is referred to as biochar (Singhal *et al.,* 2011). Singhal *et al.* (2011) again indicated that by the process of thermal decomposition where temperature is low, about less 700ºC and little supply of oxygen the organic matter is converted to biochar. Biochar is very similar to charcoal in appearance, but biochar is used for improving soil structure for crop producing. Between 10-50% of total carbon contained in the biomass is retained in the biochar during the combustion process. Garcia-Perez(2008), reported that about 2-10% of the total carbon biochar is made up of labile carbon. Labile carbon is the portion of the biochar that is decomposes quickly by soil organisms. Proper soil function results in farm productivity that is dependent on the quantity and quality on the liable carbon and its turnover rate (Chan *et al.*, 2010). Hence, the quality of biochar obtained and its worth to agronomic performance depends on the pyrolysis process used (Singhal *et al*., 2011). Biochar is used to address environmental problems such as water pollution from agrochemicals, food insecurity, climate change and soil degradation. The mean residence time (MRT) of biochar is believed to be 1,000 to 10,000 years (Lehmann and Sohi, 2008).

It is very difficult for microbial decomposition in biochar than in uncharred organic matter because of its dominant aromatic carbon in its macromolecular structure (Lehmann and Sohi,2008).

Biochar can also be used to increase the storage of soil carbon, reduce leaching of nitrogen into ground water, reduce greenhouse gases (GHGs) emissions, and increase the cation exchange capacity (CEC), regulate soil acidity, enhance water retention, improve the number of beneficial soil microbes, immobilize contaminants, improve soil fertility, improve crop yield and also increase biological nitrogen fixation (Lehmann and Sohi,2008).

2.10.1. Materials used for biochar production

Biochar can be obtained from a number of feedstock such as agricultural waste, industrial waste and crop residue. This make it advantageous in crop production to farmers as the needed material for biochar does not require food crops and does not require lands for food crop production to produce them (Lehman and Sohi, 2008).

Rice husk, wheat straw, corn stover, palm fibre, sugar cane bagasse and nut shells are the usual crop residues used. From industrial production waste such as wood chips, saw mill waste, pelletized sawdust, sewage sludge, biomass from invasive species and cardboard products. Poultry litter, leaves, stems are agricultural debris or waste mostly used (Major *et al.*, 2009).

However, though plant residues are used for biochar production, some should be left on the cultivated soil to be able to decompose and put carbon back into the soil to improve soil fertility, it also check soil surface erosion and generally improves soil health. This is very key in maintaining the fertility of our soils even in introducing biochar substrate.

Lehman and Sohi (2008) agrees with the my thoughts highlighted above, by indicating that a study conducted in Ohio showed that when more than 25% of crop residue was removed after cultivation for bioenergy production there was great impact on fertility and soil carbon quantity in the soil.

As much as we seek to formulate new technologies to improve production it must be done in a way to facilitate sustainable agriculture in the future.

2.10.2. Biochar production.

Biochar can be produced by various methods such as carbonization, gasification, slow pyrolysis and fast pyrolysis (Lehman and Sohi, 2008). The carbon negative product obtained

by heating or partial combustion of plant biomass in the absence of little or no oxygen is the process referred to as pyrolysis (Major *et al.,* 2009). At a molecular level the biomass breaks down and there is a release of producer gases also known as 'syn-gas' which is a volatile gas during the thermal decomposition process. To be able to produce various forms of energy the gases are cleanly and efficient condensed. The major biochar production process used is carbonization (Lehmann and Sohi,2008).

Plants take carbon dioxide during the process of photosynthesis. Hence, if all the carbon dioxide by this process is emitted during the pyrolysis process a carbon neutral biomass will be created, but since some of the carbon is retained in the plant biomass, a carbon negative process is created. This allows experimenters to be able to obtain enough carbon needed in the full cycle of the biochar production process. Lehman and Sohi (2008) again ascertained that this results in the retention of approximately half of the carbon in the plant biomass.

2.10.3. Carbonization

The carbonization process by which the biochar is produced closely resembles that by which charcoal is processed traditionally. This is done by a simple partial combustion method is used mostly in the rural areas in most countries to produce biochar because of it low cost and easy to use as compared to other pyrolysis methods. Okimori *et al.* (2003) indicated that a brick, a drum and a hume pipe kiln are three methods that have been investigated to be used in the carbonization process of biomass wastes. Ogawa *et al.* (2006) agrees with the accession made by Okimori *et al.* (2003). When the temperature is increased between 300 ºC to 800 ºC the carbon content contained in the biochar produced increases to 93% and the amount of biochar produced decreases to about 26%. However, when temperature is kept below 300º C the carbon content retained is about 56% and the biochar yield is 67%. This clearly shows the negative relationship between biochar yield (amount of biochar content produced) and carbon content (Tanaka,1963).

Kuwagaki and Tamura(1990) conversely believe that the above stated theory by Tanaka (1983) was not wholly the case and proposed that at a definite threshold, the mass of the biochar will reduce and will translate into the increase in ash content in biochar but there would be no effect on the carbon content. A study carried out by Kuwagaki and Tamura(1990) indicated that at a temperature between 300ºC to 800ºC the ash content of the biochar from 0.67% to 1.2%.

2.10.4. Standards for agronomically used biochar

The characteristics of biochar produced after the thermal process is dependent on the quality of feedstock from which it was produced. Hence, there is the need to carefully select the feedstock, so as to be able to obtain the right quality of biochar for optimum crop development (Major *et al.* 2009). To select the feedstock there is the need to analyse its sustainability and lifecycle. To measure agronomically used biochar there is the need to access it based on certain parameters such as pH, pore volume, specific surface area, ash content, water holding capacity and volatile compound (Kuwagaki, 1990).

2.10.5. Benefits of biochar for developing countries.

Thies *et al.* (2009) believed that biochar could solve world poverty, because biochar improves crop production, increases on-farm income of farmers as they use biochar instead of purchasing high cost fertilizers, create job opportunities by empowering the communities from converting local resources into useful materials. Biochar could be used for manufacturing biochar cooking stove in homes for cooking, which prevents smoke inhalation, used to power decentralized heaters and other power facilities, Biochar allows for easy water filtration, reduced pressure on forest ecosystem, the toil of carrying firewood is reduced and allows the farming communities in accessing global carbon market as the undertake projects to produce biochar. The generative system provided by biochar is

sustainable and gives a positive self-reinforcing feedback cycle which ensures availability of quality food (Thies *et al.,* 2009).

2.10.6. Impact of biochar on crop production.

Many scholars do believe that biochar gives higher yield in crop production. Rondon *et al.*(2007) reported that in a pot experiment carried out indicated that biological nitrogen fixation of maize planted in a pot containing biochar was higher than those that had no biochar. Chan *et al.*(2007) concedes with the study of Rondon *et al.* (2007) as a pot study on radish using biochar resulted in higher yield and higher nitrogen uptake. Other research conducted in the semi-arid parts of Australia by Chan *et al.*(2007) proves that biochar treated plots with fertilizers such as NPK gave higher yields. In Indonesia higher yields were also realised when biochar made from bark and nitrogen fertilizer was applied soils used for growing maize and peanut (Yamato *et. al.,* 2006). Fertilizer use efficiency is improved by the introduction of biochar into the soil, this translates into improved crop yields and this is also the case in the Amazon region after the forests were cleared for crop production (Steiner *et al.,*2008; Kimetu *et al.,* 2008)

2.10.7. Carbonated Rice Husk

Rice husk are the covering of rice discarded after rice processing (Ebara, 2005). This waste product processed and used in crop production for enhancing the soil for seedling growth. (Pablico, 2003). As a soil enhancer, it is permeable, it has high aeration and able to hold water for a relative period of time making it appropriate for plant growth during the dry season, but not as able to hold water like palm fibre and cocopeat.

It is easier to transplant seedling when used for nursing seeds as pulling of plants out of the carbonated rice husk substrates is very easy. Taguinod *et al.* (2002), confirmed the above accession by indicating that when 10kg/bag of organic fertilizer containing carbonated rice

husk was incorporated into the seed beds at 1m x 20m of rice field the pulling of the crops became easier. It is also easy to transport as it its bulk density is low.

Taguinod *et al.* (2002) underlined that carbonated rice husk is very high in phosphorus, potassium, magnesium, calcium and other micronutrients very relevant for crop. Crops grown in carbonated rice husk are free of most pests and diseases as the substrate is well sterilized during the preparation period (Taguinod *et al.*,2002). Carbonated rice husk is able to contain heat from the sun because of its black colour. Silica is also present in carbonated rice husk and when spread on top of the soil it irritates insects and pests (i.e. termites and snail) in the soil.

Some manufacturers mix carbonated rice husk (CRH) with organic materials to produce organic fertilizers. Taguinod *et al.* (2002) reported that carbonated rice husk, garden soil and compost mixed in a ratio of 1:1:1, produces a great potting mix that gives very high yields in crop production.

The equipment and technologies for preparation of carbonated rice husk though not very modern, the process of perfecting it is still underway in Ghana. However, in the developed countries biomass experts have perfected the carbonization process. The carbonated rice husk is produced in large quantities and is sold not only on the local market, but also on the foreign market (Philippine Rice Research Institute report, 2003; Pabilico, 2003).

2.11. Palm Fibre

Palm fibre is a substrate obtained from oil palm residue after the palm tree has been felled and decomposed. It is a fairly new feedstock on the market and there is therefore the need to study palm fibre to confirm its use substitute for cocopeat.

Ahmed *et al.* (2013) claimed the above fact true. In the research palm fibre was used to grow cucumber and results obtained were ideal total porosity, moderate bulk density, ability to retain enough water needed for optimum crop growth, adequate drainage rate, optimum pH and optimum electrical conductivity. Palm fibre was seen to do better than top soil and peat moss with the roots and shoots correlation for cucumber grown with palm fibre being 0.751 and 40% more fruit production realised in palm fibre than the peat moss and top soil.

2.12. Cocopeat

This is the most commonly used substrate in greenhouse production worldwide. Cocopeat is the produced from coconut husk. Until recently coconut coir was dumped indiscriminately as it was considered as a waste product (Shivdas, 1989). It is now prepared and used as substrate for growing of crops in greenhouse.

It is difficult for coconut coir to decompose, because of its lignin and tannin composition (Shivdas, 1989), hence, makes a pollutant for long years. Shivadas (1989) reported that, till the discovery of cocopeat, peat moss was the commonly used substrates. Another substrate called the rock wool was also developed in Denmark and introduced to the United States, Europe and other developing countries these were however observed to be environmentally un-friendly as to obtain peat moss it is mined and this has an impact on the ecology while rock wool is difficult to get rid of its slabs though it was good for crop production and mostly used by greenhouse users.

Since cocopeat is organic and biodegradable in nature it is environmentally friendly and gives the needed yield that would have been obtained from rock wool and peat moss. The fact that it is obtained from renewable resource is an added advantage (Shivdas, 1989).

The high salt content of cocopeat can cause lysis as a result of the movement of water from the plant to the substrate by the process of reverse osmosis. To address this problem

farmers are advised to wash cocopeat thoroughly with water low in salt before using for cultivation. Calcium nitrate can also be applied in a ratio of 5 part cocopeat to 1 part calcium nitrate to reduce the salt content.

Cocopeat is slow decomposing hence as a soil conditioner stays in the soil for over 3 years before totally decomposing. It can also be used in the greenhouse as a soilless medium for more than 3years. Cocopeat is able to retain moisture which allows for plant nutrients in solution to remain in the soil at the root zone and this in term facilitates root formation and consequently high crop yield.

Also, its high water holding content facilitates lowering of temperatures and crop load demand still ensuring that air supply is enough. Cocopeat is also very high in organic compound, micro and macronutrient and this helps in the resistance of pest and disease and also helps in root growth and development (Shivdas, 1989).

Cocopeat is used in container growth, seed starting mixes and also in bedding plants. It has a pH of 5.0 -6.8, which is adequate for alkaline garden soil and is consequently resistant to bacterial and fungal growth. It holds about 8 to 9 times its weight in water. The nutrients are also stored and released to the plants periodically for a long time to plants and also have high oxygenation properties which are needed for healthy root development.

Shivdas(1989) emphasised that manufacturers of cocopeat should bear in mind the purpose for which the substrate is to be used and the agro-climatic condition in which it will be used to be able to manufacture the best cocopeat substrate. Also it can be enhanced by adding micro and macro nutrients needed for plant growth that is not already contained in it. This should be done with fore knowledge of the nutrient requirement of crop production.

2.13. Effects of Container sizes on plant growth and development.

Container sizes cause root restriction that changes the morphology and physiological response of plants and this has been reported in many studies. It is necessary to use container sizes that will give best quality performance and high yield of crops. The yield and performance results obtained from research done on these containers on tomatoes and other plants production vary (Vavrina *et al.,* 1993)**.**

There is a difference in morphology of roots of plants grown in open field and those grown in containers in the greenhouse (Peterson *et al.,* 1991). Peterson *et al.* (1991) again added that in a research carried out it was observed that tomatoes grown in containers had lost most of its primary roots in favour of lateral ones. The inverse was true for those grown in open field.

The physiology and morphology of plants is altered in many ways when the rooting volume is reduced. This has the tendency to affect the quality and performance of the plants (Aloni *et al.,* 1991).

The container size used for production affects the rate of root restrictions which will then have an effect on the accumulation and partitioning of biomass, root and shoot development, leaf chlorophyll content, photosynthetic rates, uptake of nutrients, the relationship between the crops and water, respiration rate, flowering, yield and yield component of the crops(NeSmith and Duval, 1998).

Peterson *et al.* (1991), reported that when roots compete for essential resources (i.e. water, oxygen, nutrients, etc.) when they are restricted in smaller containers. This is because their root mass would increase as the plants grow and the rooting space available is smaller, hence causing the competition.

It has been noted that the behaviour of different crops when volume of soil used in crop production is reduced varies. Even within species and cultivars these variation in responses has been seen (Cantliffe, 1993). Cantliffe (1993) again observed that mostly when the container increases the biomass of the shoot and the root, as well as the leaf area of the plant increases.

Tonutti (1990) accessed that, the growth rates of the shoot is dependent on the roots and vice versa.

Leskovar *et al.* (1990) believes that when the container size is decreased the roots become restricted and reduces root volume. This creates an imbalance in the direct relationship that lies between the shoots and roots. It was again explained that the aerial portion of the plant photosynthesizes and produce various hormones that help root growth and development. While the roots provide nutrients, support, hormones and water to the aerial portions of the plants. Hence, if these benefits are curtailed or reduced with root restrictions it can affect the development and growth of the plants short and long term.

For optimum growth of roots there is not only the need for adequate supply of water, high fertility of media and favourable condition of the media, but there is the need also for a favourable physical rooting environment (Leskovar *et al.,* 1990).

Weston and Zandstra (1986) added that when a larger container is used for growing crops, large root are produced which prevents post-plant shock and which reduces the length of time for production.

When small container sizes are used, more alteration of the root morphology occurs and this causes drought stress in plants roots are unable to thoroughly explore the soil's water reservoir (Aloni *et al.,* 1991). Krizek *et al.* (1985) agreed with Aloni *et al.*1991.

Aloni *et al.* (1991), indicated that, when root restricted seedlings are transplanted into open field they are unable to make up for the loss of water from evapotranspiration no matter how well the transplants are watered.

Bilderback and Fonteno, (1987) pointed out that the geometry of the container used as well as the type of media selected for cultivation of crops has an effect on the amount of moisture and aeration in the soil. Again they emphasized that the reduction in the water holding capacity and the aeration in the media is due the reduction in the height and width of the container causing the root mass in the container to increase consequently reducing the pore spaces in the media to be reduced.

The reduction in biomass and height of shoot for tomatoes has been observed to be as a result of small containers (Peterson *et al.,* 1991). The same case was observed for marigold (Latimer, 1991). Maynard *et al.* (1996) recorded the same occurrence in muskmelon and so was the case for watermelon (Hall, 1989; Liu and Latimer, 1995).

However, the biomass of the stem of tomatoes and soybean was seen to improve considerably with the increase in container size (Krizek *et al.*, 1985). Well documented research has confirms that the leaf growth in crops such as tomatoes, pepper, watermelon, squash, marigold, soybean and cabbage increases with larger containers (Weston and Zandestra, 1986; Weston 1988; Ne Smith *et al.,* 1992; Liu and Latimer, 1995; NeSmith, 1993, Latimer, 1991; Krizek *et al.*, 1985; Csizinszky and Schuster, 1993 respectively).

This reduction in leaf growth was attributed to the reduction in photosynthetic rate which translates from a reduction in plant biomass. Peterson *et al.*(1991) also realized that the flowering period of tomatoes was reduced when smaller container was used which causes root restriction. The time of sowing to the time of anthesis was also seen to shorten when

tomatoes was planted in a smaller container (Ruff *et al.*, 1987; Kemble *et al.*, 1994).Fruit maturation was also delayed tomatoes when smaller container was used(Ruff *et al.*, 1987).

For vines it was noted that when they were nursed in larger containers and transplanted unto the field their growth was very high (Hall, 1989).

2.13.1. Effects of smaller container sizes.

In contrast, Ruff *et al.*(1987) observed that root restriction caused by planting in small containers accelerated the flowering process and caused early harvest. Weston and Zandstra(1986), saw an increase in yields of tomato that was grown in smaller containers. Cost of production of tomatoes is reduced when small containers are used (Schrader, 2000). With small containers the number of plants produced increases (Schrader, 2000) and reduces the space needed for production of tomatoes (NeSmith and Duval, 1998), which is mostly adopted by commercial farmers. Spiers and Percy(2007) explained that larger pots cause drying of substrates at the surface and middle portion as a result of leaching. This makes nutrients and water unavailable to plants. In smaller pots water and nutrients are readily available to the plants.

There are varied studies on the effect of container size on tomato production and other crops both agreeing and contrasting. Due to differing responses and contradictory evidence obtained for the same plant there is the need for further experimentation.

Also, research carried on this study was done some years back and not many current studies have been carried on the topic. Though extensive studies on container size effect on tomatoes and crops in other parts of the world. This has not been extensively studied in Ghana. There is therefore the need for further research to ascertain type of container size that best works for tomato production in Ghana.

2.14. Greenhouse technology

Domestication of plants is one of the greatest achievements of man. This allowed mankind to propagate types of crops they desired in larger quantities. Now human beings have chosen to cultivate crops under protected environment to prevent the effect of abiotic and biotic stress. This seeks to ensure that maximum production of crops can be grown on a small piece of land and year round production is also assured. This ensures food security and reduces poverty(FAO, 2013).

Greenhouse technology is the system where crops are grown in an enclosed structure. Agro-climatic conditions favourable for plant growth is created in the enclosed space and the amount of solar radiation needed for plant growth is regulated (Thipe *et al.,* 2017).

A greenhouse is usually a framed structure. However, in some cases it can be an inflated structure. In both cases it is covered by a translucent or transparent material that is able to regulate environment and prevents the influence of external climatic conditions (Chandra and Panwar, 1987). The size of the greenhouse structure allows for all cultural practices which would otherwise be performed on the field to take place also in the greenhouse (Thipe *et al.,* 2017).

The materials (i.e. plastics, fibreglass or sheet glass) for greenhouse construction is selected to ensure heat retention and light transmission (Thipe *et al.*, 2017).

For greenhouse production quality of crop produced is of utmost importance. The grower often focuses on receiving high returns on investment as a result of the cost of production (Wittwer and Castilla, 1995).

The technology looks at the type of crops that can be cultivated under greenhouse conditions, customised modelling of the greenhouse structure, process of agronomic

management, the cost of production and the market available for greenhouse produce, among other pertinent factors (Thipe *et al.*, 2017).

Vegetables, fruits, ornamentals, seedling and flowers are the plants usually grown under greenhouse conditions (Castilla *et al.*, 2013).

There is the upsurge of greenhouse technology around the globe with about 405,000 ha of greenhouses are spread around the world. How advanced the greenhouse technology employed in each country is dependent on their climate requirements, as well as the economy of the country (FAO, 2013).

Northern Europe was one of the first people to adopt the greenhouse system and this yielded good result and caused it to spread to the Mediterranean climate areas. The Mediterranean regions have since then been one of the leading producers of greenhouse vegetables, harvesting not less than 300 tonnes per hectare annually (FAO, 2013).

The Mediterranean areas do not only consume greenhouse crops on their local market but they export large quantities of high value crops to other countries. This has helped build the economies of these countries as their foreign trade balance is improved (FAO, 2013).

From 1997 to 2008 Food and Agriculture Organization (FAO) has carried out series of research in many countries to analyse the effectiveness of greenhouse production in different countries. Ghana is no exception. Their findings indicated that greenhouse production helped limit the impact of agriculture on climate change and the environment in general. This was in line with FAO ‘save and grow’ paradigm. Also yield and quality of produce was very high (FAO, 2013).

Greenhouse technology is being widely adopted in Ghana with hundreds of greenhouse structures under construction and utilization across the country. The embracing of this

technology has been attributed to the high demand for vegetables on both the local and foreign market. Since these vegetables grown in the greenhouse are high value crops, the farmers earn more income (Herms *et al.,* 2016).

The government has also shown key interest and in 2015 facilitated the construction of 150greenhouses (Herms *et al.,* 2016).

Though this technology has been embraced by growers. Many growers have also abandoned their greenhouses as a result of inability to manage it, fluctuating yields and incidence of pest and diseases. Currently, most greenhouse farmers are experiencing low yields of about 0.0165- 0.0221tonnes per hectare annually after their fifth and sixth year. In Kenya production from greenhouse farming is about 0.0221-0.0276 tonnes per hectare annually (Ghana Veg, 2016; Herms *et al.,* 2016).

Many of the greenhouses were part of the 160greenhouses that was constructed in Ghana in 2015 by West African Productivity Programme sponsored by World Bank (WAAPP report 2018).

It is therefore very clear that, in greenhouse production and number of factors (i.e. good design, inputs used, substrates, container types and crop management practices) need to be considered to be able to obtain consistently high yields (Herms *et al.,* 2016).

Reports show that the EnviroDome greenhouse design was by far better than the other designs currently on the Ghanaian market (Ghana Veg, 2016).

The Institute of Applied Science and Technology, University of Ghana-Legon in partnership with Cosmos Ghana are looking for ways to send recommendations on how to make greenhouse production more successful to greenhouse farmers.

Ghana Veg in partnership with other experts, institutions and organisation have carried out research on the designs, agronomic practices and inputs to be used for greenhouse. The effect of container size in greenhouse production has not been researched at all. However, the substrate used effect is still undergoing experimentation (Wagneningen University research, 2016; Ghana Veg, 2016).

The Minister of Food and Agriculture, Dr. Owusu Afriyie Akoto led a delegation of experts to Morocco to attend the 13th Edition of Salon International agricultural fair. The purpose of the visit was to seek support from Morrocco to improve our existing greenhouse farms and add on new cooperative units. It was reported that the Minister indicated that with the huge potential for greenhouse farming in Ghana, Ghana was ready to go into a private public partnership with big cooperative greenhouse organisation to develop the already existing Dahwenya greenhouse farm into a village and spring some up in Kasoa and Akomedan (Report by Kale –Derry graphic online , 2018).

World Bank has again in 2018 donated 2 million dollars to WAAPP under the direct supervision of WECARD (West and Central African Council for Agricultural Research and Development) for construction of 260 greenhouses for tomato, cucumber and sweet pepper. It is believed that this will provide employment for over 700,000 people (WAAPP report 2018).

The most common crop grown in the greenhouse in Ghana is tomatoes. This is because the demand for tomatoes is high throughout the year and therefore higher prices can be obtained in the dry season, also farmers are able to prolong their production up to six months with the indeterminate varieties (Ghana Veg, 2017).

The Centre for Scientific and Industrial research reports that Ghana can be Africa's leading tomato producers if greenhouse farming is expanded (Report by Debrah Myjoyonline, 2016).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Baseline Survey

A baseline survey was conducted between 5th to 29thJune,2017 to identify functional greenhouses and ascertain standards for greenhouse tomato production in Ghana after the introduction of this technology in 2010. The baseline survey targeted varying growing containers, bag sizes and media being used in these greenhouses. The results from the survey were used for the development of the theoretical framework of the study.

For this survey unstructured questions, probing questions and observations were employed to obtain the necessary information from the farmers guided by a list of issues pre-defined rather than detailed in a questionnaire .

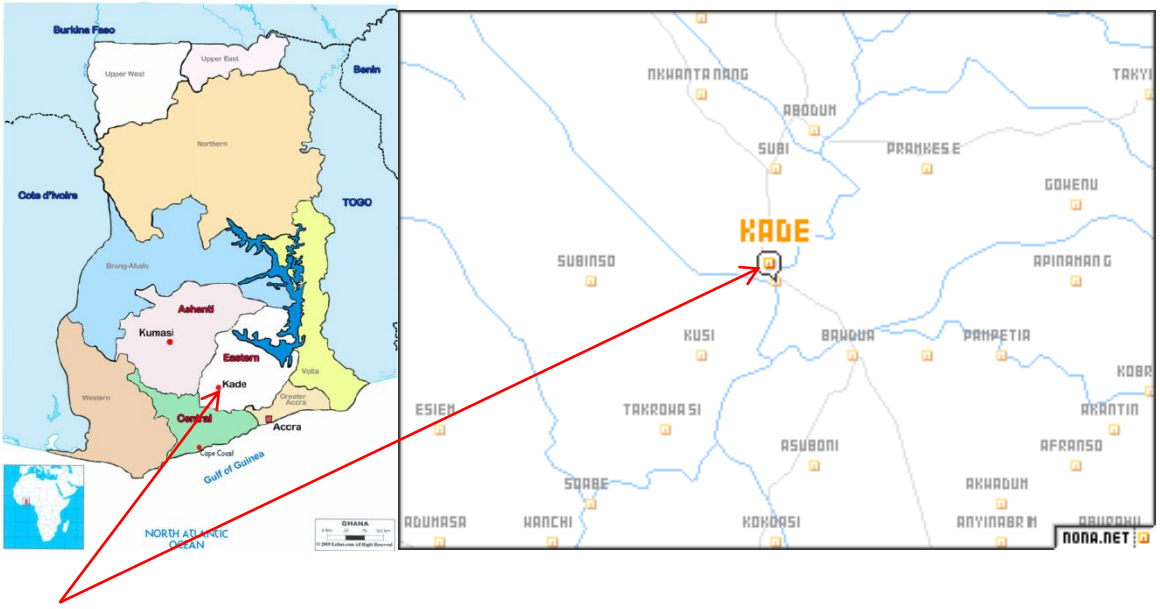
Ten functional greenhouse farmers were identified in the Greater Accra, Eastern, Central, Ashanti , Volta and Brong Ahafo regions of Ghana. One greenhouse farmer (i.e. at Konkonuru the Eastern Region of Ghana) was selected at random to pre-test the instrument.After which, eight greenhouses (i.e. Dahwenya, Kade, Ahwirse, Ashiaman, Budu Atta, Kwadaso, Brekuso and Vume) were selected for the study.

3.2. ENVIRODOME Greenhouse Studies to evaluate the effect of different potting container size and growing media of selected tomato varieties

Two separate experiments were carried out between September, 2017 and May, 2018 to assess the response of two selected tomato varieties to different potting container sizes and growing media as identified from the baseline survey.

3.2.1. Description of the experimental are

3.2.1.1. Geographical location of experimental Site.



Experimental site

Figure 1: Map of Ghana showing Kade (Experimental site)

The experimental study was carried in an ENVIRODOME greenhouse at FOHCREC (Forest and Horticultural Crops Research Centre), Okumaning camp in Kade which is in the Kwaebibirem district found in the Eastern Region of Ghana (6° 05' N; 0° 05' W), 175 km from Accra. The centre is about 150 m above sea level. The experimental site is located in the humid semi-deciduous forest vegetation zone in the Eastern part of Ghana.(Ofosu-Budu, 2003; Nkansah *et al*., 2007).

3.2.1.2 Climatic Condition

The Climate of the area is humid and tropical. The monthly average temperature reaches a maximum of 25-33°C in February and March and a minimum of 23 – 28°C in July and August. The rainfall pattern is bi-modal with peaks (150 and 200mm) in May/June and September/ October. The potential evapotranspiration varies between 3 mm to 4 mm daily during the rainy season and 5 mm to 6 mm daily during the dry season and may reach an annual value of 140 mm.

Table 1: Mean values of temperature and relative humidity in the ENVIRODOME greenhouse during the experimental period.

Months	Mean minimum temperature values (°C)	Mean maximum temperature values (°C)	Minimum mean relative humidity (%)	Maximum mean relative humidity (%)
September, 2017	23.59	29.39	62.9	79.3
October, 2017	24.71	31.54	61.4	78.9
November, 2017	25.02	31.70	65.2	79.9
December, 2017	24.89	32.03	66.4	78.9
February, 2018	26.64	32.46	66.8	79.4
March, 2018	30.44	32.63	69.1	79.7
April, 2018	26.55	32.22	70.2	80.2
May, 2018	21.94	32.54	74.1	80.4

Source: FOHCREC Greenhouse thermo hydrometer, Okumaning - Kade.

3.3. Sources and preparation of substrates

3.3.1 Palm Fibre

Materials needed for collection of palm fibre

- Cutlass, Sacks and Shovel.

The Palm Fibre substrate was obtained at the FOHCREC research centre from a felled oil palm tree plantation, that is now a maize field and a pear plantation. The palm fibre was taken from the axil and trunk of the decomposed oil palm tree. The weeds around the decomposed felled palm tree were cleared with a cutlass. The shovel was then used to scoop the palm fibre into the sacks for transport in the tractor to the greenhouse.

Materials needed for sterilization of palm fibre

- Sterilization bath, firewood, watering can filled with water, wheel barrel, match sticks and kerosene.

The palm fibre was poured into a bath and fire was lit underneath the bath. After which water was sprinkled unto the palm fibre and sterilized. This was done to make the palm fibre heat up very fast. It took about 30minutes for the sterilization process to be completed.

After completion, the sterilized palm fibre was collected and transported to the greenhouse and spread out on a tarpaulin to cool. After an hour the palm fibre was ready to be bagged and used.

3.2.2. Carbonated Rice Husk

Materials needed for collection of the rice husk

- Shovel, pan and sacks.

The rice husk was obtained from the University of Ghana rice mill in Kade. The rice husk was collected into sacks and transported with a tricycle from the mill at Kade to FOHCREC, Okumaning. It was off loaded at the carbonation area and covered with a tarpaulin to prevent rain from wetting the husk.

Materials needed for the carbonation process

- Shovel, open perforated barrel, water hose connected to a stand pipe, firewood, match sticks and kerosene.

The process used for the carbonation of the rice husk was the partial combustion method. The firewood was lighted on the ground and the open perforated drum (200L) was placed on the lit fire. A perforated drum was used to ensure uniform and gradual burning of the rice husk as the perforation controls the intensity of heat from the fire that can burn the rice husk. If the drum is not perforated the fire will heat up and burn the rice husk into soot instead. The barrel is then filled with more firewood. After which it was ensured that the fire was lit properly. A quantity of the rice husk was heaped around the barrel a distance above the middle portion of the barrel so that the heat from the fire carbonated it. The rice husk was continually turned with a shovel every 30 minutes to facilitate even carbonation to obtain the characteristic uniform black colour of the biochar. The temperature recorded during the heating process was between 400ºC – 700ºC. Maturity period of the substrate depended largely on the quantity to be heated at a time and the substrate type. The maturity period of carbonation for the rice husk was about an hour and 30 minutes. When the

carbonation process was completed the heap was thinly spread out with a shovel and water from a hose was sprinkled on it while turning the carbonated rice husk to expel the heat. This was done so that the entire rice husk did not burn to soot when left over night. The wet carbonated rice husk was heaped unto a tarpaulin and allowed to cool and dry for about 24 hours after which it was ready to be bagged and used.

1.3.2. Cocopeat

Thirty (38) bags of cocopeat was purchased from a supplier in Adjei Kojo in Ashiaman. Due to the high salt content of cocopeat which can cause burning in tomato plant and can inhibit flowering and fruiting in the plants, the purchased cocopeat was washed to reduce the salt before the substrate was used.

The initial salt content of the cocopeat was determined to be 13.11ms/cm. After the wash, the final salt content was 4.51 mS/cm.

Table 2: Salt concentration of soil or growing medium based on EC levels.

Electrical Conductivity(ms/cm)	
0- 3.0	Non-saline
4.5 -9	Slight salinity
9- 18	Medium salinity
More than 18	High salinity

Source: FAO United Nations training manual for International support programme for irrigation water management (1986).

From the table above the cocopeat substrate bought was medium saline and could affect the plants, hence there was indeed the great need to wash it. The obtained value of the cocopeat

after the wash was 4.51mS/cm. Meaning it became less saline as it boarded on the edge of becoming non saline.

Materials required for the wash

- Bath with an outlet/ drain, water hose connected to a stand pipe or tank, a sieve for squeezing and tarpaulin for drying.

The cocopeat was placed in the bath. Water was poured unto the cocopeat via a water hose connected to a stand pipe or tank. Initial pH and salt content was determined from the solution collected when water was added to cocopeat. The cocopeat was kneaded and squeezed several times and the water was allowed to drain out. This process was carried out four times, after which on the fifth time the pH and salt content was determined. When the EC was determined and was found to be at a level which can facilitate optimum plant growth the water was drained from the cocopeat. The cocopeat was squeezed to drain out all the remaining water. The cocopeat was then spread on a tarpaulin to dry under the sun for 24hours. After which the cocopeat was bagged and ready to be used.

3.4. Nursery Management.

- **Nursing of Seeds**

Materials needed for nursing seeds.

- Cell trays, tomato seeds (Limbobo and Rodeo), palm fibre growing medium, NPK 19: 19:19, top cop, A4 Sheet and pen/celletape.

A 72 plastic cell tray was filled with palm fibre substrate. Palm fibre was used in sowing the seed because it is very smooth, it facilitates good seedling growth and it is the substrate mostly used at FOHCREC to nurse tomato seeds. In filling the cell tray the medium was not compressed to allow for aeration. The palm fibre growing media in the cell tray was sprayed

with 'top cop' a broad spectrum pesticide which controls bacteria, fungi and mites to control residual pathogens and insect pests that might have escaped during the sterilisation process. After which seeds were sown and watered with water mixed with top cop insecticides. In all 1000 limbobo and 1000 rodeo seeds each were sown for both the 1st and 2nd experiment. Two seeds were sown per cell of the nursery tray. The cell trays were labelled according to the variety of tomatoes sown. The tray was covered with paper to conserve moisture particularly at the surface. The piece of paper was removed as soon as seed emergence began.

A measured quantity (i.e. 2 g/L) of starter solution (NPK 19:19: 19 solution) was applied five (5) days after seed emergence. The starter solution was prepared by dissolving 2g of NPK 19:19:19: in 1L of water. The pH was tested and found to be 6.2 which is optimum for plant growth. Pricking out was done 7 days after sowing of seed to one per cell. 10 g/L of Mancozep 80 WP (Mancozeb dithiocarbonate) fungicide was sprayed on seedlings at 7days old to control fungal infection especially damping off. This was repeated at days 12 and 17. Watering was done once or twice a day depending on whether or not the growing medium was dry. 6 g/L of N.P.K. 19:19:19 solution was applied weekly to provide nutrition to the seedlings.

3.5. Preparation of the greenhouse

The greenhouse was cleaned thoroughly by removing previously cultivated plants. Mulch material (i.e. black polythene bag) was laid in the greenhouse. After which the inside and outside of the greenhouse was fumigated with Cydim Super at what rate insecticide to kill all insects. Hot water treatment was also applied using a washing machine at 100ºC to spray the nets, ceilings, floors, corners and crevices of the greenhouse. The greenhouse was left for three days after which the greenhouse was ready to be used.

3.6. Substrate Analysis

Analysis of the substrates used in the experiment looked at both physical and chemical characteristics and was carried out at the Soil Science Department, University of Ghana, Legon. Physical characteristics (parameters measured) were bulk density and water holding capacity. The chemical analysis was on electrical conductivity, organic carbon, pH, potassium, nitrogen and phosphorus. This was done so as to ascertain if the growing media to be used were optimum for tomato plant growth.

3.6.1. Bulk density

The core method was employed in calculating the bulk density of the substrates. This method is used when substrates to be tested are coarse and have diameters less than 2 mm (Carter, 1990).

Materials used for calculating bulk density

- Measuring balance, ruler, micrometre, core, moisture can, oven and desiccator.

The core was used to collect and transfer the substrate into the bag which was sent to the laboratory (Harding and Ross, 1969). The volume (i.e. height, radius and diameter) of the core was measured.

Core volume – ($\Pi r^2 h$)

Height (h) – 4cm

$r^2 – (5.6)^2$

Π-3.142

Core weight -105.13.

The core was used to collect the sample of the substrate and the moisture can (g) was weighed.

Weight of the moisture cans (g)

31.57g.

The core and sample of substrate were transferred into a measuring can and weighed.

Weight of measuring can, core (g) and sample of substrate.

Palm Fibre – 162.72.

Carbonated Rice Husk – 155.34

Cocopeat – 68.70.

Cocopeat + Palm Fibre- 115.71

The weighed moisture can, core and sample of substrate were placed in an oven for 24hours at 105ºC to dry. The dried moisture can, core and sample of substrate were placed in the desiccator to cool. After cooling, the weight of the dried sample of substrate, core and moisture can was measured. The procedure used is based on Blakemore *et al*.(1987)

Dry weight (g)

Palm Fibre – 122.23.

Carbonated Rice Husk – 160.38.

Cocopeat -40.64

Cocopeat + Palm Fibre – 81.435

The measured parameters were used to compute the bulk densities of the substrates.

Bulk density Formula

$$\text{Bulk density} = \frac{\text{Oven dry sample mass}}{\text{Core volume}}$$

Computation

Palm Fibre

162.72 -31.57 = 131.15 wet.

122.23 – 31.57= 90.66 dry.

Mass = 131.15 -90.66 = **40.49g**

Volume = $\Pi r^2 h$ = 3.142 x $(5.6)^2$ x 4

Volume = **29.735cm^3**

Bulk Density = 40.49g/ 29.735cm^3

Bulk Density = **1.362g/cm^3.**

Carbonated Rice Husk

155.34 – 105.17 = 50.17 wet.

160.38– 105.17 - 31.57= 23.64 dry.

Mass = 50.17 - 23.64 = 26.53**g**

Volume = $\Pi r^2 h$ = 3.142 x $(5.6)^2$ x 4

Volume = **29.735cm^3**

Bulk Density = 26.53g/ 29.735cm^3

Bulk Density = **0.89g/cm^3.**

Cocopeat

68.70 -31.57 = 37.13 wet.

40.64 – 31.57= 9.07 dry.

Mass = 37.13 -9.07 = **28.06g**

Volume = $\Pi r^2 h$ = 3.142 x $(5.6)^2$ x 4

Volume = **29.735cm^3**

Bulk Density = 28.06g/ 29.735cm^3

Bulk Density = **0.943g/cm^3.**

Cocopeat + Palm Fibre

115.71 -31.57 = 84.14 wet.

81.435 – 31.57= 49.865dry.

Mass = 84.14 – 49.865 = **34.275g**

Volume = $\Pi r^2 h$ = 3.142 x $(5.6)^2$ x 4

Volume = **29.735cm^3**

Bulk Density = 34.275g/ 29.735cm^3

Bulk Density = **1. 15 g/cm^3.**

3.6.2. Water holding capacity

The funnel method of determining water holding capacity of growth medium was used.

Materials for measuring water holding capacity

- Retort Stand, funnel, measuring cylinder, rubber tubing and filter paper.

The funnel was clamped to the retort stand. A filter paper was placed in the funnel. It was ensured that the filter paper was dry. The sample of the substrate was weighed and placed into the funnel lined with filter paper. A measuring cylinder was placed under the funnel. 250ml of water was added to the substrate in the funnel. The set up was allowed to stand for 24 hour for the water in the funnel to move into the cylinder through the rubber tube. The water was collected in a measuring cylinder, hence the volume was determined and recorded. All the measurements recorded were used in the calculation.

$$\text{Water Holding Capacity} = \frac{[\text{Weight of sample} - \text{Volume of water collected}]}{\text{Volume of water added}} \times 100$$

NB: The water holding capacity of any growing medium is expressed as a percentage (Zanghe *et al*, 2012)

3.6.3 pH

Five empty containers were labelled for each of the substrates (i.e. palm fibre, cocopeat, carbonated rice husk and cocopeat + palm fibre). The weights of the empty containers were measured and the substrates added to the containers. The weights of the empty containers + substrates were measured. After which 25 ml of water was added to each of the substrates in the containers. A glass stirrer was used to stir the solution thoroughly for 30 minutes to enable all the ions in the substrate dissolve in solution. Leave the solution in the empty containers to settle for 30 minutes in the room where the readings will be taken. This is in line with Blakemore *et al.* (1987) study. This will help the solution to acclimatize to the room temperature. This is necessary as pH has a direct relationship to temperature.

A PL 700AL pH and electrical conductivity meter was used to measure the pH. The pH and electrical conductivity meter was turned on while waiting for the substrate solution to settle in order to warm the machine.

The pH electrode was calibrated with two (2) buffers. Buffer 7, which is basic and buffer 4, which is acidic to standardise the meter. The pH electrode was washed with distilled water after each calibration was done. The pH electrode was placed in the solution in the containers successively. The set-up was left for 2 to 3 minutes for readings to stabilize and values recorded. The pH of each sample was taken three (3) times. The electrode was washed with distilled water after the pH of each substrate was taken.

3.6.4 Electrical Conductivity

The same machine PL700 AL was used to measure the Electrical Conductivity (EC) of the substrates. The same process carried out for the pH was done for the EC. Except that with the electrical conductivity analysis, the EC electrode was calibrated with an EC standard buffer -1413µs/cm to standardise it. After which the EC electrode was used to test the EC of the substrate. The electrode was washed with distilled water after each substrate tested.

3.6.5. Nitrogen, Organic Carbon and Sulphur

The nitrogen, organic carbon and sulphur content of the substrates were determined at the preparation room in the soil science department using the CNS Tru Mac Analyser. Three boat crucibles were placed on a balance and the weights indicated on a computer monitor.

The balance and the CNS machine are all synchronised to a PC and whatever information is read from them is recorded on the PC monitor.

These three blanks were then placed in the sample loader and each were picked up and burnt separately for about six minutes each, after which the values were recorded on the monitor

for the parameters to be measured. Three standards or controls (i.e. glycine EDTA 98%) were placed in three boat crucibles then weighed on the balance and its weight recorded on the monitor. They were then placed in the sample loader and moved to the CNS analysing chamber to burn. Their measurement for organic carbon, nitrogen and sulphur were recorded on the monitor. These values were already known and the figures obtained were cross checked with those indicated on the bottle. When the figures matched, the substrates were tested for. Both the blanks and controls were used to standardise the machine before the substrates were tested for.

Boat crucibles to be used for the substrate analysis were weighed and their weights recorded on the monitor. 0.3g of an accelerator or catalyst called COMCAT was placed in each of the crucibles and their weights taken and recorded. The 0.3g of the substrates was also added to the COMCAT in the crucibles and weights taken and recorded. The substrates and the COMCAT in the crucibles were thoroughly mixed and placed in the sample loader for burning and determination of results of the parameters to be tested. Each substrate took six (6) minutes and the figures indicated on the monitor, and graphs drawn to show the peaks and trends.

3.6.6. Potassium

The Atomic Absorption Spectrometer A Analyst 800 in the Soil Science department was used to test for potassium amount in the substrates. 0.1g of the samples (i.e. palm fibre, cocopeat and cocopeat + palm fibre) was placed in a measuring cylinder and a mixture of sulphuric acid + hydrogen peroxide of 2.34 mol/litre were added. Biochar on the other hand becomes cumbersome to digest with the mixture of sulphuric acid + hydrogen peroxide. So for the biochar sample a tenure mixture was used. The tenure mixture used was a combination of nitric acid and pechloric of 4.79 mol/ litre. Tenure mixture is usually used to digest plant samples and compost. All samples were digested with a block digester for a

day. When the digestion was done the substrate became clear. The substrate solution was allowed to cool as when poured on the filter paper it will melt. After cooling the substrate solution was filtered and then diluted to 250 ml. The Atomic Absorption Spectrometer was calibrated with water to standardise it. The solution was then placed in the Atomic Absorption Spectrometer to undergo ionization and the values of potassium for the substrates measured.

3.6.7. Phosphorus

A Cole Parmer spectrometer in the soil science department was used to determine the phosphorous content of the substrates to be used. A volume of the aliquot of the filtrates of each of the substrates used to test for potassium was placed in a beaker. A colour development test was done.

Process of the colour development test was as follows:

a) 2mls of the filtrate was taken and a drop of paranitrophenol reagent was added. The colour of the solution remained colourless.
b) A few drops of ammonium were then added to the solution of the filtrate and paranitrophenol to get a yellow coloured solution.
c) The pH was adjusted by adding 10mls of distilled water to the solution above to get a pale yellow colour.
d) 8mls of ascorbic acid is added to reagent A which is thoroughly mixed and then added to the pale yellow solution. This then changes the colour of solution to blue
e) Reagent A is a mixture made up of sulphuric acid, ammonium molybidate and antinum potassium tatarate kept in the dark.
f) Blanks are prepared by adding the reagents to distilled water. These blanks are measured in the spectrometer to standardise the machine.

g) After the blue colour solution is obtained for the four substrates. They are poured into tubes and the tubes placed in the spectrometer for the phosphorus values to be measured.

3.7 Bagging of Substrates

There were three volumes (i.e. 5L,10L and 15L) to be bagged for each of the substrates. Each of the substrates will have 270 bags. 5L – 90 bags, 10 L-90 bags and 15 L-90 bags. The 1st experiment has three substrate making 270 x 3 and the 2nd experiment had four substrates making 270 x 4. In all 810 bags and 1080 bags were filled in the greenhouse for the experiment 1 and 2 respectively.

Black polythene bags were used; each was doubled to make it firmer. The volumes were measured with a 500ml beaker. For the 5Ls, 10 of the 500mls beaker filled it. For the 10 Ls, 20 of the 500mls beaker filled it and for the 15Ls, 30 of the 500mls beaker filled it.

The experiment was then set up in the greenhouse. The bags were spaced at 40cm by 80cm as the planting distances.

3.8. Experimental Design

3.8.1 Treatments

The treatments consisted of 3 different substrates; carbonated rice husk (CRH), palm fibre (PF) and cocopeat. Also three growing bag volumes; 5L, 10L and 15L. Lastly two varieties of tomatoes; Limbobo (Plum type) and Rodeo (beef steak type).

Table 3: Treatment description and codes

No.	Treatment Description	Treatment Code
	Beefsteak variety	
1	Carbonated Rice husk 1	CRH 5L
2	Palm Fibre 1	PF 5L
3	Cocopeat 1	CP 5L
4	Carbonated Rice husk 2	CRH 10L
5	Palm Fibre 2	PF 10L
6	Cocopeat 2	CP 10L
7	Carbonated Rice husk 3	CRH 15L
8	Palm Fibre 3	PF 15L
9	Cocopeat 3	CP 15L
	Plum variety	
10	Carbonated Rice husk 1	CRH 5L
11	Palm Fibre 1	PF 5L
12	Cocopeat 1	CP 5L
13	Carbonated Rice husk 2	CRH 10L
14	Palm Fibre 2	PF 10L

15	Cocopeat 2	CP 10L
16	Carbonated Rice husk 3	CRH 15L
17	Palm Fibre 3	PF 15L
18	Cocopeat 3	CP 15L

*__CRH__ – Carbonated Rice husk **PF** –Palm Fibre **CP**-Cocopeat

3.8.2. Design Layout

A factorial experiment with three factors. The treatments used are 2x 3x3= 18.

The treatments of 18 were replicated 3 times in a Randomised Complete Block Design, which gave 54bags.

15 plants were planted for each treatment. Hence the total experimental growing bags and plants were 810, with 270 bags for each substrate and 405 bags for each variety.

3.8.3. Experimental Plan

Two trials of the experiment were carried out. This was to help check if the same results will be obtained if the experiment is repeated. To estimate the variability of the results (assess how close they are to each other) and to increase the accuracy of the estimate.

1st Experiment

The first experiment was carried out between August 1st 2017 to December 19th 2017. The substrate preparation and analysis, greenhouse preparation, obtaining of materials for the experiment and bagging of substrates were done in August, 2017. The seeds for the first experiment were sown on the 1st of September, 2017 and transplanted done on the 22nd of September, 2017. 50% flowering occurred on the 18thof October, 2017 and fruiting started

on the 6th of November, 2017. On the 19th of December, 2018 harvesting and yield determination was done. Yield component parameters were determined on the 20th of December, 2017.

2nd Experiment

The second experiment was carried out between January 19th 2018 to May 19th 2018. The clearing and cleaning of the greenhouse and obtaining of materials for the experiment were done from January 19th to January 31st. The seeds for the second experiment were sown on the 9th of February, 2018 and transplanting done on the 28th of February, 2017. 50% flowering occurred on the 7th of March, 2018 and fruiting started on the 21st of March, 2018. On the 19th of May, 2017 harvesting and yield determination was done. Yield component parameters were determined on the 20th of May, 2018.

3.9. Transplanting

Transplanting of healthy seedlings were done three (3) weeks after seed sowing. Transplanted seedlings had 4-6 leaves with an average height of 10-13cm. Prior to transplanting, the seedlings were well watered before removal of the tomato seedling from the cell trays. To avoid stress, the seedlings are watered again after transplanting. Immediately after the seedling was transplanted 50ml of crop starter to 15L of water was applied to help seedling establishment and enhance uptake of nutrients. 'Top Cop' at 150ml to 15L of water was also applied to manage pathogens and insect pest.

3.10. Agronomic Practices

3.10.1. Fertigation

3.10.1.1. Fertigation done with polyfeed (N.P.K 19:19:19)

Watering of plants was done daily. Amount of water supplied to each plant was about 1L per plant. 6g of N.P.K (19:19:19) was applied per plant fortnightly (recommended rate) as a vegetative booster. N.P.K (19:19:19) was applied until flowering started.

3.10.1.2. Fertigation with Calcium Nitrate

13g was placed in 1 Litre of water and applied once a week after transplanting till harvest. This was to check blossom end rot.

3.10.1.3. Fertigation with Potassium Nitrate

2 kg was added to 1 L of water and applied once a week after the first truss of flowering started till harvest. This was to facilitate flowering and fruiting of the tomato plants.

3.10.2. Trellising

The trellis system in the greenhouse was used to train the tomato plants to grow erect, by using the twine ropes to support the plants.

3.10.3. Weeding and Pruning

Weeds were regularly uprooted from the growing bags. After the number of leaves was recorded at the reproductive stage the lower yellowish leaves were pruned.

3.10.4. Pesticide application

3.10.4.1. Akape (Anty Ataa) 250ml bottle

Akape is a systemic broad spectrum insecticide. Its active ingredient is MIDACLOPRID 200g/L. 30ml of Akape was mixed in 15L of water. It was applied at 14 days interval from

transplanting through to harvesting. Akape was used to prevent aphid, white fly, caterpillar, thrips, leaf miner or mealy bug.

3.10.4.2. Top Cop with sulphur (1 Litre)

150 – 300mls of Top Cop (active ingredient: Copper Sulphate Tribasic) with sulphur was put in CP15 sprayer and sprayed when white fly was seen on the tomato plant. The same dose was repeated every 14 days until harvest. However, four (4) days before harvesting top-cop was no longer applied.

3.10.5. Plant hormone application

Since the two varieties of tomatoes grown were parthenocarpic, plant hormone was applied anytime flowers appeared to aid fruiting. 5ml per litre was applied to the entire flowers.

3.10.6. Harvesting

After reaching full maturity the tomato fruits were handpicked. It took about three months for the tomato plant to reach its full maturity after transplanting.

3. 11. Data Collection

3.11.1. Growth indices

Growth factors such as stem girth, leaf area, plant height, leaf numbers and chlorophyll content was measured at 2, 4 and 8 weeks after transplanting (WAT).

Five (5) plants per treatment in all the replication were used for the recording of the growth parameters. In all, three destructive samplings were carried out, two at the vegetative phase and one at the reproductive stage of growth. On the 2^{nd} , 4^{th} and 8^{th} weeks after transplanting, data on the fresh and dry weight of roots and shoots, shoot-root ratios, as well as longest root length (destructive sampling) were determined.

3.11.2. Process of Destructive Analysis

Materials used

- Balance, ruler, cork borer ,oven and brown envelope.

One plant from each treatment was selected. In all 54 plants were selected for each of the destructive analysis in both the 1st experiment and 2nd experiment. The roots were washed and cut off. The length and weight of the root was measured. The leaves were plucked and their weight measured. The leaf area metre (Opti-Sciences CI- 202) was used to measure the leaf area. The stem was chopped and weighed as well. The weighed leaves, stem and root were placed in a brown envelope. The envelopes containing the plants were placed in an oven at a temperature of 70ºC for three (3) days to facilitate proper drying. Then the stem, roots and leaf dry weight were measured.

The three destructive analysis carried out was used to calculate the actual performance of crops and help ascertain whether the treatment enhanced vegetative or reproductive growth or both.

Growth analysis parameters (Net assimilation rate, Leaf weight ratio, Leaf area ratio, Specific leaf area and Relative growth rate) were computed using the weights of the dry matter of the plants.

- **Plant height (cm)**

A metre rule was used to measure the height of the plant. The measurement was taken from above the root or the bottom of the tomato plant to the tip of its apical leaf.

- **Stem girth(mm)**

A pair of vernier calliper was used to determine the stem girth of the plants at 5cm above the substrate level.

- **Number of Leaves**

All fully opened leaves were counted on the plant to determine the number of leaves. The buds at the shoot apex were not included.

- **Chlorophyll content ($\mu mol.m^{-2}$)**

A chlorophyll metre (CCM 200) was used to measure the chlorophyll content. Ten (10) leaves were selected from each plant and their chlorophyll content measured, the mean value was calculated to obtain the value of the chlorophyll content for a plant.

- **Mean Leaf Area(mm^2)**

A Leaf area meter (Opti-Sciences CI- 202) was used to determine the leaf area. Five (5) leaves were selected from each plant and their Leaf Area was measured, the mean values of the leaf area of the leaves were calculated to get the leaf area for the plant.

- **Longest root length(cm)**

This was determined by cutting the root of the harvested plant and washing the roots to get rid of the growth media. After which, the bulk of the root section was then placed on a meter rule and the longest root length was measured.

- **Fresh weight (g)**

The harvested plant sample was separated into shoot (leaves and stems) and roots. The weights of the various parts were measured immediately after harvest using an electric balance.

- **Dry weight (g)**

The freshly weighed leaves stem and roots were put in well labelled envelopes and then placed in an oven to dry at 70°C for 3 days (72 hours). After which the dry weights were measured with an electric balance.

- **Shoot : root ratio**

The dry weights of the stem and the leaves of each sampled plant per treatment were added to get the dry matter weight of the shoot. To determine the shoot: root ratio the dry weights of the shoot were then divided by that of the dry weights of root.

Shoot: root ratio = weight of dried shoot/ weight of dried root.

3.11.3. Growth Analysis

The growth analysis was calculated to explain the differences in growth and development impacted on the plants by the different treatments used in the experiment. Growth indices calculated included: Specific leaf area, Net assimilation rate, Relative growth rate, Leaf area ratio and Leaf weight ratio.

Formula used for calculating each growth index

- RGR-Relative Growth Rate $= \frac{(\ln Wf - \ln Wi)}{(T2-T1)}$

- NAR-Net Assimilation Rate $= \frac{(Wf-Wi)}{(T2-T1)} \times \frac{(\ln Af - \ln Ai)}{(Af-Ai)}$

- SLA-Specific Leaf Area $= \frac{LA}{LDW}$

- LAR(Leaf Area Ratio)= $\frac{LA}{TPDW}$

- LWR(Leaf Weight Ratio)= $\frac{LDW}{TPDW}$

Where :

Net Assimilation Rate-NAR Relative Growth Rate-RGR Specific Leaf Area-SLA.

Leaf Weight Ratio-LWR Leaf Area Ratio-LAR Initial dry weight-Wi

Final dry weight-Wf. Leaf area at reproductive stage-Af

Leaf area vegetative stage-Ai Time lapse between the vegetative stage and reproductive stage (T2-T1).

3.11.4 Harvesting of mature fruits

At fully ripe stage the tomato fruits were handpicked, leaving at least 1cm of the fruit stalk attached to the fruit. Harvested fruits were weighed on a measuring balance.

3.11.5 Yield and Yield components

Yield and yield components were measured after the third (3^{rd}) truss.

- **Fruit number per plant**

Fruit numbers per plant were counted, recorded and harvested thereafter.

- **Weight of fruits per plant(kg)**

The harvested fruits per plant were weighed using the measuring balance and recorded thereafter.

- **Fruit size(kg)**

To compute for the average fruit size, the weight(kg) of fruits per plant was divided by the number of fruits/plant.

- **Yield(t/ha)**

The yield was computed by multiplying the fruit weight(kg) by the plant population per hectare. The result obtained for the yield was divided 1000 to get answer in tonnes.

3.11.6. Fruit quality determination

The parameters for the quality determination measured were:

- Total soluble solids content (% Brig).
- pH of fruits, titratable acidity, total soluble solids (Brix) and shelf life

3.11.6.1. Sample preparation and evaluation

Three(3) firm fruits were randomly picked from five plants per treatment. The fruits selected were cleaned and cut into four(4) parts. After which it was blended in a blender at high speed for about 60seconds. Samples from this macerate were used to determine the fruit quality parameters. These analyses were carried out at the FOHCREC laboratory in Okumaning- Kade.

3.11.6.1.1 Total Soluble Solids (% Brix)

An ATAGO N1,Japan model of digital refractometer was used to determine the total soluble solids of the fruits. 1g of the macerate (tomato juice)was placed on the lens of the refractometer. The value was then read and recorded for the particular sample.

3.11.6.1.2. pH of fruits

A PL 700AL pH and electrical conductivity metre at the Soil Science Department was used to check for the pH of the fruits. 1g of macerate (tomato juice) was placed in a container and placed in a room where the pH reading was taken. This is necessary as pH has a direct relationship to temperature. The pH meter was turned on, while the macerate was settling down in order to warm the machine.

The pH meter was then calibrated with a buffer. Two buffers (i.e. buffer 7 and buffer 4) were used. The pH meter was washed with distilled water after each calibration was done. Buffer 7 is a neutral or basic buffer , while buffer 4 is an acidic buffer. After calibration the pH electrode was dipped into the sample of the macerate. The set-up was left for 2 to 3 minutes for readings to stabilize and record them. After each sample testing the pH electrode was washed with distilled water. The pH of each sample was taken three (3) times.

3.11.6.1.3. Titratable Acid

The pH of the 5mls of diluted tomato macerate for different treatments is taken, after which it is titrated with 0.1 N Sodium hydroxide. The normality of the sodium hydroxide is determined. According to Gould(1983), the acidity will be calculated as a percentage of the citric acid, which is the predominant acid found in the tomato macerate (juice).

$$\text{Citric acid} = \left(\frac{\text{Volume of NaOH X Normality of NaOH X Meq of acid weight}}{}\right) \times 100$$

Volume of sample titrated

Meq Weight of acid = Milliequivalent of the acid which is 0.064 for citric acid.

3.11.6.1.4. Fruit Shelf life

To determine the fruit shelve life, five (5) healthy tomato fruits per treatment were handpicked and stored at room temperature. The number of days for the tomatoes from roting after harvesting was noted.

3.11.6.15. Partial Budget Analysis

The partial budget analysis for the different growing media was done, to compare the cost effectiveness of different media tested.

3.12. Statistical Analysis.

Data collected on the growth indices (stem girth, plant height, number of leaves, chlorophyll content of leaves, as well as other quantitative variables) were input into an excel sheet and Analysis of Variance (ANOVA) was applied to data collected using Genstat software. Statistical comparison was made at 0.05 level of significance. LSD was used in the separation treatments means where analysis of variance indicated significant differences at 5% among the treatment means.

CHAPTER FOUR

4.0. RESULTS

4.1. Baseline survey

1. All the greenhouses visited, did not have a standard growing system in terms of growing media and growing bag sizes.
2. Cocopeat was the substrate mainly used.
3. Mostly polythene bags, buckets and troughs of varying volumes were used for the cultivation of tomatoes.
4. Yields were indeed fluctuating between 4.6 to10.6 tons.

4.2.Substrate Analysis

4.2.1. Physical Analysis

Table 4 shows the physical properties of the substrates taken prior to the start of the experiment, before the second experiment and at the end of the study. Palm fibre recorded the highest bulk density of (1.36 g/cm^3, 1.62 g/cm^3 and 0.40g/cm^3) before experiment 1, before experiment 2 and at the end of the study respectively, followed by cocopeat substrate (0.94 g/cm^3, 1.36g/cm^3 and 0.31g/cm^3) and the lowest being carbonated rice husk (0.89g/cm^3, 0.59g/cm^3 and 0.14g/cm^3). Cocopeat recorded highest water holding capacity of 90% prior to the start of experiment 1 and experiment 2, followed by palm fibre (86% and 84% respectively) and then carbonated rice husk (81.3% and 81% respectively). At the end of the study highest water holding capacity was recorded in carbonated rice husk (95.1%), then cocopeat (89%) and the lowest being palm fibre (70.3%).

Table 4: Physical characteristics (Bulk density and water holding capacity) of substrates used in the study.

	BEFORE EXP1		BEFORE EXP 2		AT THE END OF STUDY	
Substrate	Bulk Density (G/Cm3)	Water Holding Capacity (%)	Bulk Density (G/Cm3)	Water Holding Capacity (%)	Bulk Density (G/Cm3)	Water Holding Capacity (%)
PALM FIBRE	1.36	86	1.62	84	0.4	70.3
COCOPEAT	0.94	90	1.36	90	0.31	89
CARBONATED RICE HUSK	0.89	81.3	0.59	81	0.14	95.1

4.2.2. Chemical Analysis

Table 4 shows the chemical characteristics of substrates before experiment 1, before experiment 2 and at the end of the study.

Prior to experiment 1 palm fibre substrate had the highest pH value (6.2), followed by carbonated rice husk (5.8) and palm fibre giving the lowest value obtained(5.1). The highest EC was obtained for cocopeat substrate (4200µScm^{-1}**)**, followed by carbonated rice husk (588µScm^{-1}) and the lowest EC was recorded in palm fibre (385µScm^{-1}). Carbonated rice husk had the highest organic carbon content (48.1%), followed by palm fibre(43.4%) and then cocopeat recorded the lowest (34.6%). Highest nitrogen amount is recorded in cocopeat (0.87%), followed by carbonated rice husk (0.37%) and with palm fibre recording the lowest nitrogen content of 0.23%. The highest phosphorus content was recorded in cocopeat (0.031%), followed by carbonated rice husk (0.030%) and then palm fibre (0.026%). Cocopeat gave the highest potassium level of 3.10%, the second highest is carbonated rice husk (0.84%) and the lowest palm fibre (0.58%).

Prior to experiment2 carbonated rice husk had the highest (6.5), followed by cocopeat (6.2) and the lowest was recorded in palm fibre (5.1). Electrical conductivity was numerically highest in cocopeat (2200µScm^{-1}**),** followed by carbonated rice husk (554 µScm^{-1}) and then palm fibre (270 µScm^{-1}). Cocopeat had the highest organic carbon content of 37.5%, followed by carbonated rice husk (37.1%) and the lowest was recorded by palm fibre (23.0%). Nitrogen level was highest in cocopeat (1.12%), carbonated rice husk was the second highest (0.70%) and the lowest was recorded in palm fibre (0.42%). Phosphorus content was highest in palm fibre (0.27%), second highest is carbonated rice husk (0.12%) and the lowest was recorded in cocopeat (0.08%). For potassium content the highest recorded was cocopeat (1.55%), the second highest was carbonated rice husk (0.49%) and palm fibre (0.49%).

For results of the chemical analysis at the end of the research, the highest pH was recorded in cocopeat (6.2), followed by carbonated rice husk (6.0) and the lowest was recorded in palm fibre (5.1). Electrical conductivity was highest in cocopeat (4150µScm^{-1}), followed by carbonated rice husk (385 µScm^{-1}) and Cocopeat (385µScm^{-1}). Organic carbon content was numerically highest in carbonated rice husk (38.89%), followed by cocopeat (30.81%) and palm fibre had the lowest organic carbon content of 5.95 %. Cocopeat recorded the highest nitrogen content of 0.9%, followed by carbonated rice husk (0.3%), then palm fibre (0.2%). Palm fibre and cocopeat recorded the highest phosphorus content of 0.030% and the lowest was recorded in 0.024%. The cocopeat recorded the highest potassium content of 3.00%, followed by 0.80% and palm fibre had the lowest potassium content of 0.50%.

Table5: Chemical characteristics of substrates used in experiments.

Substrates	pH ($1.5H_2O$)	EC (μScm^{-1})	O.C (%)	N (%)	P (%)	K (%)
BEFORE EXPERIMENT 1						
Palm Fibre	5.1	385	43.4	0.23	0.026	0.58
Cocope at	6.2	4200	34.6	0.87	0.031	3.10
Carbonated Rice Husk	5.8	588	48.1	0.37	0.030	0.84
BEFORE EXPERIMENT 2						
Palm Fibre	5.1	270	23.0	0.42	0.27	0.49
Cocopeat	6.2	2200	37.5	1.12	0.08	1.55
Carbonated Rice Husk	6.5	554	37.1	0.70	0.12	0.49
END OF STUDY						
Palm Fibre	5.1	385	5.95	0.20	0.030	0.50
Cocopeat	6.2	4150	30.81	0.90	0.030	3.00
Carbonated Rice Husk	6.0	385	38.89	0.30	0.024	0.80

4.3. Tomato plant growth indices (vegetative growth phase) at 2, 4 and 8 WAT

4.3.1. Effect of different substrates and growing bag sizes on growth indices of two varieties of tomato at 2 WAT.

Table 6 shows the mean plant height of Limbobo and Rodeo tomato plants at 2, 4 and 8 WAT as determined by the type of substrate and growing bag size for experiment 1.

At 2WAT plant height differed significantly ($P<0.05$) among substrates and varieties only. For the substrates the highest was recorded in palm fibre (39.2cm) and the lowest was recorded in cocopeat (31.5cm), though was not significantly different from carbonated rice husk. For variety the highest was recorded in Rodeo(35.7cm) and the lowest was in Limbobo(32.5cm). At 4 WAT plant height differed significantly ($P<0.05$) among substrates only. The highest was recorded in palm fibre (106.0cm) and the lowest was recorded in cocopeat (91.5cm). At 8 WAT significant difference ($P<0.05$) was recorded in plant height among substrates, growing bag size and variety. For substrate the highest was in palm fibre(117.3cm) and lowest was recorded in Cocopeat(91.3cm). For growing bag size the highest was 15 Litre (113.4cm) and the lowest was recorded in 5 L(95.7cm). For variety the highest was Limbobo(110.9cm) and the lowest was in Rodeo(96.5cm).

Table 6:Mean Plant height (cm) of Limbobo and Rodeo varieties as a result of different substrates and growing bag sizes at 2WAT, 4WAT and 8WAT (Experiment 1) .

		2WAT					4WAT					8WAT				
S	V	GROWING BAG SIZES			**S X V MEAN**	S MEAN	GROWING BAG SIZES			**S X V MEAN**	S MEAN	GROWING BAG SIZES			**S X V MEAN**	S MEAN
		5L	10L	15L			5L	10L	15L			5L	10L	15L		
	LB	36.9	36.2	35.6	**36.3**	39.2	101.9	118.1	102.8	**107.6**		113.9	122.8	135.5	**124**	
PF	RD	42.2	42.2	42.3	**42**		99.9	102.1	110.8	**104.3**	106	105.2	108.1	118.1	**110.5**	117.3
S X G Mean		**39.2**	**39.3**	**39**			**100.9**	**110.1**	**106.8**			**109.5**	**115.4**	**126.8**		
	LB	31.9	30.9	29.1	**30.7**		95.2	89.6	101.8	**95.5**		91.3	99.9	114.9	**102**	
C	RD	33.4	33.1	30.5	**32.4**	31.5	93.7	85.3	83.2	**87.4**	91.5	85.2	78.9	77.7	**80.6**	91.3
S X G Mean		**32.7**	**32**	**29.8**			**94.4**	**87.4**	**92.5**			**88.3**	**89.4**	**96.3**		
	LB	30.3	31.3	30	**30.6**		91.2	99.7	105.2	**98.7**		89.3	104.7	125.5	**106.5**	
CRH	RD	32.1	32.7	33.2	**32.6**	31.6	89.6	97.4	108	**98.4**	98.6	89.2	97.7	108.6	**98.5**	102.5
S X G Mean		**31.2**	**32**	**31.6**			**90.4**	**98.6**	**106.6**			**89.2**	**101.2**	**117**		
G Mean		34.4	34.4	33.5			95.2	98.7	102			95.7	102	113.4		
		5L	**10L**	**15L**	V Mean		**5L**	**10L**	**15L**	V Mean		**5L**	**10L**	**15L**	V Mean	
	LB	33.1	32.8	31.6	32.5		96.1	102.5	103.3	100.6		98.2	109.1	125.3	110.9	
	RD	35.7	36	35.3	35.7		94.4	95	100.7	96.7		93.2	94.9	101.5	96.5	

2WATLSD ($P \leq 0.05$); Substrates(S) = 2.61 Growing bag sizes(G) = 2.61
Substrate* Growing bag sizes (S X G) = 4.53 Substrate* Variety(S x V) = 3.7
Substrate* Growing bag sizes* Variety = 6.4
LSD ($P \leq 0.05$); Variety (V) = 2.13 Growing bag sizes* Varieties = 3.7

4WATLSD ($P \leq 0.05$); Substrates (S) = 7.54 Growing bag sizes(G)= 7.54
Substrate* Growing bag size(S X G) =13.06 Substrate* Variety(S X V) = 10.67
Substrate* Growing bag sizes* Variety= 18.47
LSD ($P \leq 0.05$); Variety (V) = 6.16 Growing bag sizes* Varieties = 10.67

8 WATLSD ($P \leq 0.05$); Substrates (S)= 7.9 Growing bag sizes(G)= 7.9
Substrate* Growing bag sizes(S X G) = 13.7 Substrate* Variety(S X V)= 11.2
Substrate* Growing bag sizes* Variety= 19.4
Variety (V) =6.5 Growing bag sizes* Varieties = 11.2
***LB**-Limbobo, **RD**-Rodeo, **C**-Cocopeat, **CRH**-Carbonated Rice Husk, **PF**-Palm Fibre

Table 7 shows the mean plant height of Limbobo and Rodeo tomato plants at 2, 4 and 8 WAT as determined by the type of substrate and growing bag size for experiment 2.

At 2WAT a significant difference ($p<0.05$) was observed in plant height among substrates, growing bags, variety, substrate x growing bags and substrate x growing bags x variety. For the interaction between the substrates, growing bags and variety. Rodeo plant in 15Litre carbonated rice husk gave the highest value and the lowest value was recorded in Rodeo plants in 15Litre of palm fibre. A look at the interaction between the substrate and the growing bag size, 15Litre of carbonated rice husk gave the highest height and the lowest was recorded in palm fibre at 10Litre and 15Litre. At4 WAT plant height differed significantly ($P<0.05$) among substrate, growing bag, variety, substrate x growing bag size, substrate x variety and substrate x growing bag size x variety. The highest was recorded in Limbobo in 15Litre cocopeat (83.6cm) and the lowest recorded in Rodeo plant 5Litre carbonated rice husk (38.9cm).

At 8 WAT plant height differed significantly ($P<0.05$) among substrates, growing bag size, variety, substrate x variety and substrate x growing bag size x variety. The highest plant height was recorded in Limbobo plant in 15 Litre cocopeat (131.4cm) and the lowest was recorded in Rodeo in 5 Litre in carbonated rice husk(53.3cm).

Table 7: Mean Plant height (cm) of Limbobo and Rodeo varieties as a result of different substrates and growing bag sizes at 2WAT, 4WAT and 8WAT (Experiment 2).

		2WAT					4WAT					8WAT				
S	V	GROWING BAG SIZES			**S X V MEAN**	S MEAN	GROWING BAG SIZES			**S X V MEAN**	S MEAN	GROWING BAG SIZES			**S X V MEAN**	S MEAN
		5L	10L	15L			5L	10L	15L			5L	10	15L		
	LB	25.5	28.1	28.8	**27.5**		47	55.4	49.8	**50.6**		67.7	82.7	70.8	**73.7**	69.9
PF	RD	23.4	20.3	20	**21.2**	24.3	41	39.9	49.8	**43.6**	47.1	59.1	59.5	79.7	**66.1**	
S X G Mean		**24.4**	**24.2**	**24.2**			**44**	**47.6**	**49.8**			**63.4**	**71.1**	**75.2**		
	LB	33.9	40.9	35.9	**36.9**		63	73.9	83.6	**73.5**		92.4	106.8	131.4	**110.2**	85.7
C	RD	31.9	30.3	32.1	**31.4**	34.2	46	49.3	46.3	**47.2**	60.1	55.1	68.2	60.5	**61.3**	
S X G Mean		**32.9**	**35.9**	**34**			**55**	**61.6**	**65**			**73.7**	**87.5**	**95.9**		
	LB	34.4	35.3	35.2	**35**		59	65.7	66	**63.4**		82.7	86.9	96.6	**88.7**	87.5
CRH	RD	24.5	30.3	45.3	**33.3**	34.2	39	68.9	71.2	**59.7**	61.5	53.3	107.4	98.2	**86.3**	
S X G Mean		**29.4**	**32.8**	**40.3**			**49**	**67.3**	**68.6**			**68**	**97.2**	**97.4**		
G Mean		28.9	30.9	32.9			49	58.8	61.1			68.4	85.3	89.5		
		5L	**10L**	**15L**	V Mean		**5L**	**10L**	**15L**	V Mean		**5L**	**10L**	**15L**	V Mean	
	LB	31.3	34.8	33.3	33.1		56	65	66.5	62.5		80.9	92.1	99.6	90.9	
	RD	26.5	27	32.5	28.6		42	52.7	58.8	50.2		55.8	78.4	79.4	71.2	

2 WAT- LSD ($P \leq 0.05$); Substrates (S)=2.5 Growing bag sizes(G)=2.5
Substrate* Growing bag sizes(S X G) = 4.4 Substrate* Variety(S X V)=3.6
Substrate* Growing bag sizes* Variety= 6.2
Variety(V) = 2.1 Growing bag sizes* Varieties = 3.6

4 WAT-LSD ($P \leq 0.05$); Substrates(S) = 3.7 Growing bag sizes(G)= 3.7
Substrate* Growing bag sizes(S XG) = 6.4 Substrate* Variety(S X V)=5.2
Substrate* Growing bag sizes* Variety=9.0
Variety(V) = 3.0 Growing bag sizes* Varieties = 5.2

8WAT-LSD ($P \leq 0.05$); Substrates(S) = 7.6 Growing bag sizes(G)= 7.6
Substrate* Growing bag sizes(S X G) = 13.1 Substrate* Variety(S X V)= 10.7
Substrate* Growing bag sizes* Variety= 18.5
Variety(V) = 6.2 Growing bag sizes* Varieties = 10.7
*__LB__-Limbobo, __RD__-Rodeo, __C__-Cocopeat, __CRH__-Carbonated Rice Husk, __PF__-Palm Fibre

Table 8 shows the mean stem girth of Limbobo and Rodeo tomato plants at 2, 4.8 WAT as determined by the type of substrate and growing bag size for experiment 1. At 2WAT a significant differences ($P<0.05$) was observed in stem girth among substrates and variety only. For substrates the highest stem girth was recorded in cocopeat (0.5mm) and the lowest was recorded in palm fibre (0.3mm). For variety the highest was recorded in Rodeo (0.5mm) and Limbobo was the lowest (0.3mm). At 4 WAT a significant difference ($P<0.05$) was observed in stem girth among growing bag and variety only. For the growing bag 15 Litre recorded the highest with 8.16mm and the lowest was recorded in 5 Litre (6.98mm). For the variety Rodeo recorded the highest of 8.18mm and the lowest was Limbobo (7.14mm). At 8 WAT no significant difference ($P>0.05$) was recorded in stem girth among treatments.

Table 8:Mean stem girth (mm) of Limbobo and Rodeo varieties as a result of different substrates and growing bag sizes at 2WAT, 4WAT and 8WAT (Experiment 1).

		2WAT					4WAT					8WAT				
S	V	GROWING BAG SIZES			**S X V MEAN**	S MEAN	GROWING BAG SIZES			**S X V MEAN**	S MEAN	GROWING BAG SIZES			**S X V MEAN**	S MEAN
		5L	10L	15L			5L	10L	15L			5L	10L	15L		
PF	LB	0.4	0.4	0.4	**0.4**		6.33	7.35	7.87	**7.18**		8.2	8.3	7.3	**8**	
	RD	0.5	0.5	0.7	**0.6**	0.3	8.09	8.27	8.83	**8.4**	7.79	8.8	8.6	7.5	**8.3**	8.1
S X G Mean		**0.5**	**0.5**	**0.5**			**7.21**	**7.81**	**8.53**			**8.5**	**8.5**	**7.4**		
C	LB	0.3	0.3	0.3	**0.3**		6	7.47	7.53	**7**		7.4	8.3	8.3	**8**	
	RD	0.4	0.4	0.4	**0.4**	0.5	7.77	7.85	8.4	**8.01**	7.5	7.6	8.5	8.4	**8.2**	8.1
S X G Mean		**0.3**	**0.3**	**0.3**			**6.88**	**7.66**	**7.96**			**7.5**	**8.4**	**8.4**		
CRH	LB	0.3	0.3	0.3	**0.3**		6.34	7.84	7.52	**7.23**		8.3	8.5	8.4	**8.4**	
	RD	0.4	0.5	0.5	**0.5**	0.4	7.33	8.25	8.16	**8.13**	7.68	8	8.4	8.5	**8.3**	8.3
S X G Mean		**0.3**	**0.4**	**0.4**			**6.84**	**8.05**	**8.16**			**8.1**	**8.5**	**8.4**		
G Mean		0.4	0.4	0.4			6.98	7.84	8.16			8	8.4	8.1		
		5L	**10L**	**15L**	V Mean		**5L**	**10L**	**15L**	V Mean		**5L**	**10L**	**15L**	V Mean	
	LB	0.3	0.3	0.3	0.3		6.22	7.55	7.64	7.14		7.9	8	8	8.1	
	RD	0.4	0.5	0.5	0.5		7.73	8.13	8.7	8.18		8.1	8.5	8.1	8.3	

2WAT- LSD ($P \leq 0.05$); Substrates(S) = 0.04 Growing bag sizes(G)= 0.04
Substrate* Growing bag sizes(S X G) = 0.08 Substrate* Variety(S X V)= 0.06
Substrate* Growing bag sizes* Variety= 0.11

Variety(V) = 0.04 Growing bag sizes* Varieties = 0.06.

4WAT-LSD (P ≤ 0.05); Substrates(S) = 0.06 Growing bag sizes(G)=0.06
Substrate* Growing bag sizes(S X G) = 0.10 Substrate* Variety(S X V)=0.09
Substrate* Growing bag sizes* Variety= 0.15
Variety(V) = 0.05 Growing bag sizes* Varieties = 0.09

8WAT- LSD (P ≤ 0.05); Substrates(S) = 0.6 Growing bag sizes(G)=0.6
Substrate* Growing bag sizes(S X G) = 1.1 Substrate* Variety(S X V)= 0.9
Substrate* Growing bag sizes* Variety=1.6
Variety(V) = 0.30 Growing bag sizes* Varieties = 0.52

*__LB__-Limbobo, __RD__-Rodeo, __C__-Cocopeat, __CRH__-Carbonated Rice Husk, __PF__-Palm Fibre

Table 9 shows the mean stem girth of Limbobo and Rodeo tomato plants at 2,4,8 WAT as determined by the type of substrate and growing bag size for experiment 2.

At 2 WAT stem girth differed significantly ($P<0.05$) among substrates, variety and substrate X variety. For interaction between substrate x variety the highest stem girth was recorded in Limbobo plant in cocopeat (1.1mm) and the lowest was recorded in Rodeo plant in palm fibre (0.3mm). At 4 WAT a significant difference ($P<0.05$) was observed in stem girth among growing bag, variety, substrate x growing bag and substrate x variety. For substrates x growing bag size 15Litre of carbonated rice husk, 15Litre of palm fibre, 15Litre of cocopeat, 10Litre cocopeat and 10Litre carbonated rice husk recorded the highest stem girth of 0.9mm. The lowest was recorded in 10Litre of palm fibre (0.6mm). At 8 WAT a significant difference ($P<0.05$) was recorded in stem girth for variety only. The highest was recorded in Limbobo (1.5mm) and the lowest in Rodeo(0.5mm).

Table 9:Mean stem girth (mm) of Limbobo and Rodeo varieties as a result of different substrates and growing bag sizes at 2WAT, 4WAT and 8WAT (Experiment 2).

		2WAT					4WAT					8WAT				
S	V	GROWING BAG SIZES			**S X V MEAN**	S MEAN	GROWING BAG SIZES			**S X V MEAN**	S MEAN	GROWING BAG SIZES			**S X V MEAN**	S MEAN
		5L	10L	15L			5L	10L	15L			5L	10	15L		
PF	LB	0.7	0.7	0.7	**0.7**	0.5	1.2	0.9	1.4	**1.1**	0.7	1.7	1.1	2.1	**1.6**	1
	RD	0.2	0.2	0.3	**0.3**		0.4	0.3	0.4	**0.4**		0.3	0.4	0.5	**0.4**	
S X G Mean		**0.4**	**0.5**	**0.5**			**0.8**	**0.6**	**0.9**			**1**	**0.7**	**1.3**		
C	LB	1.1	1.1	1	**1.1**	0.7	1.1	1.3	1.4	**1.3**	0.9	1.2	1.6	1.8	**1.5**	1
	RD	0.4	0.4	0.4	**0.4**		0.5	0.5	0.4	**0.5**		0.5	0.6	0.5	**0.5**	
S X G Mean		**0.8**	**0.7**	**0.7**			**0.8**	**0.9**	**0.9**			**1**	**0.7**	**1.3**		
CRH	LB	0.9	0.9	1	**0.9**	0.7	0.9	1.2	1.2	**1.1**	0.8	1.1	1.5	1.4	**1.3**	0.9
	RD	0.4	0.5	0.6	**0.5**		0.7	0.6	0.6	**0.5**		0.5	0.6	0.7	**0.6**	
S X G Mean		**0.6**	**0.7**	**0.8**			**0.7**	**0.9**	**0.9**			**0.8**	**1**	**1**		
G Mean		0.6	0.6	0.7			0.7	0.8	0.9			0.9	0.9	1.1		
		5L	**10L**	**15L**	V Mean		**5L**	**10L**	**15L**	V Mean		**5L**	**10L**	**15L**	V Mean	
	LB	0.9	0.9	0.9	0.9		1.1	1.1	1.3	1.2		1.3	1.4	1.7	1.5	
	RD	0.3	0.3	0.4	0.4		0.4	0.5	0.5	0.4		0.4	0.5	0.5	0.5	

2WAT -LSD ($P \leq 0.05$); Substrates(S) = 0.06 Growing bag sizes(G)=0.06
Substrate* Growing bag sizes(S X G) = 0.10 Substrate* Variety(S X V)=0.09
Substrate* Growing bag sizes* Variety= 0.15
Variety(V) = 0.05 Growing bag sizes* Varieties = 0.09

4WAT-LSD ($P \leq 0.05$); Substrates (S) = 7.54 Growing bag sizes(g)= 7.54
Substrate* Growing bag size(S X G)=13.06 Substrate* Variety(S X V)= 10.67
Substrate* Growing bag sizes* Variety= 18.47
Variety((V) = 6.16 Growing bag sizes* Varieties = 10.67

8WAT-LSD ($P \leq 0.05$); Substrates(S) = 0.2 Growing bag sizes(G)= 0.2
Substrate* Growing bag sizes(S X G) = 0.4 Substrate* Variety(S X V)=0.3
Substrate* Growing bag sizes* Variety= 0.6
Variety (V)= 0.2 Growing bag sizes* Varieties = 0.3

Table 10 shows the mean leaf number of Limbobo and Rodeo tomato plants at 2, 4, 8 WAT as determined by the type of substrate and growing bag size for experiment 1.

At 2 WAT the significant difference ($P<0.05$) was observed in leaf number among substrate and variety. For substrate the highest leaf number was recorded in palm fibre (32.5) and the lowest leaf number recorded was in cocopeat (23.6). For variety the highest was recorded in Rodeo (28.9) and the lowest was recorded in Limbobo (25.2). At 4 WAT no significant difference ($P>0.05$) was observed in leaf number among treatments. At 8 WAT no significant difference ($P>0.05$) was recorded in leaf number/plant among the treatments.

Table 10: Mean leaf number/plant of Limbobo and Rodeo varieties as a result of different substrates and growing bag sizes at 2WAT, 4WAT and 8WAT (Experiment 1).

		2WAT					4WAT					8WAT				
S	V	GROWING BAG SIZES			**S X V MEAN**	S MEAN	GROWING BAG SIZES			**S X V MEAN**	S MEAN	GROWING BAG SIZES			**S X V MEAN**	S MEAN
		5L	10L	15L			5L	10L	15L			5L	10L	15L		
PF	LB	30.8	32.7	28.3	**30.8**		165.7	197.1	134.6	**165.8**		146.7	225.3	143.4	**171.8**	
	RD	34.5	35.7	33	**34.4**	32.5	161.7	167.7	201.4	**167.5**	166.6	132.7	132.4	130.9	**132**	151.9
S X G Mean		**32.7**	**34.2**	**30.6**			**163.7**	**182.4**	**153.8**			**139.7**	**178.8**	**137.1**		
C	LB	21.3	22.8	21.2	**21.8**		123.2	139.6	159	**140.6**		100.6	174.6	160.3	**145.2**	
	RD	26.3	26.7	23.5	**25.5**	23.6	137.9	127.4	111.6	**125.6**	133.1	121.7	133	170.8	**141.8**	143.5
S X G Mean		**28**	**24.8**	**22.4**			**130.5**	**133.5**	**135.3**			**111.1**	**153.8**	**165.6**		
CRH	LB	20.9	24.4	24.2	**23.1**		109.3	162.5	201.4	**157.8**		116.6	163.9	190.7	**157.1**	
	RD	24.3	26.5	29.3	**26.7**	24.9	131.9	145.8	171	**149.6**	153.7	121.1	144.6	170.7	**145.5**	151.3
S X G Mean		**22.6**	**25.4**	**26.8**			**120.6**	**154.2**	**186.2**			**118.8**	**154.2**	**180.7**		
G Mean		26.3	28.1	26.6			138.3	156.7	158.4			123.3	162.2	161.1		
		5L	**10L**	**15L**	V Mean		**5L**	**10L**	**15L**	V Mean		**5L**	**10L**	**15L**	V Mean	
	LB	7.1	7.1	6.9	7		132.7	166	165	154.7		15.2	16.7	16.9	16.3	
	RD	6	6.5	7.1	6.5		143.8	147	151.9	147.6		10.1	12.7	12.8	11.9	

2WAT- LSD ($P \leq 0.05$); Substrates(S) = 2.6 Growing bag sizes(G)= 2.6

Substrate* Growing bag sizes(S X G) = 4.4 Substrate* Variety(S X V)= 3.6
Substrate* Growing bag sizes* Variety= 6.3.
Variety(V) = 2.1 Growing bag sizes* Varieties = 3.6

4WAT - LSD ($P \leq 0.05$); Substrates(S) = 32.39 Growing bag sizes(G)= 32.39
Substrate* Growing bag sizes(S X G) = 56.09 Substrate* Variety(S X V)= 45.80
Substrate* Growing bag sizes* Variety= 79.33
Variety(V) = 26.44 Growing bag sizes* Varieties = 45.80

8WAT-LSD ($P \leq 0.05$); Substrates (S)= 41.3 Growing bag sizes(G)=41.3
Substrate* Growing bag sizes(S X G) =71.6 Substrate* Variety(S X V)=58.5
Substrate* Growing bag sizes* Variety=101.2
Variety(V) = 26.44 Growing bag sizes* Varieties = 45.80

Table 11 shows the mean leaf number of Limbobo and Rodeo tomato plants at 2, 4, 8 WAT as determined by the type of substrate and growing bag size for experiment 2.

At 2WAT a significant difference ($P<0.05$) was observed in leaf number among substrates. Carbonated rice husk gave the highest leaf number (7.4) and palm fibre gave the lowest (6.1). At 4 WAT, leaf number differed significantly ($P <0.05$) among substrate, growing bag size, variety, substrate x growing bag size and substrate x growing bag size x variety. The highest leaf number was recorded in Limbobo plant in 15 Litre cocopeat and Limbobo plant in 15 Litre carbonated rice husk (15.3). The lowest was recorded for Rodeo in 5 Litre carbonated rice husk (7.3). At 8 WAT a significant difference was recorded in chlorophyll content among variety and substrate x growing bag. The highest was recorded in palm fibre 10 Litre, cocopeat at 5Litre and 15Litre and carbonated rice husk at 10 Litre (23.2µmol.m^{-2}) and the lowest was recorded in palm fibre at 5 Litre and 15 Litre, cocopeat at 10 Litre and carbonated rice husk at 5 and 15 Litre (21.3 µmol.m^{-2}).

Table 11: Mean leaf number/plant of Limbobo and Rodeo varieties as a result of different substrates and growing bag sizes at 2WAT, 4WAT and 8WAT (Experiment 2).

		2WAT					4WAT					8WAT				
S	V	GROWING BAG SIZES			**S X V MEAN**	S MEAN	GROWING BAG SIZES			**S X V MEAN**	S MEAN	GROWING BAG SIZES			**S X V MEAN**	S MEAN
		5L	10L	15L			5L	10L	15L			5L	10	15L		
	LB	6	6.3	6	**6.1**		10.7	11	8.5	9.9	9.1	15.3	15	11	**13.8**	
PF	RD	6	6	6	**6**	6.1	8.3	8.3	8.3	8.2		11.3	11	11.3	**11.2**	12.5
S X G Mean		**6**	**6.2**	**6**			**9.5**	**9.3**	**8.4**			**13.3**	**13**	**11.2**		
	LB	7.3	8	7.3	**7.6**		10.7	13	15.3	13	10.9	13	18.3	23	**18.1**	
C	RD	6	6.5	6.3	**6.3**	6.9	8.3	9.3	9	8.9		10.7	12	11.3	**11.3**	14.7
S X G Mean		**6.7**	**7.3**	**6.8**			**9.5**	**11**	**12.2**			**11.8**	**15.2**	**17.2**		
	LB	8	7	7.3	**7.4**		12.7	12	15.3	13.2	11.7	17.3	16.7	16.7	**16.9**	
CRH	RD	6	7	9	**7.3**	7.4	7.3	11	12	10.1		8.3	15	15.7	**13**	14.9
S X G Mean		**7**	**7**	**8.2**			**10**	**11**	**13.7**			**12.8**	**15.8**	**16.2**		
G Mean		6.6	6.8	7			9.7	11	11.4			12.7	14.7	14.2		
		5L	**10L**	**15L**	V Mean		**5L**	**10L**	**15L**	V Mean		**5L**	**10L**	**15L**	V Mean	
	LB	7.1	7.1	6.9	7		11.3	12	13.1	12.1		15.2	16.7	16.9	16.3	
	RD	6	6.5	7.1	6.5		8	9.4	9.8	9.1		10.1	12.7	12.8	11.9	

2WAT-LSD ($P \leq 0.05$); Substrates(S) = 1.4 Growing bag sizes(G)= 1.4
Substrate* Growing bag sizes (S X G)= 2.5 Substrate* Variety(S X V)= 2.0
Substrate* Growing bag sizes* Variety= 3.5

Variety(V) =1.2 Growing bag sizes* Varieties = 2.0

4WAT-LSD ($P \leq 0.05$); Substrates(S) = 1.1 Growing bag sizes(G)= 1.1
Substrate* Growing bag sizes(S X G) = 2.0 Substrate* Variety(S X V)= 1.6
Substrate* Growing bag sizes* Variety= 2.8
Variety(V) = 0.9 Growing bag sizes* Varieties = 1.6

8WAT- LSD ($P \leq 0.05$); Substrates(S) = 1.4 Growing bag sizes(G)= 1.4
Substrate* Growing bag sizes(S X G) = 2.5 Substrate* Variety(S X V)= 2.0
Substrate* Growing bag sizes* Variety= 3.5
Variety(V) =1.2 Growing bag sizes* Varieties = 2.0

Table 12 shows the mean chlorophyll content of Limbobo and Rodeo tomato plants at 2,4,8 WAT as determined by the type of substrate and growing bag size for experiment 1.

At 2WAT a significant difference ($P<0.05$) was observed for chlorophyll content among variety only. Hence, the highest was recorded in Rodeo (15.8µmol.m^{-2}) and the lowest in Limbobo (12.0µmol.m^{-2}). At 4 WAT a significant difference ($P<0.05$) was observed in chlorophyll content among substrate, growing bag size, variety, substrate x growing bag size and substrate x variety. For substrate x growing bag size the highest chlorophyll content was recorded in 10 Litre of palm fibre(50.6µmol.m^{-2}) and the lowest was recorded in 5 Litre in cocopeat(19.7µmol.m^{-2}). For substrate x variety the highest was recorded in Rodeo in palm fibre (55.3µmol.m^{-2}) and the lowest was recorded in Limbobo in cocopeat (16.8µmol.m^{-2}). At 8 WAT a significant difference was recorded in chlorophyll content among variety and substrate x growing bag. The highest was recorded in palm fibre 10 Litre , cocopeat at 5 Litre and 15 Litre and carbonated rice husk at 10 Litre (23.2µmol.m^{-2}) and the lowest was recorded in palm fibre at 5 Litre and 15 Litre, cocopeat at 10 Litre and carbonated rice husk at 5 and 15 Litre (21.3 µmol.m^{-2}).

Table 12:Mean chlorophyll content (µmol.m^{-2}) of Limbobo and Rodeo varieties as a result of different substrates and growing bag sizes at 2WAT, 4WAT and 8WAT (Experiment 1).

		2WAT					4WAT					8WAT				
S	V	GROWING BAG SIZES			**S X V MEAN**	S MEAN	GROWING BAG SIZES			**S X V MEAN**	S MEAN	GROWING BAG SIZES			**S X V MEAN**	S MEAN
		5L	10L	15L			5L	10L	15L			5L	10L	15L		
PF	LB	12	11.8	11.8	**12**		24.4	36.9	22.6	**28**		23	23.7	23	**23.2**	
	RD	15.6	16.9	14.8	**15.8**	13.8	55.9	64.2	45.7	**55.3**	41.6	19.6	22.8	19.6	**20.7**	22
S X G Mean		**13.8**	**14.4**	**13.3**			**40.11**	**50.6**	**34.2**			**21.3**	**23.2**	**21.3**		
C	LB	12.9	11.5	11.8	**12.1**		16.7	18.1	15.5	**16.8**		23.7	23	23.7	**23.5**	
	RD	17.4	13.7	16.7	**16**	14	22.7	31	35.7	**29.8**	23.4	22.8	19.6	22.8	**21.7**	22.6
S X G Mean		**15.2**	**12.6**	**14.4**			**19.7**	**24.5**	**25.6**			**23.2**	**21.3**	**23.2**		
CRH	LB	11.9	12	11.7	**11.9**		18.7	18.6	22.4	**19.9**		23	23.7	23	**23.2**	
	RD	15.8	16.4	15.2	**15.8**	13.8	25.6	32.8	35.1	**31.2**	25.6	19.6	22.8	19.6	**20.7**	22
S X G Mean		**13.9**	**14.2**	**13.4**			**22.2**	**25.7**	**28.8**			**21.3**	**23.3**	**21.3**		
G Mean		14.3	13.7	13.7			27.3	33.6	29.9			22	22.6	22		
		5L	**10L**	**15L**	V Mean		**5L**	**10L**	**15L**	V Mean		**5L**	**10L**	**15L**	V Mean	
	LB	23.2	23.5	23.2	23.3		19.9	24.5	20.2	21.6		23.2	23.5	23.2	23.3	
	RD	20.7	21.7	20.7	21		34.7	42.7	38.9	38.8		20.7	21.7	2.7	21	

2WAT-LSD ($P \leq 0.05$); Substrates (S)= 1.1 Growing bag sizes(G)=1.1

Substrate* Growing bag sizes(S X G) = 1.9 Substrate* Variety(S X V)= 1.6
Substrate* Growing bag sizes* Variety= 2.7
Variety (V) = 0.9 Growing bag sizes* Varieties = 1.6

4WAT-LSD ($P \leq 0.05$); Substrates(S) = 4.68 Growing bag sizes(G)= 4.68
Substrate* Growing bag sizes(S XG) = 8.11 Substrate* Variety(S X V)= 6.62
Substrate* Growing bag sizes* Variety= 11.47
Variety(V) = 3.82 Growing bag sizes* Varieties = 6.62

8WAT- LSD ($P \leq 0.05$); Substrates (S) = 1.1 Growing bag sizes(G)=1.1
Substrate* Growing bag sizes(S X G) = 1.8 Substrate* Variety(S X V)= 1.5
Substrate* Growing bag sizes* Variety=2.6
Variety (V)=0.9 Growing bag sizes* Varieties = 1.5

Table 13 shows the mean chlorophyll content of Limbobo and Rodeo tomato plants at 2,4,8 WAT as determined by the type of substrate and growing bag size for experiment 2.

At 2WAT a significant difference ($P<0.05$) was observed for chlorophyll content among substrates, variety, substrate x growing bags, substrate x variety, growing bag sizes x variety and substrates x growing bag size x variety. The highest chlorophyll content was recorded in Rodeo plant at 10 Litre of palm fibre(27.1µmol.m^{-2}) and the lowest was recorded in Rodeo plant at 10 Litre of carbonated rice husk(12.2µmol.m^{-2})

At 4 WAT a significant differences ($P<0.05$) was observed in chlorophyll content among growing bag size, variety, substrate x growing bag size, substrate x variety and growing bag size x variety. For substrate x growing bag size the highest was recorded in 15 Litre of palm fibre(24.8µmol.m^{-2}) and the lowest was recorded 10 Litre of carbonated rice husk (17.2 µmol.m^{-2}). For substrate x variety the highest was Rodeo in cocopeat (25.7µmol.m^{-2}) and the lowest was Limbobo in palm fibre(17.6 µmol.m^{-2}). For the growing bag size x variety the highest recorded was Rodeo in 15 Litre (µmol.m^{-2}) and the lowest was Limbobo 5 Litre (14.4µmol.m^{-2}). At 8 WAT significant difference($P<0.05$) in chlorophyll content among substrate, growing bag size, variety, substrate x growing bag size and substrate x growing bag size x variety. The highest was in Rodeo plants at 10 Litre of cocopeat (40.4µmol.m^{-2}) and the lowest was Limbobo plants in 10 Litre of carbonated rice husk (8.4µmol.m^{-2}).

Table 13 :Mean chlorophyll content (µmol.m^{-2}) of Limbobo and Rodeo varieties as a result of different substrates and growing bag sizes at 2WAT, 4WAT and 8WAT (Experiment 2) .

		2WAT					4WAT					8WAT				
S	V	GROWING BAG SIZES			**S X V MEAN**	S MEAN	GROWING BAG SIZES			**S X V MEAN**	S MEAN	GROWING BAG SIZES			**S X V MEAN**	S MEAN
		5L	10L	15L			5L	10L	15L			5L	10	15L		
	LB	14.8	15.9	16.2	**15.6**		13	15.1	24.8	**17.6**		9.8	15			
PF	RD	21.6	27.1	16.6	**21.7**	18.7	26	25.1	24.8	**25.2**	21.4	29.6	22.8	33.4	19.4	24
S X G Mean		**18.2**	**21.5**	**16.4**			**19**	**20.1**	**24.8**			**19.7**	**18.9**	33.1	28.5	
	LB	14.5	15	17.7	**15.7**		13	19.8	20.2	**17.8**		12.5	24.6	**33.2**		
C	RD	19.9	17.5	15	**17.5**	16.6	24	27.1	26.5	**25.7**	21.8	27.1	40.4	22.7	20	27.5
S X G Mean		**17.2**	**16.2**	**16.4**			**19**	**23.5**	**23.3**			**19.8**	**32.5**	37.9	35.1	
	LB	15.6	16.4	7.2	**16.4**		17	14.6	24.6	**18.6**		17.8	8.4	**30.3**		
CRH	RD	16	12.2	16.5	**14.9**	15.7	22	19.7	24.6	**22.1**	20.4	28.1	27.2	22	16.1	22.7
S X G Mean		**15.8**	**14.3**	**16.8**			**20**	**17.2**	**24.5**			**23**	**17.8**	32.7	29.4	
G Mean		17.1	17.4	16.5			19	20.2	24.2			20.8	23.1	**27.4**		
		5L	**10L**	**15L**	V Mean		**5L**	**10L**	**15L**	V Mean		**5L**	**10L**	**15L**	V Mean	
	LB	15	15.8	17	15.9		14	16.5	23.2	18		13.4	16	26.1	18.5	
	RD	19.2	18.9	16	18		24	24	25.3	24.3		28.2	30.1	34.6	31	

2WAT-LSD ($P \leq 0.05$); Substrates (S) =1.1 Growing bag sizes(G)=1.1
Substrate* Growing bag sizes(S X G) = 2.0 Substrate* Variety(S X V)= 1.6
Substrate* Growing bag sizes* Variety= 2.8
Variety(V) =0.9 Growing bag sizes* Varieties = 1.6

4WAT-LSD ($P \leq 0.05$); Substrates(S) = 1.7 Growing bag sizes(G)=1.7
Substrate* Growing bag sizes(S X G) = 2.9 Substrate* Variety(S XV)= 2.4
Substrate* Growing bag sizes* Variety= 4.1
Variety (V) = 1.4 Growing bag sizes* Varieties =2.4

8WAT-LSD ($P \leq 0.05$); Substrates(S) = 3.3 Growing bag sizes (G)= 3.3
Substrate* Growing bag sizes(S X G) = 5.7 Substrate* Variety(S X V)= 4.7
Substrate* Growing bag sizes* Variety= 8.1
Variety (V) =2.7 Growing bag sizes* Varieties = 4.7

4.4. Tomato plant biomass at vegetative and reproductive phase.

4.4.1. Effect of different substrates and growing bag sizes on plant biomass of two varieties of tomatoes at vegetative phase (4WAT) and reproductive phase (8 WAT).

Table 14 shows the longest root length of Limbobo and Rodeo tomato plants at the vegetative phase(4 WAT) and reproductive phase (8WAT) as determined by the type of substrate and growing bag size for experiment 1.

At the vegetative phase a significant difference ($P<0.05$) in longest root length was observed among substrates only. The highest root length was seen in carbonated rice husk(21.1cm) and the lowest was in cocopeat(14.4cm).

At reproductive phase (8 WAT)a significant difference ($P<0.05$) for root length was observed among substrate, growing bag size and growing bag x substrates. For substrate the highest was carbonated rice husk (33.3cm) and the lowest was cocopeat (25.5). For growing bag size the highest was 5litre bag and the lowest was 10Litre bag size. For growing bags x variety the highest was recorded in Rodeo at 15 Litre and the lowest was Rodeo at 10 Litre bag size.

Table 14: Mean longest root length(cm)of Limbobo and Rodeo varieties as a result of different substrates and growing bag sizes at the vegetative phase (4WAT) and reproductive phase (8WAT) Experiment 1

		VEGETATIVE					REPRODUCTIVE				
S	V	GROWING BAG SIZES			**S X V MEAN**	S MEAN	GROWING BAG SIZES			**S X V MEAN**	S MEAN
		5L	10L	15L			5L	10L	15L		
	LB	21.8	23	19.4	**21.4**		32.3	34.3	27.2	**31.3**	
PF	RD	17	16.1	20.2	**17.8**	19.6	33.5	24.8	26.2	**28.2**	27.9
S X G Mean		**19.4**	**19.6**	**19.8**			**32.9**	**29.6**	**26.7**		
	LB	15.6	15.7	15.5	**15.6**				24.7	**24.2**	
C	RD	13.3	9.8	16.3	**13.2**	14.4	33.7	22.3	24.5	**26.9**	25.5
S X G Mean		**14.5**	**12.8**	**15.9**			**29.3**	**22.7**	**24.6**		
	LB	22.3	21.8	19.4	**21.2**		35.1	32.5	38.2	**35.3**	
CRH	RD	21.7	22	19.3	**21**	21.1	41.8	23	29	**31.3**	33.3
S X G Mean		**22**	**21.9**	**19.3**			**38.5**	**27.8**	**33.6**		
G Mean		18.6	18.1	18.4			33.5	26.7	28.3		
		5L	**10L**	**15L**	V Mean		**5L**	**10L**	**15L**	V Mean	
	LB	19.9	20.2	18.1	19.4		30.7	29.9	30	30.2	
	RD	17.3	16	18.6	17.3		36.4	23.4	26.6	28.8	

Vegetative -LSD ($P \leq 0.05$); Substrates(S) = 2.7 Growing bag sizes (G) =2.7
Substrate* Growing bag sizes(S X G) =4.6 Substrate* Variety(S X V)=3.8
Substrate* Growing bag sizes* Variety= 6.5
Variety (V) = 2.2 Growing bag sizes* Varieties = 3.8

Reproductive -LSD ($P \leq 0.05$); Substrates(S) = 4.1 Growing bag sizes (G)= 4.1
Substrate* Growing bag sizes (S X G) = 7.1 Substrate* Variety(S X V)= 5.8
Substrate* Growing bag sizes* Variety=10.1
Variety (V) = 3.4 Growing bag sizes* Varieties = 5.8

Table15 shows the longest root length of Limbobo and Rodeo tomato plants at the vegetative phase(4 WAT) and reproductive phase(8WAT) as determined by the type of substrate and growing bag size for experiment 2.

At the vegetative phase root length was significantly different ($P<0.05$) among substrate and substrate x growing bag size. The longest root length was 5 Litre carbonated rice husk (18.2cm) and the lowest was recorded in 5 Litre palm fibre(8.7cm).

At the reproductive(8 WAT) root length was significantly different ($P<0.05$) among substrate, substrate x growing bag, substrate x variety, growing bag x variety and substrate x growing bag x variety. Rodeo plants in 5Litre carbonated rice husk (29.0cm) gave the highest and the lowest was recorded in Rodeo plants in 5 Litre palm fibre (10.8cm).

Table 15: Mean longest root length(cm)of Limbobo and Rodeo varieties as a result of different substrates and growing bag sizes at the vegetative phase (4WAT) and reproductive phase (8WAT) Experiment 2

		VEGETATIVE					REPRODUCTIVE				
S	V	GROWING BAG SIZES			**S X V MEAN**	S MEAN	GROWING BAG SIZES			**S X V MEAN**	S MEAN
		5L	10L	15L			5L	10L	15L		
	LB	7.1	8.6	14.4	**10**		13.2	12.8	16.6	**14.2**	
PF	RD	5	11.4	9.6	**8.7**	9.4	10.8	15.3	15.3	**13.8**	14
S X G Mean		**6**	**10**	**12**			**12**	**14**	**15.9**		
	LB	9.6	13.3	12	**11.6**		14.8	19.8	17	**17.2**	
C	RD	12.4	13.5	11.4	**12.4**	12	17	11.9	14.6	**14.5**	15.9
S X G Mean		**11**	**13.4**	**11.7**			**15.9**	**15.9**	**15.8**		
	LB	18	12	13.2	**14.4**		16.9	16.7	15.5	**16.3**	
CRH	RD	18.5	16	17.3	**17.3**	15.8	29	17.9	11.9	**19.6**	18
SX G Mean		**18.2**	**14**	**15.2**			**22.9**	**17.3**	**13.7**		
G Mean		11.8	12.5	13			16.9	15.7	15.1		
					V Mean					V Mean	
	LB	11.6	11.3	13.2	12		15	16.4	16.4	15.9	
	RD	12	13.6	12.7	12.8		19	15	13.9	16	

Vegetative-LSD ($P \leq 0.05$); Substrates(S) = 1.8 Growing bag sizes(G)= 1.8

Substrate* Growing bag sizes(S X G) = 3.1 Substrate* Variety(S X V)= 2.5

Substrate* Growing bag sizes* Variety= 4.3

Variety(V) = 1.4 Growing bag sizes* Varieties =2.5

Reproductive-LSD ($P \leq 0.05$); Substrates(S) =2.0 Growing bag sizes(G)=2.0

Substrate* Growing bag sizes(S X G) = 3.4 Substrate* Variety(S X V)=2.8

Substrate* Growing bag sizes* Variety=4.8

Variety(V) = 1.6 Growing bag sizes* Varieties =2.8

Table 16shows the fresh shoot weight of Limbobo and Rodeo tomato plants at the vegetative phase(4 WAT) and reproductive phase(8WAT) as determined by the type of substrate and growing bag size for experiment 1.

At the vegetative phase a significant difference ($P<0.05$) in fresh shoot weight among substrate and variety. For substrate the highest was palm fibre (33.6g) and the lowest was lowest cocopeat (20.4g). For variety the highest was Limbobo (29.8g) and the lowest was Rodeo (21.5g).

At the reproductive phase(8 WAT)a significant difference ($P<0.05$) for fresh shoot weight was observed among substrates and growing bag size only. For substrate the highest fresh shoot weight was in carbonated rice husk (80.5g) and the lowest was recorded in cocopeat (64.3g). For growing bag size the highest fresh shoot weight was recorded in 15 Litre (70.0g) and lowest was recorded in 5 Litre (63.6g).

Table 16:Mean fresh shoot weight(g)of Limbobo and Rodeo varieties as a result of different substrates and growing bag sizes at the vegetative phase(4 WAT) and reproductive phase (8WAT) Experiment 1.

		VEGETATIVE					REPRODUCTIVE				
S	V	GROWING BAG SIZES			**S X V MEAN**	S MEAN	GROWING BAG SIZES			**S X V MEAN**	S MEAN
		5L	10L	15L			5L	10L	15L		
	LB	34.2	44.5	43.3	**40.6**		52.8	81.6	74.5	**69.6**	
PF	RD	28.3	25.9	25.7	**26.7**	33.6	69.1	65.1	94.5	**76.2**	72.9
S X G Mean		**31.3**	**35.2**	**34.5**			**60.9**	**73.3**	**84.5**		
	LB	25.8	25.4	24.3	**25.2**		56.9	70	73.4	**66.8**	
C	RD	17.3	14.9	14.4	**15.5**	20.4	57.9	74.4	53	**61.8**	64.3
S X G Mean		**21.6**	**20.1**	**19.4**			**57.4**	**72.2**	**63.2**		
	LB	20.1	23.8	27	**23.6**		67.1	80	90.3	**79.1**	
CRH	RD	11.1	28.4	27.8	**22.4**	23	78	79.1	88.6	**81.9**	80.5
S X G Mean		**15.6**	**26.1**	**27.4**			**72.6**	**79.5**	**89.5**		
G Mean		22.8	27.1	27.1			63.6	75	79		
					V Mean					V Mean	
	LB	26.7	31.2	31.5	29.8		58.9	77.2	79.4	71.8	
	RD	18.9	23.1	22.6	21.5		68.4	72.9	78.4	73.3	

Vegetative - LSD ($P \leq 0.05$); Substrates(S) = 6.6 Growing bag sizes (G) = 6.6
Substrate* Growing bag sizes(S X G) = 11.7 Substrate* Variety(S X V)= 9.6
Substrate* Growing bag sizes* Variety=16.6
Variety(V) = 5.5 Growing bag sizes* Varieties = 9.6

Reproductive- LSD ($P \leq 0.05$); Substrates(S) = 11.1 Growing bag sizes(G)= 11.1
Substrate* Growing bag sizes(S X G) = 19.2 Substrate* Variety(S X V)= 15.7
Substrate* Growing bag sizes* Variety= 27.1
Variety(V) = 9.1 Growing bag sizes* Varieties = 15.7

Table 17 shows the fresh shoot weight of Limbobo and Rodeo tomato plants at the vegetative phase(4 WAT) and reproduction phase(8WAT) as determined by the type of substrate and growing bag size for experiment 2.

At the vegetative phase a significant difference ($P<0.05$) was observed in fresh shoot weight among substrate, variety and substrate x variety. The highest fresh shoot weight was in Limbobo plant in palm fibre (1.3g) and the lowest was in Rodeo plant in cocopeat (4.0 g). At the reproductive phase (8WAT) a significant difference ($P<0.05$) was recorded for fresh shoot weight among substrate and growing bag size. The highest was recorded for cocopeat (35.4g) and the lowest was recorded for palm fibre (18.4 g). For growing bag size the highest recorded was 15 Litre (32.1g) and the lowest recorded was for 5 Litre bag (19.2g).

Table 17:Mean fresh shoot weight(g)of Limbobo and Rodeo varieties as a result of different substrates and growing bag sizes at the vegetative phase(4 WAT) and reproductive (8WAT) Experiment 2.

		VEGETATIVE					REPRODUCTIVE				
S	V	GROWING BAG SIZES			**S x V MEAN**	S MEAN	GROWING BAG SIZES			**S X V MEAN**	S MEAN
		5L	10L	15L			5L	10L	15L		
	LB	5.9	5.6	8	**6.5**		19.8	24.9	22.8	**22.5**	
PF	RD	2.7	7.6	4.3	**4.9**	5.7	7.3	18	17.7	**14.3**	18.4
S X G Mean		**4.3**	**6.6**	**6.2**			**13.5**	**21.5**	**20.3**		
	LB			18.6	**21.8**		25.9	45.7	54.1	**41.9**	
C	RD	8.5	6.8	8.2	**7.9**	14.8	19.6	26.8	40.3	**28.9**	35.4
S X G Mean		**14.8**	**16.3**	**13.4**			**22.8**	**36.3**	**47.2**		
	LB	14.2	14.2	22.2	**16.8**		18.2	28.7	46.6	**31.2**	
CRH	RD	2.3	5.7	4	**4**	10.4	24.1	36.7	10.9	**23.9**	27.5
S X G Mean		**8.2**	**9.9**	**13.1**			**21.1**	**32.7**	**28.8**		
G Mean		9.1	11	10.9			19.1	30.1	32.1		
					V Mean					V Mean	
	LB	13.7	15.2	16.3	15.1		21.3	33.1	41.2	31.9	
	RD	4.5	6.7	5.5	5.6		17	27.1	22.9	22.4	

Vegetative -LSD ($P \leq 0.05$); Substrates(S) = 3.1 Growing bag sizes(G)=3.1
Substrate* Growing bag sizes =5.3 Substrate* Variety(S X V) =4.3
Substrate* Growing bag sizes* Variety= 7.5
Variety(V) = 2.5 Growing bag sizes* Varieties = 4.3

Reproductive -LSD ($P \leq 0.05$); Substrates(S) = 3.9 Growing bag sizes(G)= 3.9
Substrate* Growing bag sizes(S X G) =6.7 Substrate* Variety(S X V)=5.5
Substrate* Growing bag sizes* Variety=9.5
Variety(V) =3.2 Growing bag sizes* Varieties =5.5

Table 18shows the dry shoot weight of Limbobo and Rodeo tomato plants at the vegetative phase (4 WAT) and reproductive phase(8WAT) as determined by the type of substrate and growing bag size for experiment 1.At the vegetative phase dry shoot weight was significantly different ($P<0.05$) among substrate and substrate x variety. The highest dry

shoot weight was recorded in Limbobo plant in palm fibre (1.3g) and the lowest in Rodeo plant in cocopeat (0.4g).

At the reproductive(8 WAT) a significant difference (P<0.05) was seen in dry shoot weight among substrates and variety only. For substrate the highest dry shoot weight was palm fibre (6.9g) and the lowest was cocopeat (5.0g). For variety the highest variety was Rodeo (6.7g) and the lowest was Limbobo(5.6g).

Table 18:Mean dry shoot weight(g)of Limbobo and Rodeo varieties as a result of different substrates and growing bag sizes at the vegetative phase(4 WAT) and reproductive phase(8WAT) Experiment 1.

		VEGETATIVE					REPRODUCTIVE				
S	V	GROWING BAG SIZES			**S X V MEAN**	S MEAN	GROWING BAG SIZES			**S x V MEAN**	S MEAN
		5L	10L	15L			5L	10L	15L		
	LB	1.3	1.3	1.4	**1.3**		5.2	8.2	6.4	**6.6**	
PF	RD	0.8	0.6	1.1	**0.9**	1.1	7.4	6.4	8.1	**7.3**	6.9
S X G Mean		**1.1**	**1**	**1.3**			**6.3**	**7.3**	**7.3**		
	LB	0.8	0.5	0.6	**0.6**		4.1	5	5	**4.7**	
C	RD	0.4	0.5	0.4	**0.4**	0.5	6.2	5.6	4.2	**5.3**	5
S X G Mean		**0.6**	**0.5**	**0.5**			**5.1**	**5.3**	**4.6**		
	LB	0.7	0.6	0.8	**0.7**		5	5.7	5.8	**5.5**	
CRH	RD	0.7	0.8	1.2	**0.9**	0.8	7.3	6.7	8.5	**7.5**	6.5
S X G Mean		**0.7**	**0.7**	**1**			**6.1**	**6.2**	**7.2**		
G Mean		0.8	0.7	0.9			5.7	6.2	6.3		
					V Mean					V Mean	
	LB	0.6	0.8	0.9	0.9		4.8	6.3	5.7	5.6	
	RD	0.9	0.6	0.9	0.7		6.9	6.2	6.9	6.7	

Vegetative -LSD ($P \leq 0.05$); Substrates = 0.27 Growing bag sizes= 0.27
Substrate* Growing bag sizes = 0.47 Substrate* Variety= 0.39
Substrate* Growing bag sizes* Variety= 0.39
Variety = 0.22 Growing bag sizes* Varieties = 0.39

Reproductive-LSD ($P \leq 0.05$); Substrates(S) = 1.2 Growing bag sizes(G)= 1.2
Substrate* Growing bag sizes(S X G) = 2.0 Substrate* Variety(S X V)= 1.7
Substrate* Growing bag sizes* Variety= 2.9
Variety(V) = 1.0 Growing bag sizes* Varieties = 1.7

Table 19 shows the dry shoot weight of Limbobo and Rodeo tomato plants at the vegetative phase(4 WAT) and reproductive phase(8WAT) as determined by the type of substrate and growing bag size for experiment 2.

At the vegetative phase significant difference ($P<0.05$) was observed in dry shoot weight among growing bags x variety and substrate x growing bag x variety. The highest was recorded in Rodeo plants in 15 Litre carbonated rice husk and Limbobo plants in 5 Litre cocopeat. The lowest was in Rodeo plants in 5 Litre cocopeat and Limbobo plants in 5 Litre carbonated rice husk.

At the reproductive(8 WAT) a significant difference ($P<0.05$) for dry shoot weight was observed among substrates, growing bag size, variety, substrate x growing bag size, growing bag size x variety and substrate x growing bag x variety. Hence, the highest dry root was seen in Limbobo plants in 5 Litre cocopeat and Rodeo plants in 15 Litre carbonated rice husk(1.9). The lowest dry shoot weight is recorded in Rodeo plants in 5 Litre cocopeat and Limbobo plants in 5 Litre carbonated rice husk.

Table 19: Mean dry shoot weight(g)of Limbobo and Rodeo varieties as a result of different substrates and growing bag sizes at the vegetative phase(4 WAT) and reproductive phase (8WAT) Experiment 2.

		VEGETATIVE					REPRODUCTIVE				
S	V	GROWING BAG SIZES			**S X V MEAN**	S MEAN	GROWING BAG SIZES			**S x V MEAN**	S MEAN
		5L	10L	15L			5L	10L	15L		
	LB	1.6	1.2	1	**1.3**		1.6	1.2	1	**1.3**	
PF	RD	1	1.3	0.8	**1**	1.2	1	1.3	0.8	**1**	12
S X G Mean		**1.3**	**1.3**	**0.9**			**1.3**	**1.3**	**0.9**		
	LB	1.9	1.3	0.8	**1.3**		1.9	1.3	0.8	**1.3**	
C	RD	0.6	1.3	1.6	**1.2**	1.2	0.6	1.3	1.6	**1.2**	1.2
S X G Mean		**1.2**	**1.3**	**1.2**			**1.2**	**1.3**	**1.2**		
	LB	0.6	1.2	1.3	**1**		0.6	1.2	1.3	**1**	
CRH	RD	1.2	1.2	1.9	**1.4**	1.4	1.2	1.2	1.9	**1.5**	1.2
S X G Mean		**0.9**	**1.2**	**1.6**			**0.9**	**1.2**	**1.6**		
G Mean		1.1	1.2	1.2			1.1	1.2	1.2		
					V Mean					V Mean	
	LB	1.4	1.2	1	1.2		1.4	1.2	1	1.2	
	RD	0.9	1.2	1.5	1.2		0.9	1.2	1.5	1.2	

Vegetative-LSD ($P \leq 0.05$); Substrates =0.3 Growing bag sizes=0.3
Substrate* Growing bag sizes = 0.5 Substrate* Variety=0.4
Substrate* Growing bag sizes* Variety=0.7
Variety =0.2 Growing bag sizes* Varieties = 0.4.

Reproductive- LSD ($P \leq 0.05$); Substrates = 0.3 Growing bag sizes= 0.3
Substrate* Growing bag sizes = 0.5 Substrate* Variety= 0.4
Substrate* Growing bag sizes* Variety= 0.7
Variety = 0.2 Growing bag sizes* Varieties = 0. 2

Table20 shows the fresh root weight of Limbobo and Rodeo tomato plants at the vegetative phase(4 WAT) and reproductive phase (8WAT) as determined by the type of substrate and growing bag size for experiment 1.

At vegetative phase fresh root weight was significantly different (P<0.05) among substrates and variety. For substrates the highest fresh root weight was in carbonated rice husk (8.3g) and the lowest fresh root weight was in cocopeat (4.7g). For variety Limbobo was the highest (7.3g) and Rodeo was the lowest (4.6g). At the reproductive(8 WAT) a significant difference (P<0.05) is observed for fresh root weight among substrate only. The highest was then recorded in carbonated rice husk (6.9g) and the lowest was recorded in cocopeat(5.0g).

Table 20:Mean fresh root weight(g)of Limbobo and Rodeo varieties as a result of different substrates and growing bag sizes at the vegetative phase(4WAT) and reproductive phase (8WAT) Experiment 1.

		VEGETATIVE					REPRODUCTIVE				
S	V	GROWING BAG SIZES			**S X V MEAN**	S MEAN	GROWING BAG SIZES			**S X V MEAN**	S MEAN
		5L	10L	15L			5L	10L	15L		
	LB	6.2	7.7	5.8	**6.5**		11.2	14.4	11.7	**12.5**	
PF	RD	3.3	3.9	2.6	**3.3**	4.9	13.3	10.5	12.9	**12.2**	12.3
S XG Mean		**4.8**	**5.8**	**4.2**			**12.3**	**12.5**	**12.3**		
	LB	5.3	7.3	5.2	**5.9**		16	15.9	13.1	**15**	
C	RD	3.8	3.3	3.2	**3.4**	4.7	15.7	16.7	14	**15.5**	15.2
S XG Mean		**4.6**	**5.3**	**4.2**			**15.9**	**16.3**	**13.5**		
	LB	9.7	8.7	9.7	**9.4**		19.7	18.9	17.8	**18.8**	
CRH	RD	4.4	8	9	**7.2**	8.3	20.4	16.9	18.8	**18.7**	18.8
S X G Mean		**7.1**	**8.4**	**9.4**			**20.1**	**17.9**	**18.3**		
G Mean		5.5	6.5	5.9			16.1	15.6	14.7		
					V Mean					V Mean	
	LB	7.1	7.9	6.9	7.3		15.7	16.4	14.2	15.4	
	RD	3.9	5	4.9	4.6		16.5	14.7	15.2	15.5	

Vegetative -LSD (P ≤ 0.05); Substrates(S) = 1.9 Growing bag sizes(G)= 1.9
Substrate* Growing bag sizes(S X G) = 3.2 Substrate* Variety(S X V)= 2.6
Substrate* Growing bag sizes* Variety= 4.5
Variety(V) = 1.5 Growing bag sizes* Varieties = 2.6

Reproductive-LSD ($P \leq 0.05$); Substrates(S) = 3.5 Growing bag sizes(G)= 3.5
Substrate* Growing bag sizes(S X G) = 6.1 Substrate* Variety(S X V)= 5.0
Substrate* Growing bag sizes* Variety= 8.7
Variety(V) = 2.9 Growing bag sizes* Varieties = 5.0

Table 21shows the fresh root weight of Limbobo and Rodeo tomato plants at the vegetative phase(4 WAT) and reproductive phase(8WAT) as determined by the type of substrate and growing bag size for experiment 2.

At the vegetative phase a significant difference ($P<0.05$) in fresh root weight is seen among substrate, growing bag size, substrate x growing bag size and substrate x growing bag size x variety. The highest fresh root weight was Rodeo plants in 15 Litre of carbonated rice husk (6.8g) and the lowest was Rodeo at 5 Litre palm fibre (0.3g). For substrate x growing bag size, the highest was carbonated rice husk at 15 Litre (5.6g) and the lowest was palm fibre at 5 Litre (0.9g).At the reproductive(8 WAT) a significant difference ($P<0.05$) was recorded for fresh root weight among substrate, variety and substrate x growing bag size x variety. The highest was observed in Limbobo plants in 10 Litre cocopeat(8.3g) and the lowest was recorded in Rodeo plants in 5 Litre palm fibre(2.0g).

Table 21: Mean fresh root weight(g)of Limbobo and Rodeo varieties as a result of different substrates and growing bag sizes at the vegetative phase(4WAT) and reproductive phase (8WAT) Experiment 2.

		VEGETATIVE PHASE					REPRODUCTIVE PHASE				
S	V	GROWING BAG SIZES			**S X V MEAN**	S MEAN	GROWING BAG SIZES			**S X V MEAN**	S MEAN
		5L	10L	15L			5L	10L	15L		
	LB	1.5	2.2	2.5	**2.1**		4.4	3.5	3.4	**3.8**	
PF	RD	0.3	3.4	1.1	**1.6**	1.8	2	4.6	4.6	**3.7**	3.7
S X G Mean		**0.9**	**2.8**	**1.8**			**3.2**	**4**	**4**		
	LB	1.9	3.1	2.7	**2.6**		3.6	8.3	5.6	**5.8**	
C	RD	2.7	2.7	1.6	**2.3**	2.4	5.4	2.9	5.5	**4.6**	5.2
S X G Mean		**2.3**	**2.9**	**2.1**			**4.5**	**5.6**	**5.6**		
	LB	4	1.9	4.3	**3.4**		4.8	7.1	7.7	**6.5**	
CRH	RD	3.7	1.5	6.8	**4**	3.7	5.8	5.7	3	**4.8**	5.7
S X G Mean		**3.9**	**1.7**	**5.6**			**5.3**	**6.4**	**5.4**		
G Mean		2.4	2.5	3.1			4.3	5.4	5		
					V Mean					V Mean	
	LB	2.5	2.4	3.2	2.7		4.2	6.3	5.6	5.4	
	RD	2.2	2.5	3.1	2.6		4.4	4.4	4.4	4.4	

Vegetative -LSD ($P \leq 0.05$); Substrates(S) = 0.6 Growing bag sizes(G)= 0.6
Substrate* Growing bag sizes(S X G) = 1.1 Substrate* Variety(S X V)= 0.9
Substrate* Growing bag sizes* Variety=1.6
Variety(V) = 0.5 Growing bag sizes* Varieties = 0.9

Reproductive-LSD ($P \leq 0.05$); Substrates(S) = 1.2 Growing bag sizes(G)= 1.2
Substrate* Growing bag sizes(S X G) =2.1 Substrate* Variety(S X V)= 1.7
Substrate* Growing bag sizes* Variety= 2.9
Variety(V) =0.9 Growing bag sizes* Varieties =1.7

Table22 shows the dry root weight of Limbobo and Rodeo tomato plants at the vegetative phase(4 WAT) and the reproductive phase(8WAT) as determined by the type of substrate

and growing bag size for experiment 1. At reproductive phase no significant difference(P>0.05) was observed in dry root weight among the treatments. At the reproductive phase (8 WAT)a significant difference (P<0.05) was recorded for dry root weight among substrate x variety only. For substrate the highest was recorded in palm fibre(18g) and the lowest was recorded in Rodeo(1.7 g). For variety the highest was recorded in Rodeo(1.7g) and the lowest was Limbobo(1.3g).

Table 22: Mean dry root weight(g)of Limbobo and Rodeo varieties as a result of different substrates and growing bag sizes at the vegetative phase (4WAT) and reproduction phase (8WAT)Experiment 1.

		VEGETATIVE					REPRODUCTIVE				
S	V	GROWING BAG SIZES			**S X V MEAN**	S MEAN	GROWING BAG SIZES			**S X V MEAN**	S MEAN
		5L	10L	15L			5L	10L	15L		
	LB	0.3	0.7	0.4	**0.5**		1	1.6	1.9	**1.5**	
PF	RD	0.2	0.5	0.5	**0.4**	0.4	2.1	1.9	2	**2**	1.8
S X G Mean		**0.3**	**0.6**	**0.4**			**1.6**	**1.8**	**2**		
	LB	0.2	0.3	0.3	**0.3**		0.9	1	1	**1**	
C	RD	0.3	0.3	0.2	**0.2**	0.3	1.5	1.4	1.1	**1.4**	1.2
S XG Mean		**0.2**	**0.3**	**0.3**			**1.2**	**1.2**	**1.1**		
	LB	0.4	0.3	0.3	**0.4**		1.6	1.3	1.5	**1.5**	
CRH	RD	0.3	0.4	0.9	**0.5**	0.4	2	1.3	1.9	**1.7**	1.6
S XG Mean		**0.4**	**0.3**	**0.6**			**1.8**	**1.3**	**1.7**		
G Mean		0.3	0.4	0.4			1.5	1.4	1.6		
					V Mean					V Mean	
	LB	0.3	0.4	0.3	0.4		1.2	1.3	1.5	1.3	
	RD	0.3	0.4	0.5	0.4		1.9	1.6	1.7	1.7	

Vegetative - LSD ($P \leq 0.05$); Substrates(S) = 0.2 Growing bag sizes(G)= 0.2
Substrate* Growing bag sizes(S X G) = 0.3 Substrate* Variety(S X V)= 0.3
Substrate* Growing bag sizes* Variety= 0.5
Variety(V) = 0.2 Growing bag sizes* Varieties = 0.3

Reproductive-LSD ($P \leq 0.05$); Substrates(S) = 0.4 Growing bag sizes(G)= 0.4
Substrate* Growing bag sizes(S X G) = 0.8 Substrate* Variety(S X V)= 0.6
Substrate* Growing bag sizes* Variety= 1.1

Variety (V) = 0.4 Growing bag sizes* Varieties = 0.6

Table23 shows the dry root weight of Limbobo and Rodeo tomato plants at the vegetative phase(4 WAT) and reproductive phase (8WAT) as determined by the type of substrate and growing bag size for experiment 2. At the vegetative phase no significant difference (P>0.05) was observed in dry root weight among the treatments. At the reproductive(8 WAT)no significant difference (P>0.05) was recorded in dry root weight among the treatments.

Table 23:Mean dry root weight(g)of Limbobo and Rodeo varieties as a result of different substrates and growing bag sizes at the vegetative phase(4 WAT) and reproductive phase (8WAT) Experiment 2.

		VEGETATIVE					REPRODUCTIVE				
S	V	GROWING BAG SIZES			**S X V MEAN**	S MEAN	GROWING BAG SIZES			**S X V MEAN**	S MEAN
		5L	10L	15L			5L	10L	15L		
	LB	0.3	0.3	0.3	**0.3**		2.6	2.2	2.3	2.4	
PF	RD	0.3	0.4	0.4	**0.4**	0.3	2.2	2.4	1.7	**2.1**	2.2
S XG Mean		**0.3**	**0.4**	**0.4**			**2.4**	**2.3**	**2**		
	LB	0.2	0.4	0.4	**0.3**		2.4	1.9	1.6	**2**	
C	RD	0.5	0.4	0.3	**0.4**	0.4	1.9	1.9	2.3	**2**	2
S X G Mean		**0.4**	**0.4**	**0.4**			**2.2**	**1.9**	**2**		
	LB	0.5	0.3	0.4	**0.4**		2.3	1.9	2.6	**2.3**	
CRH	RD	0.3	0.3	0.2	**0.3**	0.4	2.1	1.9	1.7	**1.9**	2.1
S X G Mean		**0.4**	**0.3**	**0.3**			**2.2**	**1.9**	**2.1**		
G Mean		0.4	0.4	0.4			2.3	2	2		
					V Mean					V Mean	
	LB	0.4	0.3	0.4	0.4		2.4	2	2.2	2.2	
	RD	0.4	0.4	0.3	0.4		2.1	2.1	1.9	2	

Vegetative -LSD (P ≤ 0.05); Substrates(S) = 0.1 Growing bag sizes(G)=0.1

Substrate* Growing bag sizes(S X G) = 0.2 Substrate* Variety(S X V)=0.1

Substrate* Growing bag sizes* Variety=0.2

Variety(V) = 0.1 Growing bag sizes* Varieties =0.1

Reproductive-LSD ($P \leq 0.05$); Substrates(S) =0.3 Growing bag sizes(G)=0.3
Substrate* Growing bag sizes(S X G) = 0.6 Substrate* Variety(S X V)= 0.5
Substrate* Growing bag sizes* Variety= 0.8
Variety(V) =0.3 Growing bag sizes* Varieties =0.5

Table 24 shows the shoot: root ratio of Limbobo and Rodeo tomato plants at the vegetative phase(4 WAT) and reproductive phase (8WAT) as determined by the type of substrate and growing bag size for experiment 1. At the vegetative phase no significant difference (P>0.05) was observed in shoot root ratio among the treatments. At the reproductive(8 WAT) no significant difference (P>0.05) was recorded in shoot: root weight among the treatments.

Table 24: Mean shoot: root ratio of Limbobo and Rodeo varieties as a result of different substrates and growing bag sizes at the vegetative phase(4WAT) and reproductive phase(8WAT) Experiment 1.

		VEGETATIVE					REPRODUCTIVE				
S	V	GROWING BAG SIZES			**S X V MEAN**	S MEAN	GROWING BAG SIZES			**S X V MEAN**	S MEAN
		5L	10L	15L			5L	10L	15L		
PF	LB	4.3	2.3	3.8	**3.4**	3.1	5.1	5.8	3.9	**4.9**	
	RD	3.7	1.7	3.1	**2.8**		4	3.5	4.1	**3.9**	
S XG Mean		**4**	**2**	**3.4**			**4.6**	**4.6**	**4**		
C	LB	3.6	1.7	2.2	**2.5**	2.2	5.1	4.9	5.3	**5.1**	
	RD	1.9	1.8	1.8	**1.9**		5	5.4	4.2	**4.8**	
S X G Mean		**2.8**	**1.8**	**2**			**3.2**	**5.2**	**4**		
CRH	LB	2.3	2.1	2.6	**2.3**	2.4	3.7	5.3	4.7	**4.1**	
	RD	1.9	2.4	3	**2.4**		3.5	5.3	4.4	**4.6**	
S XG Mean		**2.1**	**2.3**	**2.8**			**3.5**	**5.3**	**4.4**		
G Mean		2.9	2	2.7			4.3	5	4.4		
					V Mean					V Mean	
	LB	3.4	2	2.8	2.7		4.4	5.3	4.4	4.7	

	RD	2.5	2	2.6	2.4		4.2	4.8	4.3	4.4	

Vegetative -LSD ($P \leq 0.05$); Substrates(S) = 0.9 Growing bag sizes(G)= 0.9
Substrate* Growing bag sizes (S X G)= 1.6 Substrate* Variety(S X V)= 1.3
Substrate* Growing bag sizes* Variety= 2.3
Variety(V) = 0.8 Growing bag sizes* Varieties = 1.3

Reproductive -LSD ($P \leq 0.05$); Substrates (S)= 1.2 Growing bag sizes(G)= 1.2
Substrate* Growing bag sizes(S X G) = 2.1 Substrate* Variety(S X V)= 1.7
Substrate* Growing bag sizes* Variety= 2.9
Variety(V) = 1.0 Growing bag sizes* Varieties = 1.7

Table25 shows the shoot: root ratio of Limbobo and Rodeo tomato plants at the vegetative phase (4 WAT) and reproductive phase (8WAT) as determined by the type of substrate and growing bag size for experiment 2. At the vegetative phase no significant difference ($P>0.05$) was observed in the shoot : root ratio among the treatments.

At the reproductive(8 WAT) a significant difference ($P<0.05$) was seen for shoot: root ratio among the growing bag size x variety, substrate x growing bag size and substrate x growing bag x variety. The highest shoot: root ratio was recorded in Limbobo plants in 10 Litre of palm fibre (5.8) and the lowest was recorded in Limbobo plants in 5 Litre carbonated rice husk (3.2).

Table 25: Mean shoot: root ratio of Limbobo and Rodeo varieties as a result of different substrates and growing bag sizes at the vegetative phase(4WAT) and reproductive phase (8WAT) Experiment 2.

		VEGETATIVE					REPRODUCTIVE				
S	V	GROWING BAG SIZES			**S X V MEAN**	S MEAN	GROWING BAG SIZES			**S X V MEAN**	S MEAN
		5L	10L	15L			5L	10L	15L		
PF	LB	0.7	0.6	0.4	**0.6**	0.6	5.1	5.8	3.9	**4.9**	4.4
	RD	0.6	0.5	0.5	**0.5**		4	3.5	4.1	**3.9**	
S X G Mean		**0.6**	**0.6**	**0.5**			**4.6**	**4.6**	**4**		
C	LB	0.8	0.7	0.6	**0.7**	0.6	5.1	4.9	5.3	**5.1**	4.96
	RD	0.3	0.7	0.7	**0.6**		4.9	5.4	4.2	**4.8**	
S X G Mean		**0.6**	**0.7**	**0.6**			**5**	**5.2**	**4.7**		
CRH	LB	0.3	0.7	0.5	**0.5**	0.6	3.2	5.2	4	**4.1**	4.35
	RD	0.6	0.7	1.2	**0.8**		3.7	5.3	4.7	**4.6**	
S X G Mean		**0.4**	**0.7**	**0.8**			**3.5**	**5.3**	**4.4**		
G Mean		0.5	0.7	0.6			4.3	5	4.4		
					V Mean					V Mean	
	LB	0.6	0.7	0.5	0.6		4.4	5.3	4.4	4.7	
	RD	0.5	0.6	0.8	0.6		4.2	4.8	4.3	4.4	

Vegetative- LSD ($P \leq 0.05$); Substrates(S) =0.2 Growing bag sizes(G)= 0.2
Substrate* Growing bag sizes(S X G) = 0.4 Substrate* Variety(S X V)= 0.3
Substrate* Growing bag sizes* Variety=0.5
Variety(V) = 0.2 Growing bag sizes* Varieties =0.3

Reproductive-LSD ($P \leq 0.05$); Substrates (S)= 0.9 Growing bag sizes(G)=0.9
Substrate* Growing bag sizes(S X G) = 1.6 Substrate* Variety(S X V)=1.3
Substrate* Growing bag sizes* Variety=2.3
Variety(V) =0.8 Growing bag sizes* Varieties =1.3

4.5. Tomato plant growth analysis (secondary response variables) at 8 WAT.

4.5.1. Effect of different substrates and growing bag sizes on plant growth analysis of two varieties of tomatoes at 8WAT

Table 26 shows the Net Assimilation Rate of Limbobo and Rodeo tomato plants at 8 WAT as determined by the type of substrate and growing bag size for experiment 1 and 2.

For experiment 1 a significant difference($P<0.05$) was seen in Net Assimilation Rate for substrate, growing bag size, variety, substrate x growing bag size, substrate x variety, growing bag size x variety and substrate x growing bag size x variety. The highest was recorded in Limbobo plants in 10 Litre palm fibre (8.4) and the lowest was recorded in Rodeo plant in 5 Litre carbonated rice husk and Limbobo plant in 15 Litre of carbonated rice husk (2.0).

For experiment 2 a significant difference($P<0.05$) was seen in Net Assimilation Rate for substrate, growing bag size, variety, substrate x growing bag size, substrate x variety, growing bag size x variety and substrate x growing bag size x variety. The highest was recorded in Limbobo plants in 10 Litre palm fibre (8.5) and the lowest was recorded in Limbobo plants in 15 Litre carbonated rice husk (2.0).

Table 26:Mean Net Assimilation Rate ($gm^{-1}day^{-1}$) of Limbobo and Rodeo tomato varieties as a result of different substrates and growing bag sizes (Experiment 1 and 2)

		EXPERIMENT 1						EXPERIMENT 2				
S	V	GROWING BAG SIZES			**S X V MEAN**	S MEAN		GROWING BAG SIZES			**S X V MEAN**	S MEAN
		5L	10L	15L				5L	10L	15L		
PF	LB	4.1	8.4	4.1	**5.5**	5.2		4.1	8.5	4.1	**5.5**	5.2
	RD	3.1	7.3	4.1	**4.8**			3.2	7.5	4.1	**4.9**	
S X G Mean		**3.6**	**7.9**	**4.1**				**3.6**	**8**	**4.1**		
C	LB	3.1	5.5	3.2	**3.9**	3.9		3.1	5.6	3.3	**4**	4
	RD	2.7	3	5.7	**3.8**			3.1	3	5.7	**3.9**	
S X G Mean		**2.9**	**4.3**	**4.5**				**3.1**	**4.3**	**4.5**		
CRH	LB	2.1	5.1	2	**3.1**	3.1		2.1	5.1	2	**3.1**	3.1
	RD	2	5	2.1	**3**			2.1	5	2.1	**3.1**	
S X G Mean		**2.1**	**5.1**	**2**				**2.1**	**5.1**	**2.1**		
G Mean		2.8	5.7	3.5				2.9	5.8	3.5		
					V Mean						V Mean	
	LB	3.1	6.4	3.1	4.2			3.1	6.4	3.1	4.2	
	RD	2.6	5.1	3.9	3.9			2.8	5.2	4	4	

EX 1 –LSD ($P \leq 0.05$); Substrates(S) = 0.09 Growing bag sizes(G)= 0.09
Substrate* Growing bag sizes(S X G)=0.16 Substrate* Variety(S X V)= 0.13
Substrate* Growing bag sizes* Variety=0.2
Variety(V) = 0.08 Growing bag sizes* Varieties =0.13

EX 2-LSD ($P \leq 0.05$); Substrates(S) =0.04 Growing bag sizes(G)=0.04
Substrate* Growing bag sizes(S X G) = 0.07 Substrate* Variety(S X V)= 0.06
Substrate* Growing bag sizes* Variety= 0.10
Variety(V) = 0.03 Growing bag sizes* Varieties = 0.06

Table27 shows the Relative Growth Rate of Limbobo and Rodeo tomato plants at 8 WAT as determined by the type of substrate and growing bag size for experiment 1 and 2 .

For experiment 1 a significant difference($P<0.05$) was seen in Net Assimilation Rate for substrate, growing bag size, variety, substrate x growing bag size, substrate x variety, growing bag size x variety and substrate x growing bag size x variety. The highest relative growth rate was recorded in Limbobo plants in 10 Litre palm fibre (0.16) and the lowest was recorded in 15 Litre palm fibre (0.04).

For experiment 2 a significant difference($P<0.05$) was observed in Relative Growth Rate among growing bag sixes, variety, substrate x growing bag sizes, substrate x variety, substrate x growing bag size x variety. The highest was recorded in Rodeo plants in 10 Litre palm fibre (0.17) and the lowest was recorded in Rodeo plants in 15 Litre cocopeat(0.11).

Table 27: Mean Relative Growth Rate ($g.g^{-1}day^{-1}$) of Limbobo and Rodeo tomato varieties as a result of different substrates and growing bag sizes (Experiment 1 and 2)

		EXPERIMENT 1						EXPERIMENT 2				
S	V	GROWING BAG SIZES			**S XV MEAN**	S MEAN		GROWING BAG SIZES			**S X G MEAN**	S MEAN
		5L	10L	15L				5L	10L	15L		
	LB	0.12	0.16	0.14	**0.14**			0.14	0.16	0.14	**0.15**	
PF	RD	0.13	0.14	0.04	**0.11**	0.12		0.13	0.17	0.14	**0.15**	0.1
S X G Mean		**0.13**	**0.15**	**0.09**				**0.14**	**0.17**	**0.14**		
	LB	0.16	0.11	0.14	**0.14**			0.16	0.12	0.13	**0.14**	
C	RD	0.14	0.14	0.11	**0.13**	0.13		0.14	0.13	0.11	**0.13**	0.1
S X G Mean		**0.15**	**0.13**	**0.13**				**0.15**	**0.13**	**0.12**		
	LB	0.14	0.05	0.15	**0.11**			0.14	0.16	0.16	**0.12**	
CRH	RD	0.14	0.06	0.15	**0.12**	0.12		0.16	0.15	0.15	**0.12**	0.1
S X G Mean		**0.15**	**0.05**	**0.15**				**0.15**	**0.16**	**0.16**		
G Mean		0.14	0.09	0.14				0.1	0.1	0.1		
					V Mean						V Mean	
	LB	0.14	0.11	0.14	0.13			0.15	0.1	0.1	0.1	
	RD	0.15	0.08	0.13	0.13			0.14	0.1	0.1	0.1	

EX 1 – LSD ($P \leq 0.05$); Substrates(S) = 0.01 Growing bag sizes(G)=0.01
Substrate* Growing bag sizes(S X G) = 0.01 Substrate* Variety(S X V)= 0.01
Substrate* Growing bag sizes* Variety= 0.01

Variety(V) = 0.01 Growing bag sizes* Varieties =0.02

EX 2- LSD ($P \leq 0.05$); Substrates(S) =0.009 Growing bag sizes(G)=0.009
Substrate* Growing bag sizes(S X G) =0.02 Substrate* Variety(S X V)= 0.01
Substrate* Growing bag sizes* Variety= 0.02

Variety(V) =0.007 Growing bag sizes* Varieties =0.01

Table 28 shows the Leaf Weight Ratio of Limbobo and Rodeo tomato plants at 8 WAT as determined by the type of substrate and growing bag size for experiment 1 and 2.

For experiment 1 the leaf weight ratio showed significant difference($P<0.05$) among substrates, growing bag size, substrate x growing bag size, substrate x variety and growing bag size x variety. For growing bag in 5 Litre palm fibre, 10 Litre cocopeat and 15 Litre cocopeat (0.6). The lowest was recorded in 15 Litre palm fibre and 15 Litre carbonated rice husk(0.5). For substrate x variety the highest was recorded in Limbobo plants in palm fibre (0.6)and the lowest were Limbobo plants in cocopeat(0.4)

For experiment 2 the Leaf weight ratio showed significant difference ($P<0.05$) among substrate, growing bag size, variety, substrate x growing bag size, substrate x variety, growing bag size x variety and substrate x growing bag size x variety. The highest recorded was Limbobo plants in 5 Litre and 15 Litre cocopeat (0.7) and the lowest was Limbobo plants in 5 and 10 Litre carbonated rice husk and Rodeo plants in 5 Litre carbonated rice husk(0.4).

Table 28:Mean Leaf Weight Ratio ($g.g^{-1}day^{-1}$)of Limbobo and Rodeo tomato varieties as a result of different substrates and growing bag sizes (Experiment 1 and 2)

		EXPERIMENT 1						EXPERIMENT 2				
S	V	GROWING BAG SIZES			**S X V MEAN**	S MEAN		GROWING BAG SIZES			**S X V MEAN**	S MEAN
		5L	10L	15L				5L	10L	15L		
	LB	0.5	0.5	0.4	**0.6**			0.5	0.6	0.5	**0.5**	
PF	RD	0.7	0.5	0.4	**0.5**	0.5		0.6	0.5	0.6	**0.6**	0.5
S X G Mean		**0.6**	**0.5**	**0.4**				**0.6**	**0.5**	**0.6**		
	LB	0.6	0.7	0.6	**0.4**			0.7	0.5	0.7	**0.6**	
C	RD	0.5	0.5	0.5	**0.5**	0.6		0.6	0.5	0.5	**0.6**	0.6
S X G Mean		**0.5**	**0.6**	**0.6**				**0.7**	**0.5**	**0.7**		
	LB	0.5	0.5	0.4	**0.5**			0.4	0.5	0.5	**0.4**	
CRH	RD	0.6	0.4	0.4	**0.5**	0.5		0.4	0.4	0.5	**0.5**	0.5
S X G Mean		**0.5**	**0.5**	**0.4**				**0.4**	**0.5**	**0.5**		
G Mean		0.5	0.5	0.5				0.5	0.5	0.5		
					V Mean						V Mean	
	LB	0.5	0.5	0.5	0.5			0.5	0.5	0.5	0.5	
	RD	0.6	0.5	0.4	0.5			0.6	0.5	0.6	0.5	

EX 1 – LSD ($P \leq 0.05$); Substrates(S) = 0.02 Growing bag sizes(G)= 0.02
Substrate* Growing bag sizes(S X G)=0.04 Substrate* Variety(S X V)=0.03
Substrate* Growing bag sizes* Variety=0.05
Variety(V) = 0.02 Growing bag sizes* Varieties =0.03

EX 2- LSD ($P \leq 0.05$); Substrates(S) =0.05 Growing bag sizes(G)=0.05
Substrate* Growing bag sizes(S X G) =0.08 Substrate* Variety(S X V)=0.06
Substrate* Growing bag sizes* Variety=0.1
Variety(V) =0.04 Growing bag sizes* Varieties =0.06

Table 29 shows the Specific Leaf Area of Limbobo and Rodeo tomato plants at 8 WAT as determined by the type of substrate and growing bag size for experiment 1 and 2.

For experiment 1 the significant difference (P<0.05) was observed in specific leaf area for substrate, growing bag size, variety, substrate x growing bag size, substrate x variety, growing bag sizes x variety and substrate x growing bag size x variety. The highest was recorded in Rodeo plants in 10 Litre cocopeat. The lowest was recorded in Rodeo plants in 5 Litre palm fibre (2065).

For experiment 2 a significant difference (P<0.05) was observed for substrate, growing bag sizes, variety, substrate x growing bag sizes and substrate x variety. For substrate x growing bag sizes the highest was 10 Litre cocopeat (5330) and the lowest was seen in 5 Litre palm fibre (2125). For substrate x variety the highest was Rodeo plants in cocopeat (7078) and the lowest in Limbobo plants in cocopeat (2600).

Table 29:Mean Specific Leaf Area ($mm^2.g^{-1}$)of Limbobo and Rodeo tomato varieties as a result of different substrates and growing bag sizes (Experiment 1 and 2)

		Experiment 1						Experiment 1				
S	V	GROWING BAG SIZES			**S X V MEAN**	S MEAN		GROWING BAG SIZES			**S X V MEAN**	S MEAN
		5L	10L	15L				5L	10L	15L		
	LB	21156	2408	2207	**2244**			2185	5130	2116	**3144**	
PF	RD	2065	5333	5130	**5130**	3210		2065	5333	2275	**3224**	3184
S X G Mean		**2091**	**3871**	**3668.6**				**2125**	**5232**	**2195**		
	LB	2200	2901	2700.1	**2600**			2200	2901	2700	**2600**	
C	RD	5915	7760	7560.1	**7078**	4839		5915	7760	7560	**7078**	4839
S X G Mean		**4058**	**5331**	**5130.1**				**4058**	**5330**	**5130**		
	LB	2526	2350	2150	**2342**			3659	2838	3088	**3194**	
CRH	RD	2140	4413	4213	**3589**	2965		2229	2342	3725	**2766**	2980
S X G Mean		**2333**	**3382**	**3182**				**2944**	**2590**	**3407**		
G Mean		2827	4194	3993.4				3042	4383	3577		
					V Mean						V Mean	
	LB	2281	2553	2352.4	2395			2681	3623	2635	2980	
	RD	3373	5835	5634.4	4948			3403	5145	4520	4356	

EX 1 – LSD ($P \leq 0.05$); Substrates(S) = 0.08Growing bag sizes(G)=0.08

Substrate* Growing bag sizes(S X G)=0.14 Substrate* Variety(S X V)=0.12
Substrate* Growing bag sizes* Variety= 0.20
Variety(V) = 0.07 Growing bag sizes* Varieties =0.12

EX 2- LSD ($P \leq 0.05$); Substrates(S) =364.2 Growing bag sizes(G)=364.2
Substrate* Growing bag sizes (S X G)=630.9 Substrate* Variety(S X V)=515.1
Substrate* Growing bag sizes* Variety=892.2
Variety(V) =297.4 Growing bag sizes* Varieties =515.1

Table 30 shows the Leaf Area Ratio of Limbobo and Rodeo tomato plants at 8 WAT as determined by the type of substrate and growing bag size for experiment 1 and 2.

For experiment 2 significant difference ($P<0.05$) was recorded for substrate, growing bag size, variety and substrate x growing bag size. The highest was seen in 15 Litre carbonated rice husk (1920) and the lowest in palm fibre at 10 Litre (1148).

For experiment 2 no significant difference ($P>0.05$) was seen in leaf area ratio among the treatments.

Table 30:Mean Leaf Area Ratio ($mm2.g^{-1}$)of Limbobo and Rodeo tomato varieties as a result of different substrates and growing bag sizes (Experiment 1 and 2)

		Experiment 1						Experiment 1				
S	V	GROWING BAG SIZES			**S X V MEAN**	S MEAN		GROWING BAG SIZES			**S X V MEAN**	S MEAN
		5L	10L	15L				5L	10L	15L		
	LB	1655	1146	1549	**1450**			1645	1156	1559	**1453**	
PF	RD	1182	1151	1298	**1211**	1330		1186	1156	1299	**1214**	1330
S X G Mean		**1418**	**1148**	**1424**				**1416**	**1156**	**1429**		
	LB	1295	1714	1475	**1495**			1295	1724	1476	**1498**	
C	RD	1107	1662	1079	**1283**	1389		1117	1667	1089	**1291**	1389
S X G Mean		**1201**	**1688**	**1277**				**1206**	**1696**	**1283**		
	LB	1816	1018	2226	**1687**			1826	1019	2227	**1691**	
CRH	RD	1979	1520	1615	**1705**	1696		1979	1530	1617	**1709**	1696
S X G Mean		**1898**	**1269**	**1920**				**1903**	**1275**	**1922**		
G Mean		1506	1369	1540				1506	1369	1540		
					V Mean						V Mean	
	LB	1589	1293	1750	1544			1590	1300	1756	1549	
	RD	1422	1444	1331	1399			1423	1445	1334	1401	

EX 1 -LSD ($P \leq 0.05$); Substrates(S) = 350.3 Growing bag sizes(G)=350.3
Substrate* Growing bag sizes(S X G) =606.8 Substrate* Variety(S X V)=496
Substrate* Growing bag sizes* Variety=858.2
Variety(V) =286.1 Growing bag sizes* Varieties =496

EXP 2 - LSD ($P \leq 0.05$); Substrates(S) = 350.3 Growing bag sizes(G)=350.3
Substrate* Growing bag sizes(S X G) =606.8 Substrate* Variety(S X V)=496
Substrate* Growing bag sizes* Variety=858.2
Variety(V) =286.1 Growing bag sizes* Varieties =496

4.6. Tomato plant yield and yield components.

4.6.1. Effect of different substrates and growing bag sizes on yield and yield components of two varieties of tomatoes.

Table 31a and 31b shows the Fruit number of Limbobo and Rodeo tomato plants as determined by the type of substrate and growing bag size for experiment 1.

Significant difference ($P<0.05$) was recorded in substrate, growing bag sizes and substrate x growing bag size x variety. The highest was recorded in 10 Litre palm fibre(11.3) and the lowest was recorded in 5 Litre carbonated rice husk (3.2).

Table 31a: Mean fruit number of Limbobo and Rodeo as a result of the effects of different substrates and growing bag sizes. (Experiment 1)

Substrate	Varieties	Growing bag sizes			**Mean**	Mean
		5 Litre	10 Litre	15 Litre		
Palm fibre	Limbobo	11.3	12.0	11.7	**11.7**	11.4
	Rodeo	10.3	10.7	12.7	**11.2**	
Mean		**10.8**	**11.3**	**12.2**		
Cocopeat	Limbobo	2.0	2.4	3.6	**2.7**	3.4
	Rodeo	4.3	5.4	4.8	**4.8**	
Mean		**3.2**	**3.9**	**4.2**		
Carbonated Rice Husk	Limbobo	3.0	2.3	5.0	**3.4**	3.1
	Rodeo	2.3	2.0	4.0	**2.8**	
Mean		**2.7**	**2.2**	**4.5**		
Mean		4.5	5.6	4.5		

LSD ($P \leq 0.05$); Substrates = 0.50 Growing bag sizes= 0.50
Substrate* Growing bag sizes = 0.87 Substrate* Variety= 0.71
Substrate* Growing bag sizes* Variety= 1.23

Table 31b: Mean Fruit number as a result of the interaction of variety of tomatoes and growing bag sizes (Experiment 1)

Varieties	Growing Bag sizes			Mean
	5 Litre	10 Litre	15 Litre	
Limbobo	4.8	4.8	5.6	5.1
Rodeo	4.2	4.2	5.6	4.7

LSD ($P \leq 0.05$); Variety =0.41 Growing bag sizes* Varieties = 0.71

Table 32a and 32b shows the Fruit number of Limbobo and Rodeo tomato plants as determined by the type of substrate and growing bag size for experiment 2.

Significant difference (P<0.05) was recorded in fruit number among substrate and growing bag size only. For substrates the highest was palm fibre (12.0) and the lowest was carbonated rice husk (3.6). For growing bags the highest is 10 Litre (7.5) and the lowest is 5 Litre (5.8)

Table 32a: Mean fruit number of Limbobo and Rodeo as a result of the effects of different substrates and growing bag sizes. (Experiment 2)

Substrate	Varieties	Growing bag sizes			**Mean**	Mean
		5 Litre	10 Litre	15 Litre		
Palm fibre	Limbobo	11.3	13.7	11.7	**12.2**	12.0
	Rodeo	10.3	12.3	12.7	**11.8**	
Mean		**10.8**	**13.8**	**12.2**		
Cocopeat	Limbobo	4.7	4.3	4.7	**4.6**	4.5
	Rodeo	3.0	4.3	6.0	**4.4**	
Mean		**3.8**	**4.3**	**5.3**		
Carbonated Rice Husk	Limbobo	3.0	4.0	5.0	**4.0**	3.6
	Rodeo	2.3	2.3	5.0	**3.2**	
Mean		**2.7**	**3.2**	**5.0**		
Mean		5.8	7.5	6.8		

LSD (P ≤ 0.05); Substrates = 1.1 Growing bag sizes= 1.1
Substrate* Growing bag sizes = 1.9 Substrate* Variety=1.5
Substrate* Growing bag sizes* Variety=2.6

Table 32b: Mean Fruit number as a result of the interaction of variety of tomatoes and growing bag sizes (Experiment 2)

Varieties	Growing Bag sizes			Mean
	5 Litre	10 Litre	15 Litre	
Limbobo	6.3	7.3	7.1	6.9
Rodeo	5.2	6.3	7.9	6.5

LSD ($P \leq 0.05$); Variety = 0.9 Growing bag sizes* Varieties =1.5

Table 33a and 33b shows the Fruit weight of Limbobo and Rodeo tomato plants as determined by the type of substrate and growing bag size for experiment 1.

Fruit weight was significantly different ($P<0.05$) among substrates, growing bag size, variety and substrate x growing bag size. The highest was recorded in 15 Litre palm fibre(0.4) and the lowest 5 Litre palm fibre and 15 Litre carbonated rice husk(0.2).

Table 33a: Mean fruit weight (Kg) of Limbobo and Rodeo as a result of the effects of different substrates and growing bag sizes. (Experiment 1).

Substrate	Varieties	Growing bag sizes			**Mean**	Mean
		5 Litre	10 Litre	15 Litre		
Palm fibre	Limbobo	0.2	0.2	0.4	**0.2**	0.3
	Rodeo	0.3	0.3	0.4	**0.3**	
Mean		**0.2**	**0.3**	**0.4**		
Cocopeat	Limbobo	0.2	0.3	0.2	**0.2**	0.2
	Rodeo	0.3	0.3	0.3	**0.3**	
Mean		**0.3**	**0.3**	**0.3**		
Carbonated Rice Husk	Limbobo	0.2	0.3	0.1	**0.2**	0.2
	Rodeo	0.3	0.3	0.2	**0.3**	
Mean		**0.3**	**0.3**	**0.2**		
Mean		0.2	0.2	0.2		

LSD ($P \leq 0.05$); Substrates = 0.06 Growing bag sizes= 0.06
Substrate* Growing bag sizes =0.10 Substrate* Variety= 0.09
Substrate* Growing bag sizes* Variety= 0.15

Table 33b: Mean Fruit weight (Kg) as a result of the interaction of variety of tomatoes and growing bag sizes (Experiment 1)

Varieties	Growing Bag sizes			Mean
	5 Litre	10 Litre	15 Litre	
Limbobo	0.1	0.2	0.2	0.1
Rodeo	0.2	0.2	0.2	0.2

LSD ($P \leq 0.05$); Variety = 0.05 Growing bag sizes* Varieties = 0.09

Table 34a and 34b shows the Fruit weight of Limbobo and Rodeo tomato plants as determined by the type of substrate and growing bag size for experiment 2.

Fruit weight was significantly different (P<0.05) among substrate ,growing bag size, variety and substrate x growing bag size. The highest fruit weight was recorded in 10 and 15 Litre palm fibre, as well as 5 Litre carbonated rice husk(0.3) and the lowest in 5 Litre palm fibre and 5,10 and 15 Litre cocopeat (0.2).

Table 34a:Mean fruit weight (Kg) of Limbobo and Rodeo as a result of the effects of different substrates and growing bag sizes. (Experiment 2).

Substrate	Varieties	Growing bag sizes			**Mean**	Mean
		5 Litre	10 Litre	15 Litre		
Palm fibre	Limbobo	0.2	0.3	0.2	**0.2**	0.3
	Rodeo	0.3	0.2	0.3	**0.3**	
Mean		**0.2**	**0.3**	**0.3**		
Cocopeat	Limbobo	0.2	0.2	0.2	**0.2**	0.2
	Rodeo	0.2	0.2	0.2	**0.2**	
Mean		**0.2**	**0.2**	**0.2**		
Carbonated Rice Husk	Limbobo	0.2	0.3	0.1	**0.2**	0.2
	Rodeo	0.3	0.3	0.2	**0.2**	
Mean		**0.3**	**0.3**	**0.2**		
Mean		0.2	0.3	0.2		

LSD (P ≤ 0.05); Substrates =0.03 Growing bag sizes= 0.03
Substrate* Growing bag sizes =0.04 Substrate* Variety= 0.04
Substrate* Growing bag sizes* Variety=0.06

Table 34b: Mean Fruit weight (kg) as a result of the interaction of variety of tomatoes and growing bag sizes (Experiment 2)

Varieties	Growing Bag sizes			Mean
	5 Litre	10 Litre	15 Litre	
Limbobo	0.2	0.2	0.2	0.2
Rodeo	0.2	0.3	0.2	0.2

LSD ($P \leq 0.05$); Variety =0.02 Growing bag sizes* Varieties =0.04

Table 35a and 35b shows the Fruit size of Limbobo and Rodeo tomato plants as determined by the type of substrate and growing bag size for experiment 1.

Significant difference ($P<0.05$) was observed in fruit size among treatments, growing bag size, variety, substrate x growing bag size and substrate x variety. For substrate x growing bag size the highest was recorded for 10 Litre palm fibre(0.16) and the lowest was recorded in 10 Litre cocopeat(0.01). For substrate x variety the highest was recorded in Rodeo in palm fibre (0.09) and the lowest was recorded in Limbobo in cocopeat(0.02).

Table 35a:Mean fruit size (mm) of Limbobo and Rodeo as a result of the effects of different substrates and growing bag sizes. (Experiment 1).

Substrate	Varieties	Growing bag sizes			**Mean**	Mean
		5 Litre	10 Litre	15 Litre		
Palm fibre	Limbobo	0.03	0.14	0.06	**0.08**	0.05
	Rodeo	0.05	0.17	0.06	**0.09**	
Mean		**0.04**	**0.16**	**0.06**		
Cocopeat	Limbobo	0.03	0.01	0.03	**0.02**	0.036
	Rodeo	0.02	0.03	0.04	**0.03**	
Mean		**0.03**	**0.02**	**0.04**		
Carbonated Rice Husk	Limbobo	0.07	0.04	0.04	**0.05**	0.10
	Rodeo	0.14	0.06	0.05	**0.08**	
Mean		**0.11**	**0.05**	**0.04**		
Mean		0.05	0.07	0.03		

LSD ($P \leq 0.05$); Substrates = 0.01 Growing bag sizes= 0.01
Substrate* Growing bag sizes = 0.03 Substrate* Variety= 0.02
Substrate* Growing bag sizes* Variety= 0.04

Table 35b: Mean Fruit weight (mm) as a result of the interaction of variety of tomatoes and growing bag sizes (Experiment 1)

Varieties	Growing Bag sizes			Mean
	5 Litre	10 Litre	15 Litre	
Limbobo	0.03	0.06	0.03	0.04
Rodeo	0.06	0.07	0.04	0.06

LSD ($P \leq 0.05$); Variety = 0.01 Growing bag sizes* Varieties = 0.03

Table 36a and 36b shows the Fruit size of Limbobo and Rodeo tomato plants as determined by the type of substrate and growing bag size for experiment 2.

Significant difference (P<0.05) is recorded for fruit size among the substrate x growing bags x variety The highest number of fruit size was seen in Limbobo plants at 10 Litre palm fibre (0.19) and the lowest was recorded for Limbobo at 10 Litre cocopeat and Rodeo at 10 and 15 Litre cocopeat(0.02).

Table 36a:Mean fruit size (mm) of Limbobo and Rodeo as a result of the effects of different substrates and growing bag sizes. (Experiment 2).

Substrate	Varieties	Growing bag sizes			**Mean**	Mean
		5 Litre	10 Litre	15 Litre		
Palm fibre	Limbobo	0.03	0.19	0.05	**0.09**	0.09
	Rodeo	0.05	0.13	0.07	**0.08**	
Mean		**0.04**	**0.16**	**0.06**		
Cocopeat	Limbobo	0.12	0.02	0.03	**0.06**	0.06
	Rodeo	0.12	0.02	0.02	**0.06**	
Mean		**0.12**	**0.02**	**0.03**		
Carbonated Rice Husk	Limbobo	0.07	0.14	0.03	**0.08**	0.09
	Rodeo	0.14	0.17	0.05	**0.12**	
Mean		**0.11**	**0.16**	**0.04**		
Mean		0.09	0.08	0.08		

LSD (P ≤ 0.05); Substrates = 0.06 Growing bag sizes=0.06
Substrate* Growing bag sizes = 0.1 Substrate* Variety=0.09
Substrate* Growing bag sizes* Variety=0.2

Table 36b: Mean Fruit weight (mm) as a result of the interaction of variety of tomatoes and growing bag sizes (Experiment 2)

Varieties	Growing Bag sizes			Mean
	5 Litre	10 Litre	15 Litre	
Limbobo	0.07	0.07	0.08	0.08
Rodeo	0.10	0.09	0.07	0.09

LSD ($P \leq 0.05$); Variety =0.05 Growing bag sizes* Varieties =0.09

Table 37a and 37b shows the total yield of Limbobo and Rodeo tomato plants as determined by the type of substrate and growing bag size for experiment 1.

Significant difference ($P<0.05$) was seen for total yield for substrate x growing bag size, growing bag size x variety and substrate x growing bag x variety. The highest to total yield was recorded in Rodeo plants in 10 Litre palm fibre (36.8) and the lowest was recorded in Limbobo plants in 15 Litre carbonated rice husk(16.3).

Table 37a:Mean total yield (t/ha) of Limbobo and Rodeo as a result of the effects of different substrates and growing bag sizes. (Experiment 1).

Substrate	Varieties	Growing bag sizes			**Mean**	Mean
		5 Litre	10 Litre	15 Litre		
Palm fibre	Limbobo	21.1	23.4	27.7	**24.1**	25.6
	Rodeo	26.9	36.8	29.0	**30.9**	
Mean		**24.0**	**30.1**	**28.4**		
Cocopeat	Limbobo	30.8	26.6	20.8	**26.1**	24.4
	Rodeo	20.9	35.2	19.6	**25.2**	
Mean		**25.8**	**30.9**	**20.2**		
Carbonated Rice Husk	Limbobo	32.3	18.1	16.3	**22.0**	25.4
	Rodeo	23.8	23.6	20.2	**22.5**	
Mean		**28.0**	**20.9**	**18.2**		
Mean		26.0	27.3	22.3		

LSD ($P \leq 0.05$); Substrates = 6.4 Growing bag sizes=6.4
Substrate* Growing bag sizes = 11.0 Substrate* Variety=9.0
Substrate* Growing bag sizes* Variety=15.6

Table 37b: Mean total yield (t/ha) as a result of the interaction of variety of tomatoes and growing bag sizes (Experiment 1)

Varieties	Growing Bag sizes			Mean
	5 Litre	10 Litre	15 Litre	
Limbobo	28.1	22.7	21.6	24.1
Rodeo	24.0	31.9	22.9	26.2

LSD ($P \leq 0.05$); Variety = 5.2 Growing bag sizes* Varieties =9.0

Table 38a and 38b shows the total yield of Limbobo and Rodeo tomato plants as determined by the type of substrate and growing bag size for experiment 2.

Significant difference($P<0.05$) was seen for total yield for substrate x growing bag size, substrate x variety, growing bag x variety and substrate x growing bag x variety. The highest was recorded in Rodeo plants at 10 Litre palm fibre(37.2) and the lowest was seen in Limbobo at 15 Litre carbonated rice husk(16.3).

Table 38a:Mean total yield (t/ha) of Limbobo and Rodeo as a result of the effects of different substrates and growing bag sizes. (Experiment 2).

Substrate	Varieties	Growing bag sizes			**Mean**	Mean
		5 Litre	10 Litre	15 Litre		
Palm fibre	Limbobo	21.3	24.4	27.0	**24.2**	26.6
	Rodeo	27.0	37.2	29.7	**31.3**	
Mean		**24.2**	**30.8**	**28.4**		
Cocopeat	Limbobo	30.9	18.6	21.0	**23.5**	24.8
	Rodeo	20.9	24.0	19.9	**21.6**	
Mean		**25.9**	**21.3**	**20.5**		
Carbonated Rice Husk	Limbobo	32.3	26.8	16.3	**25.1**	25.4
	Rodeo	23.8	36.8	20.2	**26.9**	
Mean		**28.0**	**31.8**	**18.2**		
Mean		26.0	27.3	22.3		

LSD ($P \leq 0.05$); Substrates = 6.4 Growing bag sizes=6.4
Substrate* Growing bag sizes = 11.0 Substrate* Variety=9.0
Substrate* Growing bag sizes* Variety=15.6

Table 38b: Mean total yield (t/ha) as a result of the interaction of variety of tomatoes and growing bag sizes (Experiment 2)

Varieties	Growing Bag sizes			Mean
	5 Litre	10 Litre	15 Litre	
Limbobo	28.5	23.7	21.9	24.1
Rodeo	25.0	32.0	24.0	26.2

LSD ($P \leq 0.05$); Variety = 5.2 Growing bag sizes* Varieties =9.0

4.7. Tomato plant fruit quality parameters.

4.7.1. Effect of different substrates and growing bag sizes on fruit quality parameters two varieties of tomatoes.

Table 39a and 39b shows the total soluble solids of Limbobo and Rodeo tomato plants as determined by the type of substrate and growing bag size for experiment 1.

Significant difference($P<0.05$) was observed for Total soluble solids among substrates only. Hence, the highest total soluble solids were recorded for palm fibre(4.97) and the lowest was recorded for carbonated rice husk (4.90).

Table 39a:Mean total soluble solids (% Brix) of Limbobo and Rodeo as a result of the effects of different substrates and growing bag sizes. (Experiment 1)

Substrate	Varieties	Growing bag sizes			**Mean**	Mean
		5 Litre	10 Litre	15 Litre		
Palm fibre	Limbobo	4.97	4.96	4.98	**4.97**	4.97
	Rodeo	4.97	4.97	4.99	**4.98**	
Mean		**4.97**	**4.97**	**4.99**		
Cocopeat	Limbobo	4.94	4.91	4.93	**4.93**	4.90
	Rodeo	4.93	4.92	4.92	**4.92**	
Mean		**4.94**	**4.92**	**4.93**		
Carbonated Rice Husk	Limbobo	4.95	4.93	4.91	**4.93**	4.94
	Rodeo	4.93	4.96	4.96	**4.95**	
Mean		**4.94**	**4.95**	**4.94**		
Mean		3.30	3.30	3.31		

LSD ($P \leq 0.05$); Substrates = 0.02 Growing bag sizes= 0.02
Substrate* Growing bag sizes = 0.04 Substrate* Variety= 0.03
Substrate* Growing bag sizes* Variety= 0.05

Table 39b: Mean total soluble solids (%) as a result of the interaction of variety of tomatoes and growing bag sizes (Experiment 1)

Varieties	Growing Bag sizes			Mean
	5 Litre	10 Litre	15 Litre	
Limbobo	3.31	3.30	3.30	3.30
Rodeo	3.30	3.31	3.32	3.31

LSD ($P \leq 0.05$); Variety = 0.02 Growing bag sizes* Varieties = 0.03

Table 40a and 40b shows the total soluble solids of Limbobo and Rodeo tomato plants as determined by the type of substrate and growing bag size for experiment 2.

Significant difference($P<0.05$) was observed for Total soluble solids among substrates only. Hence, the highest total soluble solids were recorded for palm fibre(5.0) and the lowest was recorded for cocopeat and carbonated rice husk (4.96).

Table 40a:Mean total soluble solids (%) of Limbobo and Rodeo as a result of the effects of different substrates and growing bag sizes. (Experiment 2)

Substrate	Varieties	Growing bag sizes			**Mean**	Mean
		5 Litre	10 Litre	15 Litre		
Palm fibre	Limbobo	4.97	4.97	4.98	**4.97**	5.0
	Rodeo	4.97	4.97	4.99	**4.98**	
Mean		**4.97**	**4.97**	**4.99**		
Cocopeat	Limbobo	4.93	4.91	4.94	**4.93**	4.96
	Rodeo	4.92	4.91	4.93	**4.92**	
Mean		**4.93**	**4.91**	**4.94**		
Carbonated Rice Husk	Limbobo	4.95	4.96	4.94	**4.95**	4.96
	Rodeo	4.95	4.96	4.96	**4.96**	
Mean		**4.95**	**4.96**	**4.95**		
Mean		3.30	3.30	3.31		

LSD ($P \leq 0.05$); Substrates = 0.02 Growing bag sizes= 0.02
Substrate* Growing bag sizes = 0.04 Substrate* Variety= 0.03
Substrate* Growing bag sizes* Variety= 0.05

Table 40b: Mean total soluble solids (%) as a result of the interaction of variety of tomatoes and growing bag sizes (Experiment 2)

Varieties	Growing Bag sizes			Mean
	5 Litre	10 Litre	15 Litre	
Limbobo	3.34	3.31	3.30	3.30
Rodeo	3.31	3.34	3.32	3.31

LSD ($P \leq 0.05$); Variety = 0.02 Growing bag sizes* Varieties = 0.03

Table 41a and 41b shows the pH of Limbobo and Rodeo tomato plants as determined by the type of substrate and growing bag size for experiment 1.

Significant difference($P<0.05$) was observed for pH among substrates only. Hence, the highest was recorded for palm fibre(4.17) and the lowest was recorded for cocopeat(4.00).

Table 41a: Mean pH of Limbobo and Rodeo as a result of the effects of different substrates and growing bag sizes. (Experiment 1)

Substrate	Varieties	Growing bag sizes			**Mean**	Mean
		5 Litre	10 Litre	15 Litre		
Palm fibre	Limbobo	4.11	4.09	4.13	**4.11**	4.17
	Rodeo	4.39	4.15	4.13	**4.22**	
Mean		**4.25**	**4.12**	**4.13**		
Cocopeat	Limbobo	4.05	4.12	4.04	**4.07**	4.08
	Rodeo	4.10	4.08	4.13	**4.10**	
Mean		**4.08**	**4.10**	**4.09**		
Carbonated Rice Husk	Limbobo	4.13	4.12	4.16	**4.14**	4.14
	Rodeo	4.12	4.16	4.16	**4.15**	
Mean		**4.13**	**4.14**	**4.16**		
Mean		2.79	2.75	2.76		

LSD ($P \leq 0.05$); Substrates = 0.07 Growing bag sizes=0.07
Substrate* Growing bag sizes =0.13 Substrate* Variety= 0.10
Substrate* Growing bag sizes* Variety=0.18

Table 41b: Mean pH as a result of the interaction of variety of tomatoes and growing bag sizes (Experiment 1)

Varieties	Growing Bag sizes			Mean
	5 Litre	10 Litre	15 Litre	
Limbobo	2.75	2.74	2.76	2.75
Rodeo	2.84	2.77	2.76	2.79

LSD ($P \leq 0.05$); Variety =0.06 Growing bag sizes* Varieties=0.10

Table 42a and 42b shows the pH of Limbobo and Rodeo tomato plants as determined by the type of substrate and growing bag size for experiment 2.

Significant difference($P<0.05$) was observed for pH among substrates only. Hence, the highest was recorded for palm fibre(4.17) and the lowest was recorded for cocopeat(4.00).

Table 42a: Mean pH of Limbobo and Rodeo as a result of the effects of different substrates and growing bag sizes. (Experiment 2)

Substrate	Varieties	Growing bag sizes			**Mean**	Mean
		5 Litre	10 Litre	15 Litre		
Palm fibre	Limbobo	4.12	4.19	4.13	**4.11**	4.17
	Rodeo	4.40	4.15	4.13	**4.22**	
Mean		**4.26**	**4.17**	**4.13**		
Cocopeat	Limbobo	4.06	4.10	4.08	**4.08**	4.00
	Rodeo	4.10	4.08	4.14	**4.11**	
Mean		**4.08**	**4.09**	**4.11**		
Carbonated Rice Husk	Limbobo	4.13	4.12	4.16	**4.14**	4.12
	Rodeo	4.12	4.16	4.16	**4.15**	
Mean		**4.13**	**4.14**	**4.16**		
Mean		2.60	2.79	2.83		

LSD ($P \leq 0.05$); Substrates = 0.07 Growing bag sizes=0.07
Substrate* Growing bag sizes =0.13 Substrate* Variety= 0.10
Substrate* Growing bag sizes* Variety=0.18

Table 42b: Mean pH as a result of the interaction of variety of tomatoes and growing bag sizes (Experiment 2)

Varieties	Growing Bag sizes			Mean
	5 Litre	10 Litre	15 Litre	
Limbobo	2.85	2.77	2.76	2.75
Rodeo	2.84	2.77	2.78	2.75

LSD ($P \leq 0.05$); Variety =0.06 Growing bag sizes* Varieties=0.10

Table 43a and 43b shows the titratable acidity of Limbobo and Rodeo tomato plants as determined by the type of substrate and growing bag size for experiment 1.

Significant difference($P<0.05$) was observed for titratable acid among substrates only. Hence, the highest Titratable acid was recorded for palm fibre (0.28) and the lowest was recorded for cocopeat(0.18).

Table 43a: Mean titratable acidity (g/L) of Limbobo and Rodeo as a result of the effects of different substrates and growing bag sizes. (Experiment 1)

Substrate	Varieties	Growing bag sizes			**Mean**	Mean
		5 Litre	10 Litre	15 Litre		
Palm fibre	Limbobo	0.19	0.20	0.20	**0.20**	0.28
	Rodeo	0.44	0.20	0.43	**0.36**	
Mean		**0.32**	**0.20**	**0.32**		
Cocopeat	Limbobo	0.19	0.17	0.20	**0.19**	0.18
	Rodeo	0.20	0.18	0.18	**0.19**	
Mean		**0.20**	**0.18**	**0.19**		
Carbonated Rice Husk	Limbobo	0.19	0.18	0.18	**0.18**	0.19
	Rodeo	0.19	0.18	0.19	**0.19**	
Mean		**0.19**	**0.18**	**0.18**		
Mean		0.17	0.13	0.17		

LSD ($P \leq 0.05$); Substrates =0.09 Growing bag sizes=0.09
Substrate* Growing bag sizes =0.16 Substrate* Variety=0.13
Substrate* Growing bag sizes* Variety=0.23

Table 43b: Mean titratable acidity (g/L) as a result of the interaction of variety of tomatoes and growing bag sizes (Experiment 1)

Varieties	Growing Bag sizes			Mean
	5 Litre	10 Litre	15 Litre	
Limbobo	0.13	0.13	0.13	0.13
Rodeo	0.21	0.13	0.21	0.18

LSD ($P \leq 0.05$); Variety =0.08 Growing bag sizes* Varieties=0.13

Table 44a and 44b shows the titratable acidity of Limbobo and Rodeo tomato plants as determined by the type of substrate and growing bag size for experiment 2.

Significant difference($P<0.05$) was observed for titratable acid among substrates only. Hence, the highest Titratable acid was recorded for palm fibre and carbonated rice husk(0.20) and the lowest was recorded for cocopeat(0.18).

Table 44a:Mean titratable acidity (g/L) of Limbobo and Rodeo as a result of the effects of different substrates and growing bag sizes. (Experiment 2)

Substrate	Varieties	Growing bag sizes			**Mean**	Mean
		5 Litre	10 Litre	15 Litre		
Palm fibre	Limbobo	0.20	0.20	0.20	**0.20**	0.20
	Rodeo	0.31	0.25	0.30	**0.29**	
Mean		**0.26**	**0.23**	**0.25**		
Cocopeat	Limbobo	0.20	0.19	0.23	**0.21**	0.18
	Rodeo	0.20	0.18	0.20	**0.19**	
Mean		**0.20**	**0.19**	**0.22**		
Carbonated Rice Husk	Limbobo	0.20	0.18	0.15	**0.18**	0.20
	Rodeo	0.19	0.20	0.19	**0.19**	
Mean		**0.20**	**0.19**	**0.17**		
Mean		0.15	0.13	0.19		

LSD ($P \leq 0.05$); Substrates =0.09 Growing bag sizes=0.09
Substrate* Growing bag sizes =0.16 Substrate* Variety=0.13
Substrate* Growing bag sizes* Variety=0.23

Table 44b: Mean titratable acidity (g/L) as a result of the interaction of variety of tomatoes and growing bag sizes (Experiment 2)

Varieties	Growing Bag sizes			Mean
	5 Litre	10 Litre	15 Litre	
Limbobo	0.15	0.17	0.18	0.13
Rodeo	0.21	0.24	0.18	0.16

LSD ($P \leq 0.05$); Variety =0.08 Growing bag sizes* Varieties=0.13

Table 45a and 45b shows the shelf life of Limbobo and Rodeo tomato plants as determined by the type of substrate and growing bag size for experiment 1.

Significant difference($P<0.05$) was observed for shelf life among substrates and substrate x growing bag size only. The highest shelf life was recorded for 10 Litre palm fibre (18.5) and the lowest was recorded for 10 Litre carbonated rice husk(8.3).

Table 45a: Mean shelf life (days) of Limbobo and Rodeo as a result of the effects of different substrates and growing bag sizes. (Experiment 1)

Substrate	Varieties	Growing bag sizes			**Mean**	Mean
		5 Litre	10 Litre	15 Litre		
Palm fibre	Limbobo	17.3	19.7	17.0	**18.0**	16.8
	Rodeo	14.7	17.3	14.7	**15.6**	
Mean		**16.0**	**18.5**	**15.8**		
Cocopeat	Limbobo	12.4	15.2	13.2	**13.6**	12.9
	Rodeo	12.8	14.8	13.9	**13.8**	
Mean		**12.6**	**15.0**	**13.6**		
Carbonated Rice Husk	Limbobo	14.0	9.0	12.0	**11.7**	11.0
	Rodeo	12.3	7.7	11.0	**10.3**	
Mean		**13.2**	**8.3**	**11.5**		
Mean		9.72	8.94	9.11		

LSD ($P \leq 0.05$); Substrates = 1.9 Growing bag sizes=1.9
Substrate* Growing bag sizes =3.3 Substrate* Variety=2.7
Substrate* Growing bag sizes* Variety= 4.7

Table 45b: Mean shelf life (days) as a result of the interaction of variety of tomatoes and growing bag sizes (Experiment 1)

Varieties	Growing Bag sizes			Mean
	5 Litre	10 Litre	15 Litre	
Limbobo	10.4	9.6	9.7	9.9
Rodeo	9.0	8.3	8.6	8.6

LSD ($P \leq 0.05$); Variety =1.6 Growing bag sizes* Varieties= 2.7

Table 46a and 46b shows the shelf life of Limbobo and Rodeo tomato plants as determined by the type of substrate and growing bag size for experiment 2.

Significant difference($P<0.05$) was observed for shelf life among substrates and substrate x growing bag size only. Hence, the highest shelf life was recorded for 10 Litre palm fibre(18.7) and the lowest was recorded for 15 Litre carbonated rice husk(6.3).

Table 46a: Mean shelf life (days) of Limbobo and Rodeo as a result of the effects of different substrates and growing bag sizes. (Experiment 2)

Substrate	Varieties	Growing bag sizes			**Mean**	Mean
		5 Litre	10 Litre	15 Litre		
Palm fibre	Limbobo	17.5	19.9	17.4	**18.3**	16.9
	Rodeo	14.8	17.4	14.7	**15.6**	
Mean		**16.2**	**18.7**	**16.1**		
Cocopeat	Limbobo	12.8	15.2	13.5	**14.0**	12.6
	Rodeo	12.8	15.2	13.9	**14.0**	
Mean		**12.8**	**15.2**	**13.7**		
Carbonated Rice Husk	Limbobo	14.0	8.8	6.6	**9.8**	12.0
	Rodeo	12.5	10.2	5.7	**9.5**	
Mean		**13.3**	**9.5**	**6.2**		
Mean		9.40	9.72	9.40		

LSD ($P \leq 0.05$); Substrates = 1.9 Growing bag sizes=1.9
Substrate* Growing bag sizes =3.3 Substrate* Variety=2.7
Substrate* Growing bag sizes* Variety= 4.7

Table 46b: Mean shelf life (days) as a result of the interaction of variety of tomatoes and growing bag sizes (Experiment 2).

Varieties	Growing Bag sizes			Mean
	5 Litre	10 Litre	15 Litre	
Limbobo	10.5	9.8	9.7	9.9
Rodeo	9.4	8.5	8.9	8.6

4.8. COST BENEFIT ANALYSIS OF SUBSTRATES.

Table 10 and 11 shows the results for the cost benefit analysis.

In table 10, palm fibre has the highest benefit, followed by the cocopeat and lastly carbonated rice husk. Conversely, the cocopeat recorded the highest cost, followed by carbonated rice husk and the lowest was recorded by the palm fibre. This resulted in palm fibre recording the highest benefit cost ratio (BCR). Carbonated rice husk recorded the second highest. Though cocopeat had a higher benefit as compared to carbonated rice husk, but cost of production for using carbonated rice husk was lower than that of cocopeat. Making the cocopeat the substrate with the lowest benefit cost ratio.

The same trend obtained in Table 10 for the cost benefit analysis of substrates for the first experiment was also obtained for the cost benefit analysis of substrates obtained for the second experiment as illustrated in Table 11.

Table 47: Cost Benefit Analysis of substrates used in experiment 1 and 2

EXPERIMENT 1			
SUBSTRATES	**BENEFITS (GH₵)**	**COST (GH₵)**	**BENEFIT COST RATIO (BCR)**
Palm Fibre	5,076.5	1,247	4.1
Cocopeat	5,039.1	2,736	1.8
Carbonated Rice Husk	4,873	1854	2.6
EXPERIMENT 2			
Palm Fibre	5,168.5	1,247	4.1
Cocopeat	5,039.1	2,736	1.8
Carbonated Rice Husk	4,834.5	1,854	2.6

CHAPTER FIVE

5.0 DISCUSSION

5.1. Baseline Survey

According to Stevenson and Fisher (1974) and Vavrina (1995) container types used in greenhouses are troughs, pots and growing bags. These were the containers that were found to be used in the greenhouses visited.

Varying size (volume) were being used as varied recommendation were made to them by researchers and extension officers that obtain these information from various studies carried out that obtained varied results. This caused farmers to experience fluctuating yields. Some of these studies are Peterson *et al.* (1991), Cantliffe(1990) and Tonutti and Giulivo (1990) who advocate for larger containers as findings indicate that smaller containers cause root restriction and reduced flowering period, shoot and root development. However, researchers such as Scot and Duval(1995) and Kembel *et al.*(2015) indicates that larger containers cause increase in dry matter production which in most cases inhibits the reproductive phase.

In Ghana, cocopeat is the only commercially produced soilless substrate and this makes it the substrate that farmers can access and use.

Greenhouse is recently gaining grounds. Hence, researchers are still working to come up with protocols for growing crops in greenhouses. Standards of growing systems in terms of growing bags and media have not been developed.

5.2. Physical characteristics of substrates.

Acquaye(2011) reports that bulk density and water holding capacity are the relevant physical characters of a substrate. Palm fibre had a higher bulk density than both cocopeat and carbonated rice husk, but had the most moderate water holding capacity levels. This was because the bulk density of palm fibre (1.36g/cm^3 and 1.62g/cm^3) was ideal, which gave it a

moderate total porosity level. This gave it the ability to retain the right amount of water needed for crop growth. This agreed with findings of Ahmed *et al.* (2013). According to Spiers and Percy(2007), when substrate is not too coarse (medium texture) and has moderate pore spacing it facilitates proper aeration and at the same time facilitates water availability to the plants. Based on the above it is realised that the smooth nature of the palm fibre may have accounted for its high yields.

Smith (2010) indicated that high levels and low levels of the moisture retention ability of substrates results in detrimental effect on growth of vegetable crops. This may have accounted for the lower yields and fruit quality levels of tomatoes grown in cocopeat and carbonated rice husk. The differences obtained in the levels of bulk density and water holding capacity of the substrate was as a result of the differences in the size of the particle of the substrate. This assertion is in line with the research of Awange *et al.* (2009) and Acquaye (2011).

5.3. Chemical characteristics

The ability of the pH content to influence the availability of plant nutrient in a media and the electrical conductivity indicating the inherent nutrient of the substrate makes it two very important characteristics to consider (Awange *et al.* 2009 and Hartman *et al.* 2018). Hartman *et al.* (2018) reported that the optimum pH of soil for soilless medium 5.4 to 6.0. Though cocopeat had the highest pH levels, followed by carbonated rice husk and then palm fibre, all the substrate fell within the optimum pH requirement range. Hence, pH may not have affected the results obtained. Lang (1996)reported that the acceptable levels for EC levels are 1000µScm^{-1} to 2000µScm^{-1} for good seedling growth and between 2000µScm^{-1} to 3000 µScm^{-1} for established plant. This agrees with FAO United Nations report on salinity levels of substrates which indicates an optimal level of up to 3.0mScm^{-1} (3000µScm^{-1}). Any substrate with EC range higher than the above levels results in decline of growth and yield

of plants. Cocopeat substrate recorded higher levels of EC that exceeded that of levels for seedlings and established plants. This could have resulted in the lower yields and fruit quality realised from plants grown with cocopeat. Though the cocopeat was washed thoroughly per recommendations by Shivdas(1989) the EC level was still high. This explains why cocopeat obtained the lowest Relative Growth Rate. This high level of salt content in cocopeat is because coconut trees are mostly located along the sea sides and absorbs some of the sea water.

The palm fibre had the lowest EC levels in the analysis. This resulted in it having highest Relative Growth Rate and the highest number of tomato fruit. Cocopeat was highest in nitrogen content followed by carbonated rice husk and palm fibre. This did not translate into high levels of growth at the vegetative stage.

5.4. Plant Biomass

Carbonated rice husk as well as palm fibre are the substrates that give highest yields for plant biomass. However, when it came to harvested fruits, palm fibre substrates was far superior. Though cocopeat was higher in some plant biomass parameters it was overshadowed by the high performance of palm fibre plants. Carbonated rice husk did better in growth indices and plant biomass compared to the other substrates. Palm fibre performed well in terms dry weight of shoots, roots, shoot: root ratio and plant height.

Bidwell (1979) indicates that growth of a plant is measured by its length, width, volume, fresh and dry weight of plant. Though 5Litre and 10Litre performed well in certain plant biomass and growth indices, 15Litre growing bag performed better. This however did not translate into yields as 10 Litre had the highest yield. This can be attributed to bigger root spaces which facilitated root development for higher growth. Roegge (2010) and Acquaye(2011) affirm the above observation that roots space (volume) available for growth. Howard (1975) adds that oxygen needed to stimulate root development is inhibited in

smaller containers.

The high yields of palm fibre could be attributed to its increased plant height . Generally, tall plants are able to traps sunlight easily. This is in line with the findings of Ogbodo(2009) findings that tall plants get access to sunlight for photosynthesis. Bulk density was lower in carbonated rice husk and this may be attributed to increased total porosity and better aeration which resulted in growth and high biomass levels. Tanguinod(2002) also reported that biochar is able to make plant uptake of nutrient better. The 15Litre growing bag with carbonated rice husk performed the best.

5.6. Growth Analysis of substrates under different substrates and container sizes.

Net Assimilation measured the photosynthetic efficiency of the plants, which was better in the 10Litre palm fibre. This was because the lower leaves in the 10 Litre palm fibre plant were not blocked by the upper leaves allowing light to reach them. Poorter and Remkes (1990) indicated that high Net Assimilation Rate caused a decrease in Specific Leaf Area and vice versa. It was explained that to increase photosynthetic rate, there was the need to increase use of photosynthetic apparatus which caused the reduction in Specific Leaf Area. This was clearly seen in the results obtained. High Specific Leaf Area of cocopeat and carbonated rice husk indicated that the plants had smaller or thinner leaves and this could be as a result of their high potassium levels. This is in line with Silvia and Uchida (2000) who indicated that a high potassium level in a substrate facilitates the production of optimum leaf sizes. As broader leaves are able to intercept enough sunlight for photosynthesis and cocopeat and carbonated rice husk produced thinner leaves this could have accounted for the lower yields realised.

Nkansah and Ito (1994) indicated that the high dry matter can contribute to crop productivity through an increase in total carbohydrate production. The findings agree with the above as palm fibre had the highest dry matter production.

5.7. Yield and Yield attributes

The 10 Litre palm fibre substrate gave the highest yield and fruit number. This is in agreement with Rozman *et al.* (2000) who reported that palm fibre is an ideal substrate used for vegetables to realise optimum yields of crops. This might be attributed to optimum or ideal pH and EC levels. Also, high Relative Growth Rate and Net Assimilation Rate may have accounted for the high performance of palm fibre.

Results obtained disagreed with those of Cornelissen *et al.* (1996) who indicated that highest Leaf Area Ratio (LAR) should give rise to higher Relative Growth Rate which invariably leads to high productivity and yield levels. However, 15 Litre carbonated rice husk had the highest and the lowest was recorded in 10 Litre palm fibre although the 10 Litre produced the highest Relative Growth Rate (RGR). Again ideal EC and pH levels could have explained its good performance.

5.8. Fruit quality of Tomato as influenced by different substrates and growing bag sizes.

Hobson and Kelby (1990) indicated that TSS of tomato fruit is the result of flavouring of tomatoes. The bag size did not show statistical difference and hence did not influence the total soluble solids (%) or sugar concentration much. Palm fibre recorded the highest and contrary to that of Voogt (1998) who reported that high potassium levels of a substrate will increase the TSS of substrate, although cocopeat had highest potassium in all the chemical analysis carried out followed by carbonated rice husk and palm fibre, palm fibre recorded the highest TSS. This could be attributed to active degradation of the polysaccharides in the fruit at the stage of maturity (Hobson and Kelby,1990).All the substrates had TSS values falling in the range reported by Nkansah *et al.*(2003) and Kumah *et al.* (2011) which is 3.5 to 5.0.

Palm fibre recorded highest pH level of the fruits. Though there was an inverse relationship

between pH and titratable acid. The lower the pH, the higher titratable acid and vice versa. This was opposite in the findings realised as palm fibre gave the highest pH and titratable acid. Thus, there may be no direct relationship between titratable acidity and pH as a result of variation in buffer capacity, this observation is in line with findings by Amerine *et al.* (1980).

10 Litre palm fibre had the longest shelf life compared to the other substrates. In the study results obtained from the yield and yield component, as well as fruit quality in Experiment 1 was not very different from results obtained in Experiment 2. This shows that the farmer is assured of stable and improving yields if the recommended by size and substrate is used under greenhouse conditions.

10 Litre bag was able to provide good yields because even though it was small enough to air prune the roots to facilitate high yields and better quality fruit, but not small enough to cause root restriction in the case of the 5Litre bag. 15 Litre allowed for too much vegetative growth which caused the photosynthates produced to be used up on biomass production.

5.9. Cost Benefit Analysis

Benefit-Cost Ratio was used as an indicator to check the profitability of various substrates used in the study(Price Gittinger, 1984). Palm fibre was seen to have the highest profitability ,as the cost of production of palm fibre was lower than cocopeat and the benefits obtained from its use were also far superior compared with the other substrates.

Carbonated Rice husk, though not as expensive to produce as cocopeat, takes a bit more labour and fuel for the carbonization process and this accounted for higher cost as compared to palm fibre . Also, benefits obtained from it are lower than palm fibre, making it the next profitable substrate to use.

Cocopeat was the least profitable because cost of production was very high and though it benefits were far higher than carbonated rice husk, its cost of production was more than that

of carbonated rice husk and thus made its BCR(Benefit Cost Ratio) lower than carbonated rice husk and less profitable of all the substrates to use. However, all the substrates used exceeded breakeven point of BCR>1, which makes the use of any of the three(3) substrates quite profitable. This agrees with the report of Price Gittinger (1984).

CHAPTER SIX

6.0. CONCLUSION AND RECOMMENDATIONS

6.1. CONCLUSION

The study revealed that:

- Though in certain cases10 Litre palm fibre gave the highest results for some vegetative parameters, it primarily facilitated reproductive production and gave higher yield and fruit quality.10 Litre growing bag size gave the highest yield, growth and fruit quality of greenhouse tomatoes followed by 15 Litre, then 5 Litre mindless of the growing season.

- Carbonated rice husk facilitated plant biomass growth, followed by palm fibre, and cocopeat. Palm fibre was the most optimum substrate for greenhouse tomato production in this study. Palm fibre was also the cheapest substrate to use, yet the most profitable.
- Although cocopeat substrate yield was not drastically lower than palm fibre, cost of use of cocopeat was very high, hence reducing the profit margin significantly.
- Though carbonated rice husk gave lowest performance in growth and yield compared to cocopeat and palm fibre, its cost of use was lower, thereby making it more profitable to use in terms of output compared to cocopeat.
- 10 Litre of Palm fibre substrate significantly had higher growth, development and fruit yield.
- Rodeo tomato variety was the best variety for greenhouse production in this study.

RECOMMENDATIONS

- 10 Litre of Palm fibre is recommended for commercial production under greenhouse conditions by virtue of the superior fruit yield per plant.
- Further work may also be conducted to assess the impact of container sizes between 15 Litre and 10 Litre on tomato growth and yield..
- Further work may be conducted to evaluate the impact of a mix of growing media in combination with 10 Litre growing bag size.
- Comparative study between the greenhouse and field may be conducted to establish their significance in tomato crop production in Ghana.

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APPENDIX

Appendix I: Baseline Survey Guidelines

Location:

Resource/Contact person:

Contact address:

Email:

Phone:

Questions

1. What type of growing containers and size do you use?

2. What type of growing media do you use?

3. What are your yields for the past 5years?

4. Observation of on-going production system and comments indicated.

Appendix 2: PLANT HEIGHT 2WKS EX1 Analysis of variance

Variate: Plant_height					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	48.07	24.03	1.61	
Rep.*Units* stratum					
Substrate	2	692.83	346.41	23.27	<.001
Growing_bag	2	10.64	5.32	0.36	0.702
Variety	1	135.34	135.34	9.09	0.005
Substrate.Growing_bag	4	19.08	4.77	0.32	0.862
Substrate.Variety	2	44.67	22.34	1.50	0.237
Growing_bag.Variety	2	2.91	1.45	0.10	0.907
Substrate.Growing_bag.Variety	4	3.77	0.94	0.06	0.992
Residual	34	506.22	14.89		
Total	53	1463.54			

Appendix 3: PLANT HEIGHT 2WKS EX2 Analysis of variance

Variate: Plant_height					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	33.60	16.80	1.21	
Rep.*Units* stratum					
Substrate	2	1160.43	580.22	41.64	<.001
Growing_bag	2	142.31	71.16	5.11	0.011
Variety	1	270.35	270.35	19.40	<.001
Substrate.Growing_bag	4	247.57	61.89	4.44	0.005
Substrate.Variety	2	55.60	27.80	2.00	0.152
Growing_bag.Variety	2	109.29	54.65	3.92	0.029
Substrate.Growing_bag.Variety	4	314.52	78.63	5.64	0.001
Residual	34	473.73	13.93		
Total	53	2807.40			

Appendix 4: PLANT HEIGHT 4WKS EX1 Analysis of variance

Variate: Plant_height					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	804.9	402.5	3.25	
Rep.*Units* stratum					
Treatment	2	1888.8	944.4	7.62	0.002
Rate	2	406.3	203.2	1.64	0.209
Variety	1	208.4	208.4	1.68	0.204
Treatment.Rate	4	796.7	199.2	1.61	0.195
Treatment.Variety	2	137.1	68.5	0.55	0.580
Rate.Variety	2	88.7	44.3	0.36	0.702
Treatment.Rate.Variety	4	625.6	156.4	1.26	0.304
Residual	34	4214.8	124.0		
Total	53	9171.3			

Appendix 5: PLANT HEIGHT 4WKS EX2 Analysis of variance

Variate: plant_height_4wks					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	268.71	134.36	4.55	
Rep.*Units* stratum					
Substrate	2	2309.72	1154.86	39.07	<.001
Growing_bag	2	1472.20	736.10	24.90	<.001
Variety	1	2055.10	2055.10	69.53	<.001
Substrate.Growing_bag	4	451.31	112.83	3.82	0.011
Substrate.Variety	2	1344.76	672.38	22.75	<.001
Growing_bag.Variety	2	24.88	12.44	0.42	0.660
Substrate.Growing_bag.Variety	4	1049.28	262.32	8.87	<.001
Residual	34	1004.97	29.56		
Total	53	9980.94			

Appendix 6: PLANT HEIGHT 8WKS EX 1 Analysis of variance

Variate: plant_height					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1893.5	946.7	6.91	
Rep.*Units* stratum					
Substrate	2	6094.6	3047.3	22.24	<.001
Growing_bag	2	2894.8	1447.4	10.57	<.001
Variety	1	2775.7	2775.7	20.26	<.001
Substrate.Growing_bag	4	588.2	147.0	1.07	0.385
Substrate.Variety	2	408.5	204.3	1.49	0.239
Growing_bag.Variety	2	793.9	396.9	2.90	0.069
Substrate.Growing_bag.Variety	4	197.8	49.5	0.36	0.835
Residual	34	4657.6	137.0		
Total	53	20304.6			

Appendix 7: PLANT HEIGHT 8WKS EX2 Analysis of variance

Variate: Plant_Height_8wks					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1750.6	875.3	7.02	
Rep.*Units* stratum					
Substrate	2	3390.6	1695.3	13.60	<.001
Growing_bag	2	4508.3	2254.1	18.08	<.001
Variety	1	5219.7	5219.7	41.87	<.001
Substrate.Growing_bag	4	865.8	216.5	1.74	0.165
Substrate.Variety	2	5839.7	2919.8	23.42	<.001
Growing_bag.Variety	2	289.7	144.9	1.16	0.325
Substrate.Growing_bag.Variety	4	3468.1	867.0	6.95	<.001
Residual	34	4238.9	124.7		
Total	53	29571.5			

Appendix 8: STEM GIRTH 2WKS EX1 Analysis of variance

Variate: Stem_girth					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.012515	0.006257	1.42	
Rep.*Units* stratum					
Substrate	2	0.215559	0.107780	24.48	<.001
Growing_bag	2	0.019604	0.009802	2.23	0.123
Variety	1	0.380017	0.380017	86.32	<.001
Substrate.Growing_bag	4	0.024985	0.006246	1.42	0.249
Substrate.Variety	2	0.008744	0.004372	0.99	0.381
Growing_bag.Variety	2	0.012878	0.006439	1.46	0.246
Substrate.Growing_bag.Variety	4	0.026911	0.006728	1.53	0.216
Residual	34	0.149685	0.004403		
Total	53	0.850898			

Appendix 9: STEM GIRTH 2WKS EX2 Analysis of variance

Variate: Stem_girth					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.014826	0.007413	0.94	
Rep.*Units* stratum					
Substrate	2	0.704395	0.352198	44.48	<.001
Growing_bag	2	0.040451	0.020225	2.55	0.093
Variety	1	3.996224	3.996224	504.71	<.001
Substrate.Growing_bag	4	0.111349	0.027837	3.52	0.017
Substrate.Variety	2	0.188751	0.094375	11.92	<.001
Growing_bag.Variety	2	0.006540	0.003270	0.41	0.665
Substrate.Growing_bag.Variety	4	0.009994	0.002498	0.32	0.866
Residual	34	0.269207	0.007918		
Total	53	5.341737			

Appendix 10: STEM GIRTH 4WKS EX1 Analysis of variance

Variate: Stem_girth					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1.1023	0.5512	1.87	
Rep.*Units* stratum					
Substrate	2	0.7698	0.3849	1.31	0.284
Growing_bag	2	13.4136	6.7068	22.77	<.001
Variety	1	14.5393	14.5393	49.37	<.001
Substrate.Growing_bag	4	0.6485	0.1621	0.55	0.700
Substrate.Variety	2	0.2411	0.1206	0.41	0.667
Growing_bag.Variety	2	1.9510	0.9755	3.31	0.049
Substrate.Growing_bag.Variety	4	0.7692	0.1923	0.65	0.629
Residual	34	10.0134	0.2945		
Total	53	43.4482			

Appendix 11: STEM GIRTH 4WKS EX 2 Analysis of variance

Variate: Stem_girth_4wks					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.03714	0.01857	0.83	
Rep.*Units* stratum					
Substrate	2	0.12181	0.06091	2.72	0.080
Growing_bag	2	0.25653	0.12827	5.72	0.007
Variety	1	7.34827	7.34827	327.82	<.001
Substrate.Growing_bag	4	0.34096	0.08524	3.80	0.012
Substrate.Variety	2	0.20514	0.10257	4.58	0.017
Growing_bag.Variety	2	0.11253	0.05627	2.51	0.096
Substrate.Growing_bag.Variety	4	0.11562	0.02891	1.29	0.294
Residual	34	0.76212	0.02242		
Total	53	9.30013			

Appendix 12: STEM GIRTH 8WKS EX1 Analysis of variance

Variate: Stem_girth					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.3925	0.1963	0.22	
Rep.*Units* stratum					
Substrate	2	0.6779	0.3390	0.37	0.690
Growing_bag	2	1.6543	0.8272	0.91	0.410
Variety	1	0.2387	0.2387	0.26	0.611
Substrate.Growing_bag	4	5.9799	1.4950	1.65	0.184
Substrate.Variety	2	0.4340	0.2170	0.24	0.788
Growing_bag.Variety	2	0.0208	0.0104	0.01	0.989
Substrate.Growing_bag.Variety	4	0.2335	0.0584	0.06	0.992
Residual	34	30.7442	0.9042		
Total	53	40.3759			

Appendix 13: STEM GIRTH 8WKS EX2 Analysis of variance

Variate: Stem_girth_8_wks					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.1245	0.0622	0.50	
Rep.*Units* stratum					
Substrate	2	0.0558	0.0279	0.23	0.799
Growing_bag	2	0.6218	0.3109	2.51	0.096
Variety	1	13.4002	13.4002	108.28	<.001
Substrate.Growing_bag	4	0.7232	0.1808	1.46	0.236
Substrate.Variety	2	0.4219	0.2110	1.70	0.197
Growing_bag.Variety	2	0.2659	0.1330	1.07	0.353
Substrate.Growing_bag.Variety	4	0.6348	0.1587	1.28	0.296
Residual	34	4.2075	0.1237		
Total	53	20.4554			

Appendix 14: TRANSFORMED LEAF NUMBER 2WKS EX 1 Analysis of variance

Variate: Leaf_number					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	74.98	37.49	2.62	
Rep.*Units* stratum					
Substrate	2	824.39	412.20	28.79	<.001
Growing_bag	2	33.67	16.84	1.18	0.321
Variety	1	186.86	186.86	13.05	<.001
Substrate.Growing_bag	4	77.46	19.36	1.35	0.271
Substrate.Variety	2	0.23	0.12	0.01	0.992
Growing_bag.Variety	2	3.24	1.62	0.11	0.893
Substrate.Growing_bag.Variety	4	11.52	2.88	0.20	0.936
Residual	34	486.82	14.32		
Total	53	1699.16			

Appendix 15: TRANSFORMED LEAF NUMBER 2WKS EX2 Analysis of variance

Variate: leaf_number					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.0093	0.0046	0.01	
Rep.*Units* stratum					
Substrate	2	16.4537	8.2269	14.11	<.001
Growing_bag	2	1.7870	0.8935	1.53	0.231
Variety	1	3.3750	3.3750	5.79	0.022
Substrate.Growing_bag	4	4.8519	1.2130	2.08	0.105
Substrate.Variety	2	4.0833	2.0417	3.50	0.041
Growing_bag.Variety	2	4.0833	2.0417	3.50	0.041
Substrate.Growing_bag.Variety	4	6.3333	1.5833	2.72	0.046
Residual	34	19.8241	0.5831		
Total	53	60.8009			

Appendix 16: TRANSFORMED LEAF NUMBER 4WKS EX 1 Analysis of variance

Variate: leaf_number					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	9694.	4847.	2.12	
Rep.*Units* stratum					
Substrate	2	10277.	5139.	2.25	0.121
Growing_bag	2	4484.	2242.	0.98	0.385
Variety	1	691.	691.	0.30	0.586
Substrate.Growing_bag	4	11010.	2753.	1.20	0.327
Substrate.Variety	2	631.	316.	0.14	0.871
Growing_bag.Variety	2	2340.	1170.	0.51	0.604
Substrate.Growing_bag.Variety	4	6357.	1589.	0.70	0.600
Residual	34	77709.	2286.		
Total	53	123194.			

Appendix 17: TRANSFORMED LEAF NUMBER 4WKS EX2
Analysis of variance

Variate: Leaf_number_4wks					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	8.898	4.449	1.58	
Rep.*Units* stratum					
Substrate	2	63.954	31.977	11.37	<.001
Growing_bag	2	27.620	13.810	4.91	0.013
Variety	1	120.005	120.005	42.68	<.001
Substrate.Growing_bag	4	39.574	9.894	3.52	0.017
Substrate.Variety	2	12.954	6.477	2.30	0.115
Growing_bag.Variety	2	2.843	1.421	0.51	0.608
Substrate.Growing_bag.Variety	4	31.574	7.894	2.81	0.041
Residual	34	95.602	2.812		
Total	53	403.023			

Appendix 18: LEAF NUMBER 8WKS EX 1
Analysis of variance

Variate: leaf_number					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	2914.	1457.	0.39	
Rep.*Units* stratum					
Substrate	2	786.	393.	0.11	0.900
Growing_bag	2	17811.	8905.	2.39	0.107
Variety	1	4502.	4502.	1.21	0.279
Substrate.Growing_bag	4	10178.	2545.	0.68	0.608
Substrate.Variety	2	3285.	1642.	0.44	0.647
Growing_bag.Variety	2	7644.	3822.	1.03	0.369
Substrate.Growing_bag.Variety	4	2654.	664.	0.18	0.948
Residual	34	126555.	3722.		
Total	53	176329.			

Appendix 19 : LEAF NUMBER 8WKS EX2
Analysis of variance

Variate: Leaf_Number_8k					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Substrate	2	65.778	32.889	7.25	0.002
Growing_bag	2	52.333	26.167	5.77	0.007
Variety	1	262.241	262.241	57.80	<.001
Substrate.Growing_bag	4	91.556	22.889	5.04	0.002
Substrate.Variety	2	41.926	20.963	4.62	0.016
Growing_bag.Variety	2	3.370	1.685	0.37	0.692
Substrate.Growing_bag.Variety	4	140.296	35.074	7.73	<.001
Residual	36	163.333	4.537		
Total	53	820.833			

Appendix 20: CHLOROPHYLL CONTENT 2WKS EX1

Variate: Chlorophyll content					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	5.914	2.957	1.11	
Rep.*Units* stratum					
Substrate	2	0.356	0.178	0.07	0.936
Growing_bag	2	4.201	2.101	0.79	0.464
Variety	1	204.945	204.945	76.71	<.001
Substrate.Growing_bag	4	20.445	5.111	1.91	0.131
Substrate.Variety	2	0.016	0.008	0.00	0.997
Growing_bag.Variety	2	0.117	0.059	0.02	0.978
Substrate.Growing_bag.Variety	4	10.012	2.503	0.94	0.454
Residual	34	90.833	2.672		
Total	53	336.839			

Appendix 21: CHLOROPHYLL CONTENT 2WKS EX2

Variate: chlorophyll					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.825	0.412	0.15	
Rep.*Units* stratum					
Substrate	2	87.359	43.679	15.79	<.001
Growing_bag	2	6.299	3.150	1.14	0.332
Variety	1	60.505	60.505	21.88	<.001
Substrate.Growing_bag	4	97.409	24.352	8.81	<.001
Substrate.Variety	2	130.466	65.233	23.59	<.001
Growing_bag.Variety	2	67.798	33.899	12.26	<.001
Substrate.Growing_bag.Variety	4	88.221	22.055	7.98	<.001
Residual	34	94.024	2.765		
Total	53	632.905			

Appendix 22: CHLOROPHYLL CONTENT 4WKS EX1

Variate: chlorophyll_content					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	104.42	52.21	1.09	
Rep.*Units* stratum					
Substrate	2	3596.46	1798.23	37.63	<.001
Growing_bag	2	365.57	182.78	3.82	0.032
Variety	1	3996.08	3996.08	83.62	<.001
Substrate.Growing_bag	4	711.50	177.88	3.72	0.013
Substrate.Variety	2	694.80	347.40	7.27	0.002
Growing_bag.Variety	2	39.91	19.95	0.42	0.662
Substrate.Growing_bag.Variety	4	209.73	52.43	1.10	0.374
Residual	34	1624.87	47.79		
Total	53	11343.34			

Appendix 23: CHLOROPHYLL CONTENT 4WKS EX2
Analysis of variance

Variate: chlorrophyll_4wks					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	8.392	4.196	0.68	
Rep.*Units* stratum					
Substrate	2	17.781	8.890	1.45	0.249
Growing_bag	2	266.579	133.289	21.75	<.001
Variety	1	536.823	536.823	87.61	<.001
Substrate.Growing_bag	4	111.689	27.922	4.56	0.005
Substrate.Variety	2	53.831	26.915	4.39	0.020
Growing_bag.Variety	2	124.652	62.326	10.17	<.001
Substrate.Growing_bag.Variety	4	45.753	11.438	1.87	0.139
Residual	34	208.336	6.128		
Total	53	1373.835			

Appendix 24: CHLOROPHYLL CONTENT 8WKS EX1
Analysis of variance

Variate: chlorophyll					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	125.238	62.619	25.24	
Rep.*Units* stratum					
Substrate	2	4.898	2.449	0.99	0.383
Growing_bag	2	4.898	2.449	0.99	0.383
Variety	1	70.956	70.956	28.60	<.001
Substrate.Growing_bag	4	39.185	9.796	3.95	0.010
Substrate.Variety	2	2.196	1.098	0.44	0.646
Growing_bag.Variety	2	2.196	1.098	0.44	0.646
Substrate.Growing_bag.Variety	4	17.567	4.392	1.77	0.158
Residual	34	84.342	2.481		
Total	53	351.476			

Appendix 25: CHLOROPHYLL CONTENT 8WKS EX2
Analysis of variance

Variate: chlorophyll_8wks					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	350.39	175.19	7.35	
Rep.*Units* stratum					
Substrate	2	225.79	112.90	4.74	0.015
Growing_bag	2	888.95	444.47	18.66	<.001
Variety	1	2112.13	2112.13	88.65	<.001
Substrate.Growing_bag	4	723.46	180.87	7.59	<.001
Substrate.Variety	2	87.78	43.89	1.84	0.174
Growing_bag.Variety	2	108.60	54.30	2.28	0.118
Substrate.Growing_bag.Variety	4	267.95	66.99	2.81	0.041
Residual	34	810.03	23.82		
Total	53	5575.07			

Appendix 26: ROOT LENGTH AT VEG EX 1 Analysis of variance

Variate: Root_Length					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	3.20	1.60	0.10	
REP.*Units* stratum					
TREATMENT	2	444.73	222.37	14.51	<.001
Growing_bags	2	2.72	1.36	0.09	0.915
Variety	1	58.91	58.91	3.85	0.058
TREATMENT.Growing_bags	4	54.88	13.72	0.90	0.477
TREATMENT.Variety	2	27.43	13.71	0.90	0.418
Growing_bags.Variety	2	51.86	25.93	1.69	0.199
TREATMENT.Growing_bags.Variety	4	29.96	7.49	0.49	0.744
Residual	34	520.89	15.32		
Total	53	1194.59			

Appendix 27: ROOT LENGTH AT VEG EX 2 Analysis of variance

Variate: root_length					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	26.140	13.070	1.91	
Rep.*Units* stratum					
Substrate	2	379.624	189.812	27.77	<.001
Growing_bag	2	13.347	6.673	0.98	0.387
Variety	1	7.676	7.676	1.12	0.297
Substrate.Growing_bag	4	173.046	43.262	6.33	<.001
Substrate.Variety	2	41.260	20.630	3.02	0.062
Growing_bag.Variety	2	18.423	9.211	1.35	0.273
Substrate.Growing_bag.Variety	4	49.284	12.321	1.80	0.151
Residual	34	232.432	6.836		
Total	53	941.233			

Appendix 28: ROOT LENGTH REP EX1 Analysis of variance

Variate: Root_Length					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	20.06	10.03	0.27	
REP.*Units* stratum					
TREATMENT	2	541.83	270.91	7.34	0.002
Growing_bags	2	466.39	233.20	6.32	0.005
Variety	1	28.89	28.89	0.78	0.382
TREATMENT.Growing_bags	4	134.52	33.63	0.91	0.469
TREATMENT.Variety	2	118.18	59.09	1.60	0.217
Growing_bags.Variety	2	360.78	180.39	4.89	0.014
TREATMENT.Growing_bags.Variety	4	81.88	20.47	0.55	0.697
Residual	34	1254.90	36.91		
Total	53	3007.43			

Appendix 29: ROOT LENGTH REP EX2 Analysis of variance

Variate: root_length					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	62.529	31.264	3.68	
Rep.*Units* stratum					
Substrates	2	141.984	70.992	8.36	0.001
Growing_bag	2	30.789	15.394	1.81	0.179
variety	1	0.017	0.017	0.00	0.965
Substrates.Growing_bag	4	277.553	69.388	8.17	<.001
Substrates.variety	2	81.024	40.512	4.77	0.015
Growing_bag.variety	2	106.068	53.034	6.25	0.005
Substrates.Growing_bag.variety	4	185.498	46.374	5.46	0.002
Residual	34	288.696	8.491		
Total	53	1174.157			

Appendix 30: FRESH ROOT WEIGHT VEG EX1 Analysis of variance

Variate: Root_Fresh_Weight					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	86.003	43.001	5.75	
REP.*Units* stratum					
TREATMENT	2	144.196	72.098	9.65	<.001
Growing_bags	2	9.238	4.619	0.62	0.545
Variety	1	96.000	96.000	12.84	0.001
TREATMENT.Growing_bags	4	18.044	4.511	0.60	0.663
TREATMENT.Variety	2	2.694	1.347	0.18	0.836
Growing_bags.Variety	2	3.914	1.957	0.26	0.771
TREATMENT.Growing_bags.Variety	4	23.574	5.894	0.79	0.541
Residual	34	254.111	7.474		
Total	53	637.775			

Appendix 31: FRESH ROOT WEIGHT VEG EX 2 Analysis of variance

Variate: fresh_root_weight					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	5.7048	2.8524	3.24	
Rep.*Units* stratum					
Substrate	2	33.2179	16.6089	18.85	<.001
Growing_bag	2	6.4848	3.2424	3.68	0.036
Variety	1	0.0474	0.0474	0.05	0.818
Substrate.Growing_bag	4	50.7630	12.6907	14.41	<.001
Substrate.Variety	2	2.7556	1.3778	1.56	0.224
Growing_bag.Variety	2	0.3848	0.1924	0.22	0.805
Substrate.Growing_bag.Variety	4	16.4696	4.1174	4.67	0.004
Residual	34	29.9519	0.8809		
Total	53	145.7798			

Appendix 32: FRESH ROOT WEIGHT AT REP EX 1 Analysis of variance

Variate: Root_Fresh_Weight					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	142.18	71.09	2.61	
REP.*Units* stratum					
TREATMENT	2	372.37	186.18	6.82	0.003
Growing_bags	2	17.06	8.53	0.31	0.734
Variety	1	0.02	0.02	0.00	0.977
TREATMENT.Growing_bags	4	26.55	6.64	0.24	0.912
TREATMENT.Variety	2	1.23	0.62	0.02	0.978
Growing_bags.Variety	2	20.84	10.42	0.38	0.686
TREATMENT.Growing_bags.Variety	4	20.23	5.06	0.19	0.944
Residual	34	927.84	27.29		
Total	53	1528.31			

Appendix 33: FRESH ROOT WEIGHT REP EX 2 Analysis of variance

Variate: fresh_root_weight					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	4.280	2.140	0.69	
Rep.*Units* stratum					
Substrates	2	36.616	18.308	5.88	0.006
Growing_bag	2	9.841	4.921	1.58	0.221
variety	1	13.202	13.202	4.24	0.047
Substrates.Growing_bag	4	2.492	0.623	0.20	0.937
Substrates.variety	2	6.534	3.267	1.05	0.361
Growing_bag.variety	2	9.738	4.869	1.56	0.224
Substrates.Growing_bag.variety	4	68.811	17.203	5.52	0.002
Residual	34	105.893	3.114		
Total	53	257.408			

Appendix 34: FRESH SHOOT WEIGHT VEG EX 1 Analysis of variance

Variate: Shoot_Fresh_Weight					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	543.7	271.9	2.72	
REP.*Units* stratum					
TREATMENT	2	1780.8	890.4	8.90	<.001
Growing_bags	2	222.2	111.1	1.11	0.341
Variety	1	922.6	922.6	9.22	0.005
TREATMENT.Growing_bags	4	349.4	87.3	0.87	0.490
TREATMENT.Variety	2	381.9	190.9	1.91	0.164
Growing_bags.Variety	2	2.8	1.4	0.01	0.986
TREATMENT.Growing_bags.Variety	4	298.1	74.5	0.74	0.568
Residual	34	3403.1	100.1		
Total	53	7904.5			

Appendix 35: FRESH SHOOT WEIGHT VEG EX 2 Analysis of variance

Variate: fresh_shoot_weight					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	158.00	79.00	3.86	
Rep.*Units* stratum					
Substrate	2	754.67	377.33	18.42	<.001
Growing_bag	2	39.52	19.76	0.96	0.391
Variety	1	1215.53	1215.53	59.33	<.001
Substrate.Growing_bag	4	76.24	19.06	0.93	0.458
Substrate.Variety	2	415.79	207.90	10.15	<.001
Growing_bag.Variety	2	12.28	6.14	0.30	0.743
Substrate.Growing_bag.Variety	4	149.70	37.43	1.83	0.146
Residual	34	696.58	20.49		
Total	53	3518.31			

Appendix 36: FRESH SHOOT WEIGHT REP EX 1 Analysis of variance

Variate: Shoot_Fresh_Weight					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	378.6	189.3	0.71	
REP.*Units* stratum					
TREATMENT	2	2378.2	1189.1	4.45	0.019
Growing_bags	2	2300.8	1150.4	4.30	0.022
Variety	1	29.6	29.6	0.11	0.741
TREATMENT.Growing_bags	4	894.5	223.6	0.84	0.512
TREATMENT.Variety	2	312.9	156.5	0.59	0.563
Growing_bags.Variety	2	459.3	229.6	0.86	0.433
TREATMENT.Growing_bags.Variety	4	1442.8	360.7	1.35	0.272
Residual	34	9092.8	267.4		
Total	53	17289.6			

Appendix 37: DRY ROOT WEIGHT VEG EX1 Analysis of variance

Variate: Root_Dry_Weight					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.22231	0.11116	1.31	
REP.*Units* stratum					
TREATMENT	2	0.36231	0.18116	2.14	0.134
Growing_bags	2	0.15815	0.07907	0.93	0.404
Variety	1	0.00782	0.00782	0.09	0.763
TREATMENT.Growing_bags	4	0.29463	0.07366	0.87	0.493
TREATMENT.Variety	2	0.14287	0.07144	0.84	0.440
Growing_bags.Variety	2	0.19593	0.09796	1.15	0.327
TREATMENT.Growing_bags.Variety	4	0.23463	0.05866	0.69	0.603
Residual	34	2.88435	0.08483		
Total	53	4.50301			

Appendix 38: DRY ROOT WEIGHT VEG EX 2 Analysis of variance

Variate: dry_root_weight					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.7004	0.3502	1.53	
Rep.*Units* stratum					
Substrates	2	0.4039	0.2019	0.88	0.423
Growing_bag	2	0.6440	0.3220	1.41	0.258
variety	1	0.5241	0.5241	2.29	0.139
Substrates.Growing_bag	4	0.4244	0.1061	0.46	0.761
Substrates.variety	2	0.4352	0.2176	0.95	0.396
Growing_bag.variety	2	0.5213	0.2606	1.14	0.332
Substrates.Growing_bag.variety	4	1.9903	0.4976	2.18	0.093
Residual	34	7.7697	0.2285		
Total	53	13.4133			

Appendix 39: DRY ROOT WEIGHT REP EX1 Analysis of variance

Variate: Root_Dry_Weight					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	1.5411	0.7706	1.85	
REP.*Units* stratum					
TREATMENT	2	3.4533	1.7267	4.16	0.024
Growing_bags	2	0.1733	0.0867	0.21	0.813
Variety	1	2.0030	2.0030	4.82	0.035
TREATMENT.Growing_bags	4	1.1567	0.2892	0.70	0.600
TREATMENT.Variety	2	0.1348	0.0674	0.16	0.851
Growing_bags.Variety	2	0.6237	0.3119	0.75	0.480
TREATMENT.Growing_bags.Variety	4	0.5219	0.1305	0.31	0.867
Residual	34	14.1256	0.4155		
Total	53	23.7333			

Appendix 40: DRY ROOT WEIGHT REP EX 2 Analysis of variance

Variate: dry_root_weight					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	0.62370	0.31185	14.67	
Replication.*Units* stratum					
Treatment	2	0.01148	0.00574	0.27	0.765
Growing_bag	2	0.00259	0.00130	0.06	0.941
Variety	1	0.00000	0.00000	0.00	1.000
Treatment.Growing_bag	4	0.06963	0.01741	0.82	0.522
Treatment.Variety	2	0.12111	0.06056	2.85	0.072
Growing_bag.Variety	2	0.02111	0.01056	0.50	0.613
Treatment.Growing_bag.Variety	4	0.19778	0.04944	2.33	0.076
Residual	34	0.72296	0.02126		
Total	53	1.77037			

Appendix 41: DRY SHOOT WEIGHT VEG EX1 Analysis of variance

Variate: Shoot_Dry_Weight					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.0226	0.0113	0.07	
REP.*Units* stratum					
TREATMENT	2	2.9183	1.4592	8.93	<.001
Growing_bags	2	0.3506	0.1753	1.07	0.353
Variety	1	0.3520	0.3520	2.16	0.151
TREATMENT.Growing_bags	4	0.3267	0.0817	0.50	0.736
TREATMENT.Variety	2	1.1345	0.5672	3.47	0.042
Growing_bags.Variety	2	0.1539	0.0769	0.47	0.628
TREATMENT.Growing_bags.Variety	4	0.2255	0.0564	0.35	0.845
Residual	34	5.5530	0.1633		
Total	53	11.0371			

Appendix 42 : DRY SHOOT WEIGHT VEG EX2 Analysis of variance

Variate: dry_shoot_weight					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.7526	0.3763	1.96	
Rep.*Units* stratum					
Substrates	2	0.0848	0.0424	0.22	0.803
Growing_bag	2	0.1159	0.0580	0.30	0.741
variety	1	0.0000	0.0000	0.00	1.000
Substrates.Growing_bag	4	2.0219	0.5055	2.63	0.051
Substrates.variety	2	1.1478	0.5739	2.99	0.064
Growing_bag.variety	2	1.7411	0.8706	4.53	0.018
Substrates.Growing_bag.variety	4	2.5878	0.6469	3.37	0.020
Residual	34	6.5274	0.1920		
Total	53	14.9793			

Appendix 43: DRY SHOOT WEIGHT REP EX1 Analysis of variance

Variate: Shoot_Dry_Weight					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	5.201	2.601	0.87	
REP.*Units* stratum					
TREATMENT	2	37.690	18.845	6.29	0.005
Growing_bags	2	2.267	1.134	0.38	0.688
Variety	1	16.667	16.667	5.56	0.024
TREATMENT.Growing_bags	4	7.270	1.817	0.61	0.660
TREATMENT.Variety	2	5.613	2.807	0.94	0.402
Growing_bags.Variety	2	11.290	5.645	1.88	0.167
TREATMENT.Growing_bags.Variety	4	11.053	2.763	0.92	0.462
Residual	34	101.839	2.995		
Total	53	198.890			

Appendix 44: DRY SHOOT WEIGHT REP EX2 Analysis of variance

Variate: fresh_shoot_weight					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	115.88	57.94	1.76	
Rep.*Units* stratum					
Substrates	2	2601.34	1300.67	39.49	<.001
Growing_bag	2	1748.97	874.49	26.55	<.001
variety	1	1216.95	1216.95	36.95	<.001
Substrates.Growing_bag	4	677.39	169.35	5.14	0.002
Substrates.variety	2	85.61	42.80	1.30	0.286
Growing_bag.variety	2	521.16	260.58	7.91	0.002
Substrates.Growing_bag.variety	4	1473.75	368.44	11.19	<.001
Residual	34	1119.78	32.93		
Total	53	9560.83			

Appendix 45: SHOOT ROOT RATIO VEG EX 1 Analysis of variance

Variate: Shoot_root_ratio					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	5.610	2.805	1.49	
REP.*Units* stratum					
TREATMENT	2	9.105	4.552	2.42	0.105
Growing_bags	2	8.811	4.406	2.34	0.112
Variety	1	1.889	1.889	1.00	0.324
TREATMENT.Growing_bags	4	8.747	2.187	1.16	0.345
TREATMENT.Variety	2	1.589	0.795	0.42	0.659
Growing_bags.Variety	2	1.700	0.850	0.45	0.641
TREATMENT.Growing_bags.Variety	4	1.456	0.364	0.19	0.940
Residual	34	64.083	1.885		
Total	53	102.992			

Appendix 46: SHOOT ROOT VEG EX 2 Analysis of variance

Variate: Shoot_root_ratio					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.11007	0.05504	0.58	
Rep.*Units* stratum					
Substrates	2	0.09407	0.04703	0.49	0.615
Growing_bag	2	0.18033	0.09016	0.94	0.399
variety	1	0.04484	0.04484	0.47	0.498
Substrates.Growing_bag	4	0.54089	0.13522	1.42	0.250
Substrates.variety	2	0.51350	0.25675	2.69	0.082
Growing_bag.variety	2	0.49058	0.24529	2.57	0.091
Substrates.Growing_bag.variety	4	0.29035	0.07259	0.76	0.559
Residual	34	3.24715	0.09550		
Total	53	5.51177			

Appendix 47: SHOOT ROOT REP EX 1 Analysis of variance

Variate: Shoot_root_ratio					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	18.651	9.326	2.97	
REP.*Units* stratum					
TREATMENT	2	4.145	2.072	0.66	0.524
Growing_bags	2	5.523	2.761	0.88	0.425
Variety	1	1.014	1.014	0.32	0.574
TREATMENT.Growing_bags	4	6.199	1.550	0.49	0.741
TREATMENT.Variety	2	5.525	2.762	0.88	0.425
Growing_bags.Variety	2	0.525	0.262	0.08	0.920
TREATMENT.Growing_bags.Variety	4	6.136	1.534	0.49	0.744
Residual	34	106.875	3.143		
Total	53	154.593			

Appendix 48 : SHOOT ROOT REP EX 2 Analysis of variance

Variate: Shoot_root_ratio					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	18.651	9.326	2.97	
REP.*Units* stratum					
TREATMENT	2	4.145	2.072	0.66	0.524
Growing_bags	2	5.523	2.761	0.88	0.425
Variety	1	1.014	1.014	0.32	0.574
TREATMENT.Growing_bags	4	6.199	1.550	0.49	0.741
TREATMENT.Variety	2	5.525	2.762	0.88	0.425
Growing_bags.Variety	2	0.525	0.262	0.08	0.920
TREATMENT.Growing_bags.Variety	4	6.136	1.534	0.49	0.744
Residual	34	106.875	3.143		
Total	53	154.593			

Appendix 49: LAR EX 1 Analysis of variance

Variate: LAR					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	338390.	169195.	1.35	
Rep.*Units* stratum					
Substrates	2	1698203.	849101.	6.76	0.003
Growing_bag_sizes	2	2405204.	1202602.	9.58	<.001
Variety	1	733950.	733950.	5.84	0.021
Substrates.Growing_bag_sizes	4	4644614.	1161154.	9.25	<.001
Substrates.Variety	2	3427.	1713.	0.01	0.986
Growing_bag_sizes.Variety	2	14179.	7090.	0.06	0.945
Substrates.Growing_bag_sizes.Variety	4	917544.	229386.	1.83	0.146
Residual	34	4269385.	125570.		
Total	53	15024896.			

Appendix 50: LAR EX 2 Analysis of variance

Variate: LAR					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	227788.	113894.	0.43	
Rep.*Units* stratum					
Substrates	2	1388636.	694318.	2.60	0.089
Growing_bag_sizes	2	297178.	148589.	0.56	0.579
Variety	1	282172.	282172.	1.05	0.312
Substrates.Growing_bag_sizes	4	2461816.	615454.	2.30	0.079
Substrates.Variety	2	179233.	89617.	0.34	0.718
Growing_bag_sizes.Variety	2	736486.	368243.	1.38	0.266
Substrates.Growing_bag_sizes.Variety	4	502008.	125502.	0.47	0.758
Residual	34	9094345.	267481.		
Total	53	15169663.			

Appendix 51: LWR EX 1 Analysis of variance

Variate: LWR					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.0023815	0.0011907	1.23	
Rep.*Units* stratum					
Substrates	2	0.1069370	0.0534685	55.28	<.001
Growing_bag_sizes	2	0.0706259	0.0353130	36.51	<.001
Variety	1	0.0054000	0.0054000	5.58	0.024
Substrates.Growing_bag_sizes	4	0.0831296	0.0207824	21.49	<.001
Substrates.Variety	2	0.1041444	0.0520722	53.84	<.001
Growing_bag_sizes.Variety	2	0.0390111	0.0195056	20.17	<.001
Substrates.Growing_bag_sizes.Variety	4	0.0116111	0.0029028	3.00	0.032
Residual	34	0.0328852	0.0009672		
Total	53	0.4561259			

Appendix 52: LWR EX 2 Analysis of variance

Variate: LWR					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.003293	0.001646	0.37	
Rep.*Units* stratum					
Substrates	2	0.128604	0.064302	14.46	<.001
Growing_bag_sizes	2	0.004281	0.002141	0.48	0.622
Variety	1	0.007585	0.007585	1.71	0.200
Substrates.Growing_bag_sizes	4	0.041630	0.010407	2.34	0.075
Substrates.Variety	2	0.030381	0.015191	3.42	0.044
Growing_bag_sizes.Variety	2	0.066548	0.033274	7.48	0.002
Substrates.Growing_bag_sizes.Variety	4	0.080985	0.020246	4.55	0.005
Residual	34	0.151174	0.004446		
Total	53	0.514481			

Appendix 53: NAR EX 1 Analysis of variance

Variate: NAR					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.04327	0.02164	1.10	
Rep.*Units* stratum					
Substrates	2	41.25160	20.62580	1050.66	<.001
Growing_bag_sizes	2	82.27003	41.13501	2095.38	<.001
Variety	1	1.17631	1.17631	59.92	<.001
Substrates.Growing_bag_sizes	4	28.75897	7.18974	366.24	<.001
Substrates.Variety	2	1.12003	0.56001	28.53	<.001
Growing_bag_sizes.Variety	2	9.88900	4.94450	251.87	<.001
Substrates.Growing_bag_sizes.Variety	4	9.76497	2.44124	124.35	<.001
Residual	34	0.66746	0.01963		
Total	53	174.94165			

Appendix 54: NAR EX 2 Analysis of variance

Variate: NAR					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.016044	0.008022	2.01	
Rep.*Units* stratum					
Substrates	2	42.372033	21.186017	5300.83	<.001
Growing_bag_sizes	2	81.048844	40.524422	10139.39	<.001
Variety	1	0.794491	0.794491	198.79	<.001
Substrates.Growing_bag_sizes	4	29.964022	7.491006	1874.28	<.001
Substrates.Variety	2	1.120404	0.560202	140.16	<.001
Growing_bag_sizes.Variety	2	9.643570	4.821785	1206.43	<.001
Substrates.Growing_bag_sizes.Variety	4	10.514985	2.628746	657.72	<.001
Residual	34	0.135889	0.003997		
Total	53	175.610283			

Appendix 55: RGR EX 1 Analysis of variance

Variate: RGR					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.00013704	0.00006852	0.81	
Rep.*Units* stratum					
Substrates	2	0.00235926	0.00117963	14.01	<.001
Growing_bag_sizes	2	0.02703704	0.01351852	160.54	<.001
Variety	1	0.00145185	0.00145185	17.24	<.001
Substrates.Growing_bag_sizes	4	0.01805185	0.00451296	53.60	<.001
Substrates.Variety	2	0.00427037	0.00213519	25.36	<.001
Growing_bag_sizes.Variety	2	0.00219259	0.00109630	13.02	<.001
Substrates.Growing_bag_sizes.Variety	4	0.01718519	0.00429630	51.02	<.001
Residual	34	0.00286296	0.00008420		
Total	53	0.07554815			

Appendix 56: RGR EX 2 Analysis of variance

Variate: RGR					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.0000148	0.0000074	0.04	
Rep.*Units* stratum					
Substrates	2	0.0016037	0.0008019	4.71	0.016
Growing_bag_sizes	2	0.0273037	0.0136519	80.23	<.001
Variety	1	0.0032667	0.0032667	19.20	<.001
Substrates.Growing_bag_sizes	4	0.0185185	0.0046296	27.21	<.001
Substrates.Variety	2	0.0040778	0.0020389	11.98	<.001
Growing_bag_sizes.Variety	2	0.0027111	0.0013556	7.97	0.001
Substrates.Growing_bag_sizes.Variety	4	0.0102444	0.0025611	15.05	<.001
Residual	34	0.0057852	0.0001702		
Total	53	0.0735259			

Appendix 57: SLA EX 1. Analysis of variance

Variate: SLA					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.000E+00	0.000E+00	0.00	
Rep.*Units* stratum					
Substrates	2	3.736E+07	1.868E+07	1.270E+09	<.001
Growing_bag_sizes	2	1.962E+07	9.810E+06	6.671E+08	<.001
Variety	1	8.795E+07	8.795E+07	5.980E+09	<.001
Substrates.Growing_bag_sizes	4	1.120E+06	2.801E+05	1.905E+07	<.001
Substrates.Variety	2	2.609E+07	1.304E+07	8.870E+08	<.001
Growing_bag_sizes.Variety	2	1.438E+07	7.191E+06	4.890E+08	<.001
Substrates.Growing_bag_sizes.Variety	4	1.777E+06	4.441E+05	3.020E+07	<.001
Residual	34	5.000E-01	1.471E-02		
Total	53	1.883E+08			

Appendix 58: SLA EX 2 Analysis of variance

Variate: SLA

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	480192.	240096.	0.83	
Rep.*Units* stratum					
Substrates	2	37431136.	18715568.	64.74	<.001
Growing_bag_sizes	2	16426802.	8213401.	28.41	<.001
Variety	1	25575577.	25575577.	88.47	<.001
Substrates.Growing_bag_sizes	4	28961599.	7240400.	25.05	<.001
Substrates.Variety	2	65519522.	32759761.	113.32	<.001
Growing_bag_sizes.Variety	2	3187910.	1593955.	5.51	0.008
Substrates.Growing_bag_sizes.Variety	4	1426372.	356593.	1.23	0.315
Residual	34	9828808.	289083.		
Total	53	188837918.			

Appendix 59: FRUIT NO. EX 1
Analysis of variance

Variate: Number_of_FRUITS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.0370	0.0185	0.03	
REP.*Units* stratum					
TREATMENT	2	1260.5926	630.2963	1150.32	<.001
Growing_bags	2	13.3704	6.6852	12.20	<.001
Variety	1	1.8519	1.8519	3.38	0.075
TREATMENT.Growing_bags	4	10.1852	2.5463	4.65	0.004
TREATMENT.Variety	2	1.0370	0.5185	0.95	0.398
Growing_bags.Variety	2	0.9259	0.4630	0.84	0.438
TREATMENT.Growing_bags.Variety	4	4.1852	1.0463	1.91	0.131
Residual	34	18.6296	0.5479		
Total	53	1310.8148			

Appendix 60: FRUIT NO. EX 2

Analysis of variance

Variate: Number_of_FRUITS					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	2.704	1.352	0.54	
REP.*Units* stratum					
TREATMENT	2	764.481	382.241	152.37	<.001
Growing_bags	2	27.148	13.574	5.41	0.009
Variety	1	2.667	2.667	1.06	0.310
TREATMENT.Growing_bags	4	12.296	3.074	1.23	0.318
TREATMENT.Variety	2	1.000	0.500	0.20	0.820
Growing_bags.Variety	2	10.111	5.056	2.02	0.149
TREATMENT.Growing_bags.Variety	4	3.556	0.889	0.35	0.839
Residual	34	85.296	2.509		
Total	53	909.259			

Appendix 61: FRUIT SIZE EX 1 Analysis of variance

Variate: Fruit_size					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.0002926	0.0001463	0.31	
REP.*Units* stratum					
TREATMENT	2	0.0890037	0.0445019	92.78	<.001
Growing_bags	2	0.0114704	0.0057352	11.96	<.001
Variety	1	0.0046296	0.0046296	9.65	0.004
TREATMENT.Growing_bags	4	0.0310519	0.0077630	16.19	<.001
TREATMENT.Variety	2	0.0039148	0.0019574	4.08	0.026
Growing_bags.Variety	2	0.0010037	0.0005019	1.05	0.362
TREATMENT.Growing_bags.Variety	4	0.0013185	0.0003296	0.69	0.606
Residual	34	0.0163074	0.0004796		
Total	53	0.1589926			

Appendix 62: FRUIT SIZE EX 2 Analysis of variance

Variate: Fruit_size					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.014604	0.007302	0.86	
REP.*Units* stratum					
TREATMENT	2	0.017970	0.008985	1.06	0.359
Growing_bags	2	0.001404	0.000702	0.08	0.921
Variety	1	0.002017	0.002017	0.24	0.629
TREATMENT.Growing_bags	4	0.129996	0.032499	3.82	0.011
TREATMENT.Variety	2	0.005733	0.002867	0.34	0.716
Growing_bags.Variety	2	0.005433	0.002717	0.32	0.729
TREATMENT.Growing_bags.Variety	4	0.003567	0.000892	0.10	0.980
Residual	34	0.289130	0.008504		
Total	53	0.469854			

Appendix 63: FRUIT WEIGHT EX 1 Analysis of variance

Variate: Fruit_weight					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.010033	0.005017	0.63	
REP.*Units* stratum					
TREATMENT	2	0.846533	0.423267	53.20	<.001
Growing_bags	2	0.015878	0.007939	1.00	0.379
Variety	1	0.038400	0.038400	4.83	0.035
TREATMENT.Growing_bags	4	0.197256	0.049314	6.20	<.001
TREATMENT.Variety	2	0.025600	0.012800	1.61	0.215
Growing_bags.Variety	2	0.001144	0.000572	0.07	0.931
TREATMENT.Growing_bags.Variety	4	0.001189	0.000297	0.04	0.997
Residual	34	0.270500	0.007956		
Total	53	1.406533			

Apendix 64: FRUIT WEIGHT EX 2 Analysis of variance

Variate: Fruit_weight					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.000181	0.000091	0.06	
REP.*Units* stratum					
TREATMENT	2	0.036181	0.018091	12.86	<.001
Growing_bags	2	0.025337	0.012669	9.01	<.001
Variety	1	0.013067	0.013067	9.29	0.004
TREATMENT.Growing_bags	4	0.029441	0.007360	5.23	0.002
TREATMENT.Variety	2	0.006211	0.003106	2.21	0.125
Growing_bags.Variety	2	0.000344	0.000172	0.12	0.885
TREATMENT.Growing_bags.Variety	4	0.006678	0.001669	1.19	0.334
Residual	34	0.047819	0.001406		
Total	53	0.165259			

Appendix 65: pH EX 1 Analysis of variance

Variate: pH					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.02501	0.01251	1.08	
REP.*Units* stratum					
TREATMENT	2	207.09188	103.54594	8928.13	<.001
Growing_bags	2	0.01348	0.00674	0.58	0.565
Variety	1	0.02200	0.02200	1.90	0.177
TREATMENT.Growing_bags	4	0.04851	0.01213	1.05	0.398
TREATMENT.Variety	2	0.03400	0.01700	1.47	0.245
Growing_bags.Variety	2	0.02005	0.01002	0.86	0.430
TREATMENT.Growing_bags.Variety	4	0.04623	0.01156	1.00	0.423
Residual	34	0.39432	0.01160		
Total	53	207.69548			

Appendix 66: Total Yield EX 1 Analysis of variance

Variate: Yield					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	31.80	15.90	0.18	
REP.*Units* stratum					
TREATMENT	2	15.58	7.79	0.09	0.916
Growing_bags	2	241.70	120.85	1.37	0.268
Variety	1	59.12	59.12	0.67	0.419
TREATMENT.Growing_bags	4	750.02	187.51	2.12	0.099
TREATMENT.Variety	2	61.65	30.83	0.35	0.708
Growing_bags.Variety	2	409.13	204.56	2.32	0.114
TREATMENT.Growing_bags.Variety	4	231.41	57.85	0.66	0.627
Residual	34	3002.12	88.30		
Total	53	4802.54			

Appendix 67: TOTAL YIELD EX 2
Analysis of variance

Variate: Yield					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.41320	0.20660	2.84	
REP.*Units* stratum					
TREATMENT	2	1.44213	0.72107	9.91	<.001
Growing_bags	2	0.08268	0.04134	0.57	0.572
Variety	1	0.07042	0.07042	0.97	0.332
TREATMENT.Growing_bags	4	0.53069	0.13267	1.82	0.147
TREATMENT.Variety	2	0.30738	0.15369	2.11	0.136
Growing_bags.Variety	2	0.00068	0.00034	0.00	0.995
TREATMENT.Growing_bags.Variety	4	0.26838	0.06709	0.92	0.462
Residual	34	2.47300	0.07274		
Total	53	5.58855			

Appendix 68: pH EX 2 Analysis of variance

Variate: Ph					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.02501	0.01251	1.08	
REP.*Units* stratum					
TREATMENT	2	207.09188	103.54594	8928.13	<.001
Growing_bags	2	0.01348	0.00674	0.58	0.565
Variety	1	0.02200	0.02200	1.90	0.177
TREATMENT.Growing_bags	4	0.04851	0.01213	1.05	0.398
TREATMENT.Variety	2	0.03400	0.01700	1.47	0.245
Growing_bags.Variety	2	0.02005	0.01002	0.86	0.430
TREATMENT.Growing_bags.Variety	4	0.04623	0.01156	1.00	0.423
Residual	34	0.39432	0.01160		
Total	53	207.69548			

Appendix 69: SHELF LIFE EX 1
Analysis of variance

Variate: Shelflife					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.259	0.130	0.02	
REP.*Units* stratum					
TREATMENT	2	2615.259	1307.630	165.64	<.001
Growing_bags	2	6.037	3.019	0.38	0.685
Variety	1	21.407	21.407	2.71	0.109
TREATMENT.Growing_bags	4	93.074	23.269	2.95	0.034
TREATMENT.Variety	2	13.481	6.741	0.85	0.435
Growing_bags.Variety	2	0.259	0.130	0.02	0.984
TREATMENT.Growing_bags.Variety	4	0.185	0.046	0.01	1.000
Residual	34	268.407	7.894		
Total	53	3018.370			

Appendix 70: SHELF LIFE EX 1 Analysis of variance

Variate: Shelflife					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.259	0.130	0.02	
REP.*Units* stratum					
TREATMENT	2	2615.259	1307.630	165.64	<.001
Growing_bags	2	6.037	3.019	0.38	0.685
Variety	1	21.407	21.407	2.71	0.109
TREATMENT.Growing_bags	4	93.074	23.269	2.95	0.034
TREATMENT.Variety	2	13.481	6.741	0.85	0.435
Growing_bags.Variety	2	0.259	0.130	0.02	0.984
TREATMENT.Growing_bags.Variety	4	0.185	0.046	0.01	1.000
Residual	34	268.407	7.894		
Total	53	3018.370			

Appendix 71: SHELF LIFE EX 2 Analysis of variance

Variate: Shelflife					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.259	0.130	0.02	
REP.*Units* stratum					
TREATMENT	2	2615.259	1307.630	165.64	<.001
Growing_bags	2	6.037	3.019	0.38	0.685
Variety	1	21.407	21.407	2.71	0.109
TREATMENT.Growing_bags	4	93.074	23.269	2.95	0.034
TREATMENT.Variety	2	13.481	6.741	0.85	0.435
Growing_bags.Variety	2	0.259	0.130	0.02	0.984
TREATMENT.Growing_bags.Variety	4	0.185	0.046	0.01	1.000
Residual	34	268.407	7.894		
Total	53	3018.370			

Appendix 72: TA EX1 Analysis of variance

Variate: TA					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.02015	0.01008	0.51	
REP.*Units* stratum					
TREATMENT	2	0.70941	0.35470	18.07	<.001
Growing_bags	2	0.01965	0.00982	0.50	0.611
Variety	1	0.03888	0.03888	1.98	0.168
TREATMENT.Growing_bags	4	0.03622	0.00906	0.46	0.764
TREATMENT.Variety	2	0.07616	0.03808	1.94	0.159
Growing_bags.Variety	2	0.01905	0.00952	0.49	0.620
TREATMENT.Growing_bags.Variety	4	0.03754	0.00938	0.48	0.752
Residual	34	0.66755	0.01963		
Total	53	1.62461			

Appendix 73: TA EX1 Analysis of variance

Variate: TA					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.02015	0.01008	0.51	
REP.*Units* stratum					
TREATMENT	2	0.70941	0.35470	18.07	<.001
Growing_bags	2	0.01965	0.00982	0.50	0.611
Variety	1	0.03888	0.03888	1.98	0.168
TREATMENT.Growing_bags	4	0.03622	0.00906	0.46	0.764
TREATMENT.Variety	2	0.07616	0.03808	1.94	0.159
Growing_bags.Variety	2	0.01905	0.00952	0.49	0.620
TREATMENT.Growing_bags.Variety	4	0.03754	0.00938	0.48	0.752
Residual	34	0.66755	0.01963		
Total	53	1.62461			

Apendix 74: TSS EX 1 Analysis of variance

Variate: TSS					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	2.533E-03	1.267E-03	1.37	
REP.*Units* stratum					
TREATMENT	2	2.948E+02	1.474E+02	1.600E+05	<.001
Growing_bags	2	2.333E-04	1.167E-04	0.13	0.882
Variety	1	1.067E-03	1.067E-03	1.16	0.290
TREATMENT.Growing_bags	4	1.467E-03	3.667E-04	0.40	0.809
TREATMENT.Variety	2	9.333E-04	4.667E-04	0.51	0.607
Growing_bags.Variety	2	1.678E-03	8.389E-04	0.91	0.412
TREATMENT.Growing_bags.Variety	4	2.156E-03	5.389E-04	0.58	0.676
Residual	34	3.133E-02	9.216E-04		
Total	53	2.949E+02			

Appendix 75: TSS 2 Analysis of variance

Variate: TSS					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	2.533E-03	1.267E-03	1.37	
REP.*Units* stratum					
TREATMENT	2	2.948E+02	1.474E+02	1.600E+05	<.001
Growing_bags	2	2.333E-04	1.167E-04	0.13	0.882
Variety	1	1.067E-03	1.067E-03	1.16	0.290
TREATMENT.Growing_bags	4	1.467E-03	3.667E-04	0.40	0.809
TREATMENT.Variety	2	9.333E-04	4.667E-04	0.51	0.607
Growing_bags.Variety	2	1.678E-03	8.389E-04	0.91	0.412
TREATMENT.Growing_bags.Variety	4	2.156E-03	5.389E-04	0.58	0.676
Residual	34	3.133E-02	9.216E-04		
Total	53	2.949E+02			

Appendix 76: Pictures of the Experimental Process

Plate 1: Experimental set-up in greenhouse

Plate 2:Transplanted seedlings

Plate 3: Watering & Application of fertilizers

Plate 4: Trellising of tomato to keep plants erect

Plate 5: Tomato plant variet Limbobo plants at flowering

Plate 6: Tomato plant variety Rodeo plants at flowering

Plate 7: Mature tomato fruits in the ENVIRODOME greenhouse