Growth, Yield and Quality of Hydroponically Grown Tomatoes as Affected By Different Particle Sizes of Sawdust

By

MABOLOKE ABRAM MAATJIE

Submitted in accordance with the requirements for
the degree of

MASTER OF SCIENCE

in the subject of

AGRICULTURE

at the

UNIVERSITY OF SOUTH AFRICA

SUPERVISOR: PROF. D.M. Modise

CO-SUPERVISOR: Dr. M.M. Maboko

2015

DECLARATION

Student Number: 36963658

I, Maboloke Abram Maatjie (7205115319087) declare that the thesis entitled “Growth, Yield and Quality of Hydroponically Grown Tomatoes as Affected by different Particle Sizes of Sawdust”, represents my work in the design and the execution. All resources quoted herein are acknowledged by means of complete references.

Student

(M.A. Maatjie)

Supervisor

(Prof D.M. Modise)

Co-Supervisor

(Dr M.M. Maboko)

ACKNOWLEGEMENTS

I would like to express my sincere gratitude to my supervisor, Prof. D.M. Modise for accepting me as his student and for the guidance and the support he provided.

Dr. M.M Maboko as my co-supervisor also deserves acknowledgement for his valuable Input in the whole research project.

I appreciate the help of Dr. Jacques van Zyl for the setting of the measuring instruments prior to the commencement of the research project.

Much appreciation should also go to Ms. Liesl Morey and Mr. Mzabalazo Ngwenya for their assistance with statistical analysis and interpretation.

Mr. Malcolm Alexander and his team also played a major role by granting me a bench space to do my research project and they also contributed to my collection of data.

My wife Mahlako Junior Maatjie supported me greatly throughout the period of my study and therefore deserves special acknowledgement.

I also thank the Western Cape Department of Agriculture for the financial support to further my studies in this regard.

List of tables

List of figures

TABLE OF CONTENTS

CHAPTER 1

CHAPTER 2 Literature Review

CHAPTER 3 Material and methods

CHAPTER 4

CHAPTER 5

ABSTRACT

The tomato is one of the most important vegetable crops grown in the South African community. Most hydroponic tomato growers in South Africa are using sawdust as a growing medium due to its availability and affordability. However, there is little or no information on how particle sizes of sawdust influence tomato yield and quality. The aim of the study was to determine the effect of the particle size of sawdust on plant growth, yield and quality of tomato. Six treatments of different particle sizes of sawdust i.e. fine (F), medium (M), coarse (C) and 50:50 ratio of F: M, C: M, and C: F extracted from pine tree were used for the experiment. Treatments were arranged in a randomized complete block design with four replicates. The size of the sawdust particles did not have a significant effect on plant height, stem diameter, leaf length and width, shelf-life, marketable yield, total yield and unmarketable yield. A tendency to increase marketable and total yield was observed when tomato plants were grown at a 50:50 C: F ratio. Fruit and leaf mineral content were not affected by sawdust particle size. After completion of the experiment, air- filled porosity was significantly high on particle size C, M, and C: M while the water holding capacity was significantly high on F followed by M. The study showed that the suitable growth medium for production of tomatoes under the hydroponics system used was the CF particle substrate. Generally, the experimental crop performed better under the CF particle substrate in terms of growth parameters, and fruit quality, thus leading to the conclusion that the CF growth medium is ideal for hydroponically grown tomato under a non-environmentally controlled polytunnel.

Keywords: Tomato, growing medium, hydroponic system, particle size, polytunnel.

CHAPTER 1

INTRODUCTION

1.1 Background to the research project

Tomato plants are originally from Peru. They were thought to be toxic to human consumption and therefore used for decorative purposes (Walls, 1987). Askew (1996) describes the tomato as an herbaceous plant that has 10-25 cm long glandular leaves and a hairy stem with yellow flowers. The author likewise mentions that it is well adapted to both temperate zones and moderate climates.

In 2010, the world's top tomato producer in tonnage was China with 33 911 702 metric tonnes (mt), followed by India (13 718 171 mt), USA (10 965 355 mt), Spain (10 313 000 mt) and Egypt with 9 204 097 mt (FAOSTATS, 2010). Egypt is ranked as the biggest tomato producer in Africa.

In South Africa, the Department of Agriculture, Forestry and Fisheries (DAFF), determined that Limpopo Province is the major production area with 3 590 ha (Northern Lowveld at 2 700 ha and the far Northern areas of Limpopo province at 890 ha),had a higher production area than all other provinces (DAFF, 2012). It further indicated that Limpopo province accounts for more than 50% of the total area under production of tomatoes in South Africa.

Maboko *et al*. (2009) reported that in South Africa, the majority of tomato producers are still practicing open field production while soilless cultivation in a protected environment has gained popularity due to improvement in yield and quality. In addition, almost all open field vegetable production is seasonal. In South Africa, with its diverse climatic conditions and soil types, growing plants in soil is unpredictable, with a range of challenges, such as changing temperatures, moisture holding capacity, available nutrient supply, poor root aeration as well as diseases and pest control (Maboko and du Plooy, 2014). Soilless production using growing media alleviates some of these problems, while giving the farmer better control over plant growth and development.

Harris (1987) defined hydroponics as the art of growing plants in a growing medium other than soil, by adding dissolved mixtures of essential plant nutrient elements in water as suggested by Gericke in 1930. The author further stated that the term hydroponics was derived from the Greek word ‘hydro’ meaning water and ponos meaning ‘labour’. The significance of a hydroponic system in tomato production is that it enables the growers to manage water and nutrient supply and optimize the plant growth in a small production area that is generally sub-optimal for plant growth, yield and quality (Niederwieser, 2001; Harris, 1974).

Raviv et al (2002) affirmed that the use of sawdust has proven to have good plant performance compared to other wood wastes as a constituent of growing media. Organic growing media, i.e. sawdust, coir (cocos) and bark, are often used in open bag hydroponic systems (Niederwieser, 2001). The author further argued that rapid corrosiveness and toxic substances found in sawdust are disadvantageous to plant growth and development. In South Africa, sawdust is popular and readily available, especially in forested areas such as Mpumalanga and KwaZulu-Natal provinces.

Sawdust is affordable compared to imported growing media, and it is suitable for use as a growing medium. Researchers have reported the favourable effect that organic growing media have on plant growth (Maboko *et al*., 2013a; Tzortzakis & Economakis, 2008; Sawan and Eissa, 1996), as it increased the porosity and water retention of the growing medium (Hardgrave and Harrisman, 1995; Marinou *et al*., 2013). Maboko et al., (2013) reported that organic growing media (sawdust and coir) did not have a significant effect on tomato yield.

Positive physical properties such as biogradability at an acceptable rate, low superficial specific gravity, high porosity, high water retention, moderate drainage and high bacterial tolerance elevated the usage of sawdust as a plant growth medium in manufacturing industries (Maharani *et al*., 2010). Despite the fact that sawdust has been commercially used for many years, data is lacking that describes specific particle sizes of sawdust that are suitable for tomato production. This study therefore investigated how the different particle sizes of the sawdust as a growing medium affect growth, yield and quality of hydroponically grown tomatoes.

1.2. Ethical considerations and demarcation

There are no ethical risks in this study. The ethics approval application was submitted to the Department of Agriculture and Animal Health, and permission was granted. A letter of intent as to where the trial was to be conducted was provided and permissions allowed.

1.3 Rationale and benefits derived from the study

A citation was conducted on Google Search and Google Scholars for "use of different particle sizes of sawdust" using search strings and key words. This was done to identify possible work done by other researchers. The key words identified included:

- Electrical conductivity (EC)
- Air-filled porosity
- Growing media/substrates
- Physical properties

The search results were for the comparison of different particle sizes of growing media on hydroponically grown tomatoes. There was minimal retrieval for different particle sizes of growth media, especially sawdust. The citation analysis showed a gap in the South African research on growth, yield and quality of hydroponically grown tomatoes as affected by particle sizes of sawdust as there was insufficient literature on the subject.

1.3.1 Motivation

There are different growing media that can be used in hydroponic systems; however in this experiment sawdust as a local available material was chosen as a growing medium. Marinou *et al*. (2013) indicated that sawdust was widely used as a growing medium component in areas with wood processing industries, because of its low cost, high moisture retention, and high availability. The author added that sawdust has been the standard growing medium for the greenhouse industry in Canada and Argentina for several decades. The use of sawdust would therefore help commercial hydroponic tomato growers to make informed decisions as to which suitable sawdust particle size to select for tomato production in a hydroponic system.

1.4 Problem statement

Sawdust is a growing medium which is popular and readily available in South Africa; however, there is little or no information on the recommended particle size of sawdust as a growing medium for soilless cultivation of tomatoes. It is generally known that the water-holding capacity and aeration as well as the distribution of the roots at the rooting zone, are influenced by the particle size of the growing medium.

Richard (2006) highlighted that a good growing medium must provide plants with adequate amounts of water, and enough porosity to supply oxygen and other gases to the roots. The big challenge when selecting a growing medium is to combine the aeration and water holding capacity while taking into consideration the decomposition rate of organic media (Niederwieser, 2001; Richard, 2006; Anlauf *et al*., 2012).

Plants growing in a medium which is poorly aerated are weaker, less succulent and more susceptible to micronutrient deficiencies and root rot pathogens such as *Pythium* spp and *Phytophthora* spp than roots growing in well-aerated media (Ingram *et al*., 2003).

1.5 Research aims and objectives

The aim of the study was to identify the most suitable particle size of sawdust for tomato production in a hydroponic system. The main objective of this study was to contribute scientific knowledge on the utilisation of different particle sizes of sawdust as a growing medium in tomato production. It also outlines the effect of different particle sizes of sawdust on the growth, yield and quality of hydroponically grown tomatoes.

1.5.1 Specific objectives

- To evaluate the performance of tomato plants grown in different particle sizes of sawdust
- To identify the most suitable particle sizes of sawdust as growing medium for tomato production
- To determine the change in chemical and physical properties of different particle sizes of sawdust over a period of a time

1.6 Research questions

- What impact will the different particle sizes of sawdust have on the growth, yield and quality of tomato?
- How will the particle sizes of sawdust influence the change in physical and chemical properties over time?

1.7 Thesis structure

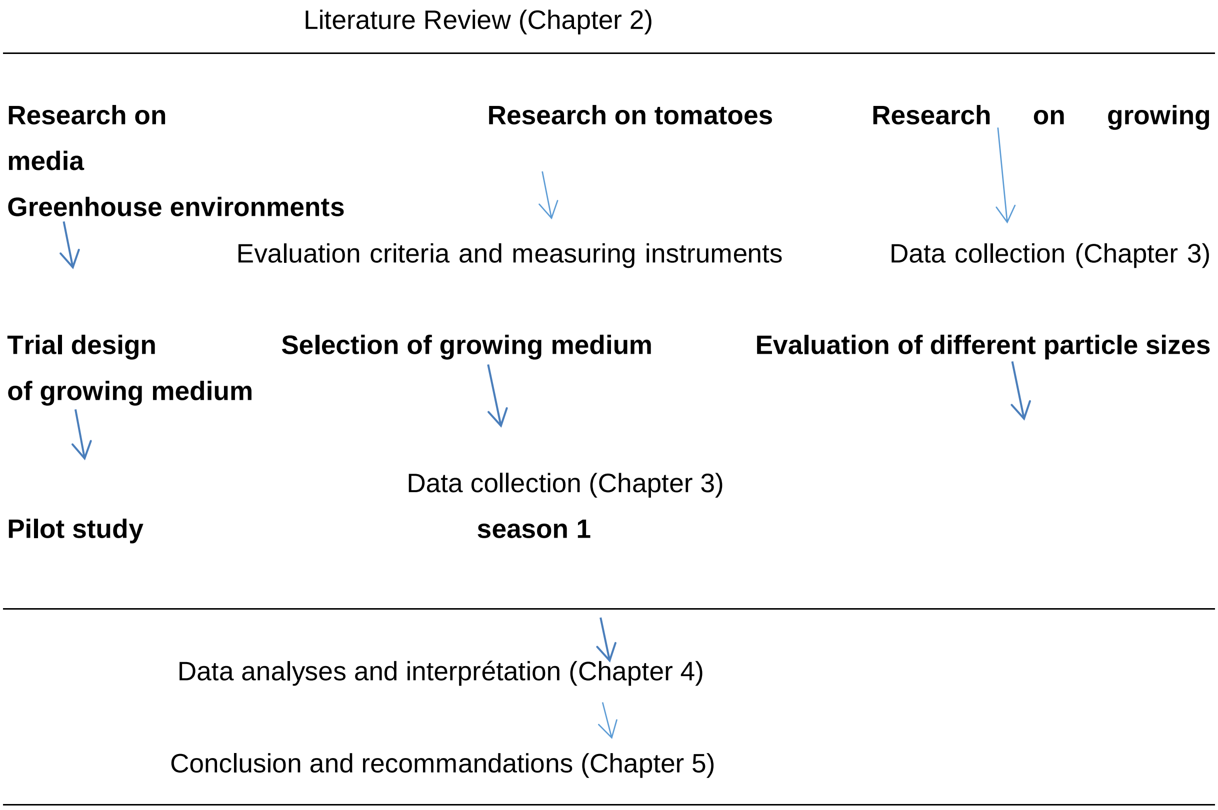

Figure 1.1 Research procedures (Adapted from Adriaanse, 2013)

CHAPTER 2

Literature review

2.1 Introduction

2.1.1 Growth substrates

Growth substrates can be made from many different substances. Some are organic while others are inorganic in origin. Common substrates that are used singly or in mixtures of varying ratios include organic substrates such as sawdust, humus, manures, organic soils, bark, peat, wood shavings and ash, while inorganic substrates include sand, volcanic rocks, pumice, perlite and others. Researchers invariably select preferred substrates for experimentation.

Mokrzecka (2000) carried out an experiment of greenhouse tomatoes in unheated plastic tunnel where sawdust from coniferous trees and grey brown podzolic soil with 2% humus content were mixed at a ratio of 3:1 and 1:1, respectively. Tomato plants that were grown in a mixture of sawdust and soil at a ratio of 3:1 gave the highest yield of 5.83 kg per plant.

Tomatoes grown in soilless conditions were reported to out-perform those grown in soil in terms of yield (Maboko *et al*., 2009). The author also reported that tomato plants grown in soil had a high incidence of fruit cracking and were severely infected by early blight fungal disease.

Several studies produced a variety of conclusions on the use of varying growing substrates. Ortega-Martinez *et al*. (2010) for example, evaluated the effect of substrates (pine sawdust, compost of sheep manure, agricultural land and red volcanic rock) on the growth and yield of tomatoes. They found that the compost that was mixed with sawdust resulted in the highest plant height, thickest stem diameter, highest average fruit mass as well as the highest yield.

Abbas (2009) employed a different approach from other researchers and tested fourteen different growing media and concluded that fine grade perlite medium significantly improved the average fruit mass, plant height and leaf area of cucumbers.

Allaire *et al*. (2004), evaluated seven substrates made up of rockwool, sawdust, wood shavings, composted bark and pure peat. The differences were noted on physical properties of the substrates in terms of water retention capacity, hydraulic conductivity, porosity, and diffusivity; however, the yields were not related to the physical properties of those substrates. Reports by Dubský and Šrámek (2009), Samadi (2011), Tzortzakis and Economakis (2008), and Raja et al. (1992), were in agreement with the notion that there was a direct relationship between physical properties of growing media and crop performance.

Raja *et al*. (1992), undertook a study where an investigation was carried out to compare the use of an alternative inorganic substrate (sand) and an organic substrate consisting of sawdust from temperate hardwood species. Sand out-performed the sawdust in terms of yield and yield components. Tzortzakis and Economakis (2008), in an unheated glasshouse with a north-south orientation, compared perlite, pumice, shredded maize stems and selected mixtures. Plants grown on pumice and perlite produced a significantly lower total number of fruits/plant than those grown on maize shredded stems. These findings are in contrast to the findings of Raja *et al*. (1992), where an inorganic substrate (sand) seemed to induce better performance in plants. Maboko and du Plooy (2014), reported that direct seeding of tomatoes in a sawdust growing medium using an open bag hydroponic system produced plants that had the highest early number of marketable fruit, and early total and marketable yield compared to transplanting seedlings at the six leaf stage.

2.2.2. Water retention

Water retention is the ability of the growing medium to hold and retain water for a period that is longer than infiltration (Maharani *et al*., 2010). The author further pointed out that particle density had a strong influence on porosity and water retention. Other studies by Maragatham *et al*. (2010) and Michel (2010), emphasized that the physical characteristics of a growing medium are those that primarily influence its ability to supply water to the plant roots without restricting the nitrogen supply. Their impression was that a coarser particle sized medium e.g. coir pith, has less water absorption compared to smaller sized media due to its macro-pores space.

A study conducted by Maharani *et al* 2010 on the physical properties of sawdust (i.e. particle size distribution, particle density, porosity, and water retention) from five tropical commercial wood species (*Shorea leprosula*, *Dryobalanops lanceolata, Dipterocarpus cornutus*, *Shorea laevis,* and *Eusideroxylon zwageri*) as prepared in various mill types (i.e. handsaw, sawmill, and milling) were analysed. The study aimed to look into the relationship between the use of different mill types, density of wood species and physical properties of the resulting sawdust. Influential factors on porosity and water retention using the General Linear Model revealed that particle density imposed a strong influence on porosity, as did particle size on water retention.

2.2.3 Nutrients

Eberhardt *et al*. (2007), have shown that in the case of the wood particles, phosphorus uptake capacity decreased with the decrease in particle size. The particle size is therefore important in nutrient uptake. It was also further indicated that although the larger wood particles provided a large amount of iron for phosphate removal, smaller wood particles may be preferred since they afforded the lowest release of iron relative to the amount of phosphate removed.

Increased growth and yield of blueberry was achieved as a result of incorporating peat and sawdust with ferrous sulfate that ultimately rectified the pH status of the medium (Vano *et al*., 2011). The author further pointed out that the growing medium also plays a role in holding the nutrients to be absorbed by the plant roots.

Reports by Martin *et al*. (2012), have shown that coconut coir has been found to be a suitable substrate for greenhouse tomato production. It was further indicated that many studies have noted equal or greater yield in coir than conventional root media. However, when compared with rock wool, coir has a higher cation exchange capacity that helps minimize the increase in nutrient concentrations that occurs with recycling.

Harmayani and Anwar (2012), investigated the adsorption characteristics of sawdust for removing nutrients (e.g., NH3-N, NO3-N, and NO2-N) from storm water. Their results have shown that sawdust is a very good adsorbent due to its ability to remove NH3-N, NO3-N, and NO2-N from an aqueous solution, especially at lower concentrations. The authors further indicated that the percentage removal of NH3-N, NO3-N, and NO2-N was increased when the amount of adsorbent dosage increased, because of the increase in adsorbent surface area.

2.2.4 Particle size

Particle size distribution has direct effects on the physical and chemical properties of any growing medium. It was observed that the smaller particles of the growing medium have more exchange sites for anions and ions adsorption (Richard, 2006). Four consecutive trials were carried out under a heated glasshouse by Savvas and Gizas (2007) on gypsophila, rose, cucumber, and lettuce. These crops were grown in two different grades of pumice. The result indicated that roses and lettuce responded poorly compared to gypsophila and cucumber to the differences in air to water ratio at the rooting zone. This was due to the variations in the physical properties of the growing media.

Yoon *et al*. (2007), conducted an experiment on raised beds composed of peat moss, perlite and expanded rice hull in the ratio of 3:4:3 (v: v: v) where short day strawberries were grown. The substrates used were as new or previously used for either one year, two years or three years. The results showed that P, K, Ca and Mg were in higher quantities in a new substrate compared to reused substrates because of its absorbability. However, there were no differences in plant height and leaf size on reused and new substrates.

In an investigation by Nurzynski (2013) on organic substrate applied to tomatoes grown in greenhouse cultivation as compared with rockwool during 2008 and 2009, four different substrates were tested with different compositions. It was demonstrated that cut rape straw is suitable for greenhouse tomato production. Although lesser fruit yields were obtained from plants growing in rockwool compared to rape straw + pine bark substratum, the differences were not significant.

Shah *et al*. (2006), conducted a study to test the effect of rooting media on root initiation and development in two different types of cuttings (hardwood and softwood). The findings were that cuttings that were planted in sawdust (soft wood) sprouted more quickly than that those planted in hardwood sawdust. However, the hardwood cuttings did not produce roots in any media. The minimum leaf number (3.3) and the shortest leaves (13 cm) were observed in plants grown in silt but they also produced the longest roots (23.7 cm) and the maximum root mass (5.3 g)

The particle size, shape and porosity of the medium particle determine the moisture retention of the medium and the particle size must be 0.5 mm (Drzal *et al*., 1999). Particle size distribution is important in describing the physical quality of the material and its suitability for plant growth. Many researchers have conducted research on particle size and its distribution on various growing media. Few, if any, have selected sawdust in their experimental units. Water holding capacity and air filled porosity is affected by particle size. A study by Bunt (1988) suggested that the oxygen availability at the root surface will not limit plant growth and development when plants are grown in peat, provided that the air-filled porosity is greater than 10%. Samadi (2011) reported an increase in the yield, plant height and leaf area of cucumbers grown in fine-grade perlite compared to a medium containing very coarse grade perlite.

This research therefore fills the gap where little has been done on sawdust particle sizes. Sawdust has specifically been chosen as test material because it is the most commonly used and readily available in South Africa (Niederwieser, 2001). It is also widely used throughout the world (Niederwieser, 2001; Miller and Jones, 1995) and it is therefore an important growth medium for commercially grown tomatoes in hydroponics.

The study is differs from other studies in that the different particle sizes of the same growing medium (sawdust) were tested on the tomato cultivar. The research gap was to find out if particle sizes of sawdust can significantly affect the growth, yield and quality of tomatoes grown in hydroponics.

The above information regarding the literature reflects that there is a correlation between the water retention capacity, nutrients uptake and the particle sizes of the specific growing medium. A good substrate must have a balance between aeration and drainage (Niederwieser, 2001). Particle sizes play a major role in availability of nutrients and water absorption.

CHAPTER 3

3.1 MATERIALS AND METHODS

3.1.1 Location

The experiment was conducted in a non-temperature controlled tunnel at Malcolm’s Tunnel Farm in Ceres (Witzenberg Municipality), Western Cape Province, South Africa, (33^0 21, 43$^{'}$ 24$^{''}$ S and 19^0 18, 42$^{'}$ 49$^{''}$ E) (Figure 3.1).

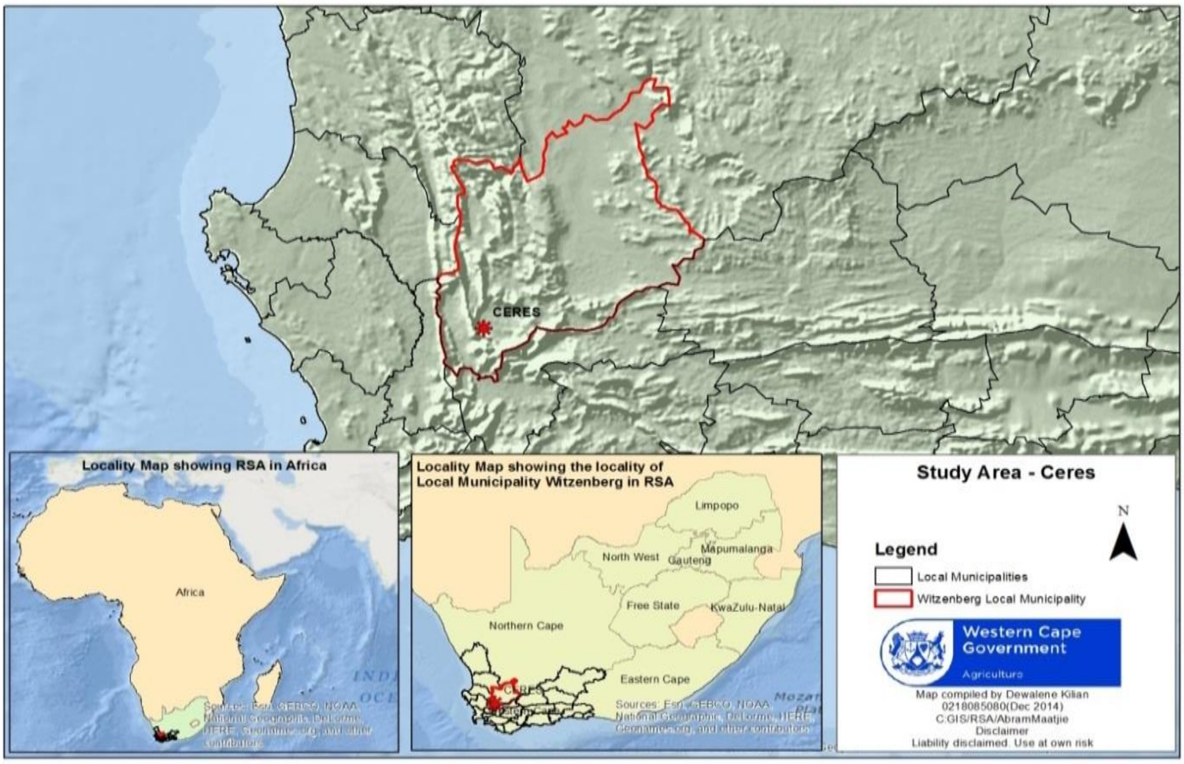

Figure 3.1 Map of Africa, South Africa, Western Cape, Cape Winelands District and Witzenberg Local Municipality

3.1.2 Sample selection and plant population

The experimental design used in the study was complete randomised block design with six treatments and four replicates. Each treatment consisted of twenty-five plants per block. Ten data plants were selected for yield, four data plants were used for plant growth parameters and two plants for measurement on water drainage and electrical conductivity per treatment and replicate. Plants were planted at a plant density of 3 plants /m^2. Each treatment per replicate consisted of twenty-five bags of sawdust and the middle 10 plants were selected as data plants while the outer plants were regarded as border plants.

3.1.3 Experimental unit and design

The plastic tunnel used in this study was 10m x 30m with a plastic thickness of 200 microns. Seedlings of an indeterminate tomato cultivar ‘Amfamia’ (Hygrotech Seed Company, South Africa) were used in this experiment. Cultivar Amfamia, is good for summer production, and had vigorous growth with good leaf coverage. It provides uniform, firm and long shelf life tomatoes with a thick fruit wall and is adapted to a wide range of conditions (Hygrotech variety profiles 2014). Five-week-old seedlings were bought from the nursery and were transplanted into 10 L black plastic bags filled with sawdust as growing medium.

Six different particle sizes of pine tree sawdust were used as treatments, i.e. fine (F) (800 um in diameter), medium (M) (1.4 mm in diameter), coarse (C) (3.35 mm in diameter), coarse + fine (C:F) (50:50 % v/v), medium + fine (M:F) (50:50 % v/v), coarse + medium (C:M) (50:50 % v/v). Universal laboratory test sieves (SABS Approved) of 800 um, 1.4 mm and 3.35 mm with apertures according to ISO 3310-1 were used to determine particle sizes of the sawdust (Figure 3.2). The Universal laboratory test sieves which are standard for laboratories were used to determine particle sizes as standardized by the ISO 3310-1.

Fine particles (**800um**) Medium particles (**1.4mm)** Coarse particles (**3.35mm)**

Figure 3.2 Illustration of different particle sizes of sawdust

The planting bags were filled with growing medium according to 6 different particle sizes i.e., coarse (C), medium (M), fine (F), coarse+fine (CF), coarse+medium (CM) and medium+fine (MF) following the trial layout (Figures 3.3, 3.4 and 3.5).

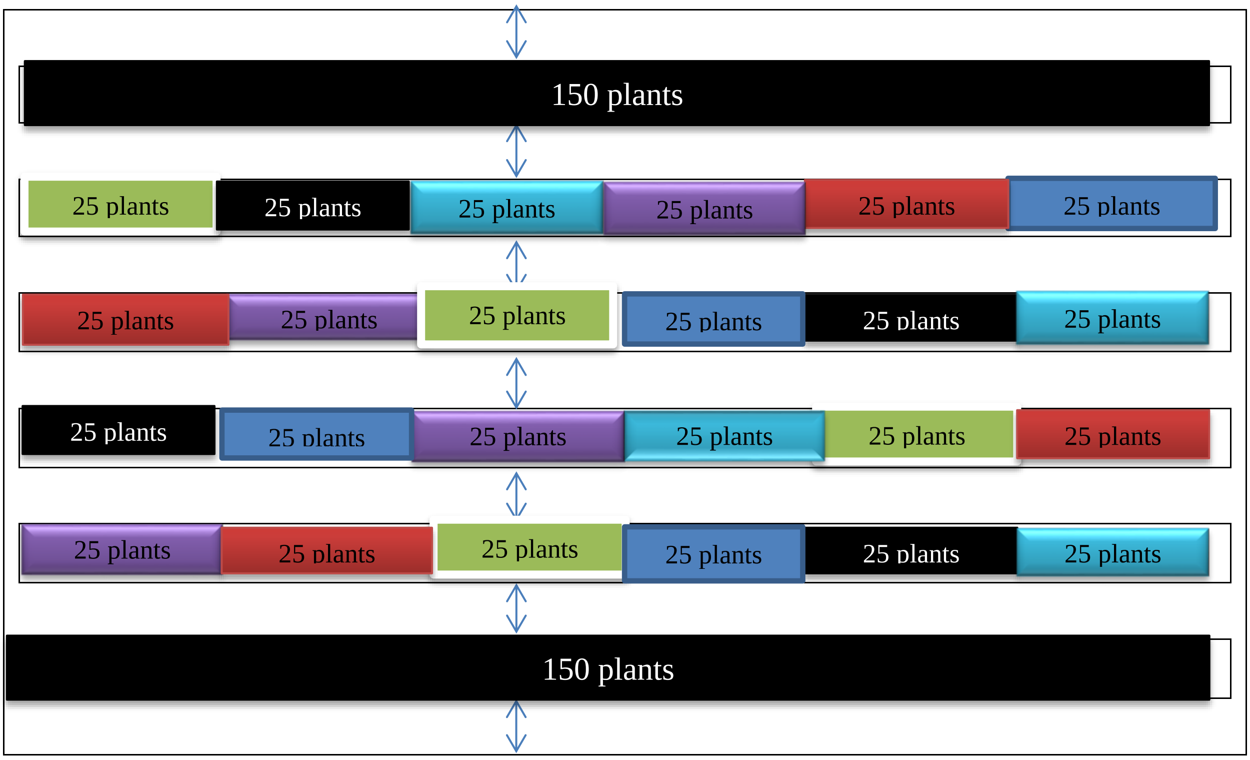

Figure 3.3 Experimental layout

Index for sawdust particle sizes

M = MEDIUM 🟩
F = FINE 🟪
CM = COARSE+MEDIUM 🟦
C = COARSE ⬛
CF = COARSE+FINE 🟥
MF = MEDIUM+FINE 🟦

Figure 3.4 Layout of the tomato plants growing in a non-temperature controlled plastic tunnel

Figure 3.5 One week old tomato transplants growing in 10L plastic bags filled with sawdust

3.2 Preparation phase

The planting bags were filled with sawdust according to particle size as treatments. The sawdust was first moistened with water before filling up the planting bags in order to improve moisture distribution and reduce transplant shock.

3.2.1 Transplanting phase

Five week old tomato seedlings were bought from the nursery and were transplanted into 10 L black plastic bags filled with sawdust as a growing medium. The seedlings were transplanted on 9 November 2013.

3.2.2 Fertigation, trellising and pruning

The plants were irrigated four times per day at 2 hourly intervals using one dripper per plant at a delivery rate of 2l/h. The irrigation volume was gradually increased as plants enlarged, to ensure that at least 5-10% of the applied water leached out of the bags to reduce salt build-up in the growing medium. Water soluble fertilizers that were used were Hydroponic®, calcium nitrate and potassium sulphate (K_2SO_4). The composition and chemical concentration of fertilizers used for tomato production were: Hygroponic® (comprising N (68 mg/kg), P (42 mg/kg), K (208 mg/kg), Mg (30 mg/kg), S (64 mg/kg), Fe (1.254 mg/kg), Cu (0.022 mg/kg), Zn (0.149 mg/kg), Mn (0.299 mg/kg), B (0.373 mg/kg), and Mo (0.037 mg/kg)); calcium nitrate [$Ca(NO_3)_2$] (comprising N (117 mg/kg) and Ca (166 mg/kg)); and potassium nitrate (KNO3) (comprising K (38.6 mg/kg) and N (13.8 mg/kg)). The soluble fertilizer applied as from the transplanting stage until the plants had tomatoes of grape size, were 1 kg Hygroponic® and 640 g calcium nitrate per 1000 L of water. Thereafter, from grape-sized fruits to the end of the experiment, 200 g of potassium sulphate, 1 kg Hygroponic® and 640 g calcium nitrate per 1000 L of water were applied.

The plants were trellised to a single stem by twisting trellis twine around the main stem and fixing it to a stay wire 2 m above ground to support the plant. Side shoots or suckers were removed weekly to maintain a single stem system. When the plants reached the horizontal wire at 2 m, the growing point was removed.

3.2.3 Pest and diseases control

Pests and diseases were scouted on a daily basis. The chemical fungicide that was used to control fungal diseases was Bravo, and Methomex was used to control insects. Red spider mites were detected towards the end of the research project and no control measures were applied.

3.3 Physical and chemical properties analysis

Six samples of the six treatments were packaged in paper bags and sent to the Agricultural Research Council (ARC) – Institute of Soil, Climate and Water laboratory (ISCW) prior to the establishment of the experiment (before planting)to determine the physical and chemical properties of the sawdust. After the completion of the research project, twenty-four samples (from 6 treatments and 4 replicates) of sawdust were taken to the ARC-ISCW laboratory for physical properties analysis. Physical properties include, bulk density, total porosity and water holding capacity of the sawdust particle sizes. After the termination of the experiment, 24 sawdust samples (from 6 treatment and 4 replicates) were collected for analysis of chemical and physical properties.

3.3.1 Method for moisture

Samples were determined in duplicate. For each determination, approximately 5g of sample was weighed into a porcelain bowl and dried in an oven at 70°C overnight or until there was no further mass loss. The samples were cooled, covered with Al foil (or placed in a desiccator) to prevent moisture absorption from the atmosphere, and then weighed. The % moisture on a mass basis in the sample was calculated as the mass loss during drying divided by the original mass of sample (x100%) and this was then converted using the bulk density to the % moisture on a volume basis (m%) The dried sub-samples were discarded and all further tests below were done on the samples as received (wet).

3.3.2 Extraction for chemical tests

A 100 ml of sample as received (no drying or milling), but very slightly compressed (the only compression was from the weight of another 100 ml sample initially placed on top) was extracted with 150 ml deionized water and the water extract was filtered.

3.3.3 Method for pH

The pH of an aliquot of the extract solution was measured using a pH electrode and pH meter (Eutech Instruments pH 700) calibrated against buffers at pH 4 and pH 7 and checked against a pH 10 buffer.

3.3.4 Method for electrical conductivity (EC)

The conductivity of another aliquot was measured with a conductivity electrode and meter (Radiometer).

3.3.5 Determination of bicarbonate (HCO_3^-)

Bicarbonate was determined by a pH titration of an aliquot of the extract.

3.3.6 Determination of all other anions by Ion Chromatography (IC)

An aliquot of the extract solution was analysed (as soon as possible after extraction) by Ion Chromatography using a Dionex Model 1600 Ion Chromatograph with a conductivity detector and eluted through the ion exchange column using a carbonate/ bicarbonate buffer solution. This was used to determine fluoride (F^-), chloride (Cl^-), nitrite (NO_2^-), nitrate (NO_3^-), phosphate (PO_4^{-3}) and sulphate (SO_4^{-2}), which elute in this order (fluoride first). The instrument was calibrated against a standard solution containing all these anions.

3.3.7 ICP-OES determination of eight elements

An aliquot of the extract solution was used for the ICP-OES (Inductively Coupled Plasma Optical Emission Spectrometric) determination of Ca, Mg, K, Fe, Zn, Mn, B and Cu. The ICP-OES was a multi-element instrument. The instrument used (Varian Liberty Series II) is a sequential instrument, where the elements are determined almost simultaneously, with only a few seconds between each element. Each element was measured at an appropriate emission wavelength, chosen for high sensitivity and lack of spectral interferences. The wavelengths used were: Mg: 383.826nm; Ca: 422.673 and 317.933nm; K: 769.896nm; Fe: 259.94nm; Mn: 257.61nm; Zn: 213.856nm; Cu: 324.754nm and B 249.678nm.

The instrument was set up and operated according to the recommended procedures in the instrument manual. It was calibrated against a series of standard solutions, containing all the elements of interest in the proportions found in typical leaf samples. [(Unpublished method developed by Mike Philpott at ARC-ISCW, based on the recommended procedures in the instrument manual: Liberty Series II (1997)].

3.3.8 Adjustment of concentrations of anions, cations & elements for moisture

The extract concentrations for all the anions, cations and other elements were adjusted for the moisture content of the samples. Thus, all the analytes in the extract (chemical tests) except the pH and the EC were adjusted. For the extraction, 100 ml of water was added to the 150 ml sample (see 2 above), but since the samples were not dried, the total amount of water present was more than 150ml. The total water present equals the 150 ml added plus the moisture already present in the samples (m where m% is the % moisture on a volume basis). The conversion factor was thus 150/(150+m).

3.3.9 Method for water holding capacity (WHC) and air filled porosity (AFP)

A cylinder of known capacity (V_S = 461.8ml) was filled with sample (uncompressed and then filled with water to saturate the sample with water, adding additional sample to the top of the cylinder if the water added caused any settling of the sample. The excess water was then drained off, measuring the volume of water drained off as V_w. The Air Filled Porosity (AFP) is then the ratio between these two volumes, i.e. AFP = V_w / V_S (multiplied by 100 to convert to a percentage).

The whole wet, drained sample was transferred to a beaker, which was weighed before (m_b) and after (m_w) transfer. The sample in the beaker was dried in an oven and then reweighed (m_d). The Water Holding Capacity (WHC) is the difference between the masses before and after drying divided by the original water saturated sample volume or WHC = $(m_w - m_d) / V_S$ (multiplied by 100 to convert to a percentage).

3.3.10 Method for bulk density

The more accurate method for bulk density was to weigh 100 ml of very slightly compressed original sample, preferably the 100ml measured for the water extraction for the chemical tests (see method 2 above). The bulk density was then just calculated as the ratio of the sample mass to sample volume i.e. sample mass in g divided by 100.

However, the 100 ml sub-samples of each sample used for the water extraction were unfortunately not weighed, and then later on, when this was discovered, there were none of the original samples left to use for the bulk density measurement. Thus, we had no option but to use the following less accurate method, using the data obtained from the WHC and AFP measurements.

The mass of dry sample was calculated ($m_d – m_b$) and was then adjusted for the moisture content on a mass basis (m_m) to get the equivalent mass of the original sample. This equivalent mass was then divided by the sample volume used for WHC and AFP (V_S = 461.8ml) to get an approximate value for the bulk density i.e. bulk density = $[(m_d – m_b) / (1 - m_m\%/100)] / V_S$. This method may give less accurate values for bulk density, due to possible slight changes in sample volume when the sample was saturated with water for the WHC and AFP measurements. Any sample volume changes due to saturation with water are likely to be less for samples where the original sample had high moisture content (ARC- ISCW laboratory). The sieves used were Reliance test sieves of 800 um, 1.4 mm and 3.35 mm with apertures according to ISO 3310-1 were used to determine particle sizes of the sawdust. They were bought from Reliance Laboratory equipment in Pretoria.

3.4 Plant height and stem diameter

The plant height and stem diameter of four plants per treatment and replicate were measured and recorded from the fourth week after transplanting and thereafter on a fortnightly basis until the plants reached 2 m in height. A 3 metre measuring tape was used to measure the plant height (Figure 3.6) while a Vernier caliper was used to measure the stem diameter (Figure 3.6). The number of leaves were also counted on four plants on a fortnightly basis. The following instruments: Vernier calipers, measuring ruler, and GGGML01 (GEMINI data logger for air temperature) were used in the study for data collection.

Stem diameter

Plant height

Figure 3.6 Measurements taken on the stem diameter and plant height

The stem diameter was measured 30 cm below the growing point of the main stem, while the plant height was measured from the plant stem crown to the growing point of the plant.

3.5 Leaf length and width

The leaf length and leaf width of four plants per treatment were measured and recorded from the fourth week after transplanting and thereafter on a fortnightly basis until the plants reached 2 m in height using a 30 cm measuring ruler (Figure 3.7).

Leaf width Leaf length

Figure 3.7 Image illustrating the measurements of leaf length and width

3.6 Yield determination

Yield data was collected from ten plants per treatment per replicate. Total yield, marketable yield and unmarketable yield as well as physiological disorders were counted, weighed and recorded. All harvested fruits, excluding the unmarketable were graded into sizes according to fruit diameter, namely extra-large (XL) (> 70 mm), large (L) (60-70 mm), medium (M) (50-60 mm), small (S) (40-50 mm) and extra-small (XS) (< 40 mm). The unmarketable yield were fruits exhibiting cracking, catface, blossom-end rot, blotchy ripening and fruits that fell into the category of extra-small sized fruits (<40mm fruit diameter). The tomatoes were weighed using a weighing balance scale (Masskot scale, 15 kg x 1 g) and a Vernier caliper was used for fruit diameter measurements.

3.7 Leaf analysis

The fourth leaf from the growing point of four plants per treatment and replicate were selected to determine leaf mineral content (N, P, K, Ca, Mg and Zn). In total, twenty four leaf samples were taken to Elsenburg laboratory, Muldersvlei (Western Cape) for the leaf mineral content analysis. The leaves were cut from the tomato plants by hand and kept in a cooler box for transport to the laboratory. Macro and trace elements were determined using Method no. 6.1.1, for feeds and plants according to the Alasa Handbook of Feeds and Plant Analysis (1998).

3.8 Fruit analysis

Four ripe medium-sized tomatoes were harvested from the 5th truss from four data plants per treatment and replicate for fruit mineral analysis (P, K, Ca, Mg, Mn, Zn, B, Cu and Fe) at the ARC-ISCW laboratory.These tomatoes were oven-dried at 70ºC for 48 h and ground using a mill with a 1 mm sieve. Nitrogen was determined on the dry milled material using a Carlo Erba NA 1500 C/N/S Analyser (Thermo Scientific). An aliquot of the digest solution was used for ICP-OES (Inductively Coupled Plasma Optical Emission Spectrometry) for determination of Ca, Mg, P, K, Fe, Zn, Mn and Cu concentration (Liberty Series II Model, Varian). All nutrient concentrations were expressed on a dry mass basis.

3.9 Determination of shelf life

Six ripe tomatoes of large size were selected from each treatment per replicate for shelf-life determination. They were stored for 20 days at room temperature. Percentage weight loss (%) was recorded after 4, 8, 12, 16 and 20 days in storage using a weighing scale (Masskot scale, 15 kg x 1 g). The room consisted of two windows that were open during the day and at night. The temperature and humidity were monitored from the first of March at 12h00 until the 20th of March at 12h00.

3.10 Water analysis

Water quality had been tested at the beginning of the research by ARC-ISCW laboratory. The anions were done by Ion chromatography on a Dionex ICS 1600. The cations were done on an ICP OES on a Jobin Yvon Ultima pH, EC and alkalinity titrations with a Mantech auto analyser. The water sample was collected in a clean plastic bottle and the chemical composition was determined as shown in Table 3.1.

Table 3.1 Water analysis used for irrigation

pH	pHs	SAR	Electrical Conductivity
6.73	8.08	1.95	64.00 mS/m at 25^{o} C

Anions	mg/L	mol(c)/L
Fluoride (1.5)	0.25	0.01
Nitrite (4.0)	0.00	0.00
Nitrate (44.0)	0.70	0.01
Chloride (250)	160.13	4.51
Sulphate (500)	46.22	0.96
Phosphate	0.00	0.00
Carbonate (20.0)	0.00	0.00
Bicarbonate	70.76	1.16
Subtotal	278.06	6.66
Sodium carbonate	0.00	0.00
Sodium Bicarbonate	0.00	0.00
Alkalinity	58.00	1.16
Temp. Hardness	58.00	1.16
Perm. Hardness	135.80	2.72
CATIONS	mg/L	mmol(c)/L
Sodium (400)	62.30	2.71
Potassium (400)	1.28	0.03
Calcium (200)	39.97	2.00
Magnesium (100)	22.73	1.87
Boron ((1.5)	0.03	0.01
Subtotal	126.31	6.62
Total		404.00
Less(*)		35.38
Total dissolved solids		368.62

Figures in brackets are recommended maximum values for human use in mg/l

3.11 Drainage water

Trays were placed underneath the planting bags to capture the water which infiltrated the sawdust. However, a measuring cylinder was used to measure the amount of water that passed through the sawdust in order to determine water usage.

3.12 Monitoring of EC and pH

The EC meter was used to measure electrical conductivity as well as the pH each time a fresh solution (fertilizer) was applied. Trays were placed underneath two planting bags on each treatment and drainage water was collected for EC and pH determination using the EC/pH meter (Figure 3.9).

Tray

EC/pH meter

Figure 3.8 Tray used for collecting drainage water (left) and the pH meter (right).

3.13 Statistical analysis

Data from the studied variables was subjected to analysis of variance (ANOVA) using a statistical package GENSTAT (RothamStead, 2010). The means were separated by Standard Error of Difference (SED) and by Least Significant Difference (LSD) at $P \leq 0.05$.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Plant growth parameters

For all the growth parameters investigated (plant height, stem diameter, number of leaves, leaf length and leaf width), it was found that only the factor: days after transplanting (DAT) had a significant effect. In all instances this factor had a p-value of < 0.001. Results showed that different particle sizes of sawdust had no significant difference on the plant growth parameters (Appendix A, Table 1A).

4.1.1 Plant height

Days after transplanting (DAT) with a p-value of <0.001 were found to have a significant effect on plant height (Figure 4.1). The mean plant height increased with an increase in number of days after transplanting (Figure 4.1). The different particle sizes and DAT had no interaction with p-values of 0.312 and 0.347 respectively (Appendix A, Table 1A).

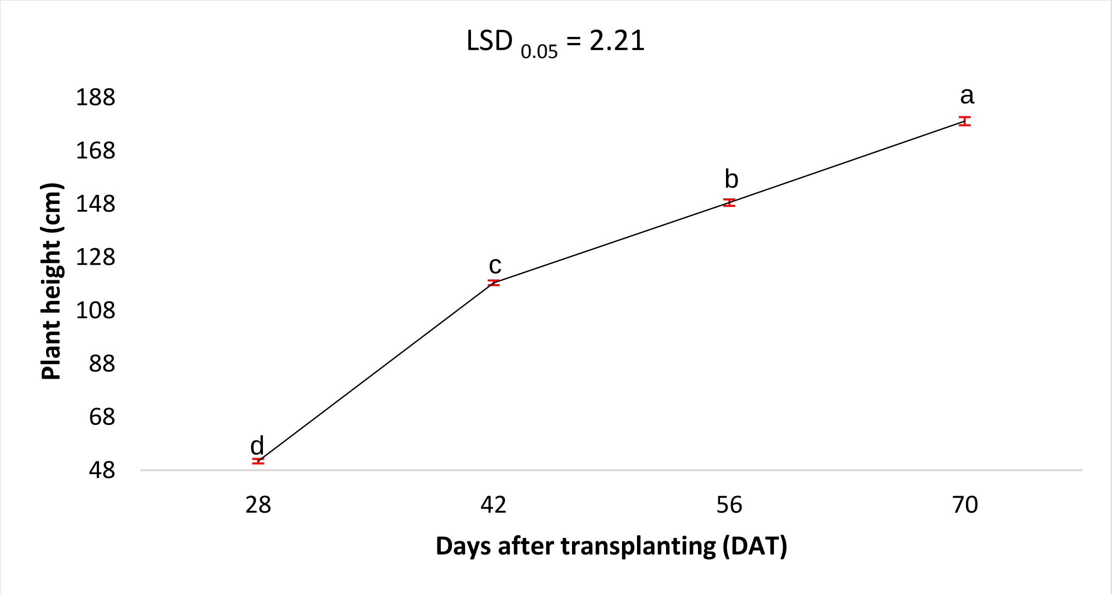

Figure 4.2 Effect of days after transplanting on plant height.

The growing pattern of the plant height was in a linear form (Figure 4.1). At 42 days after transplanting, there was a power failure for a day that severely affected the growing point of the plants. Tomato plants have shown a rapid growth rate at the developmental stage and tend to slower growth during the reproductive stage as the photosynthates are distributed to flowers and fruits (Hurd *et al*., 1979).

4.1.2 Stem diameter

The “DAT” factor with a p-value of < 0.001 was found to have a highly significant effect on plant stem diameter (Appendix A, Table 1A). Stem diameter was significantly thicker at 42 DAT, followed by 56 DAT and 70 DAT, compared to the thinner stem diameter which was obtained at 28 DAT (Figure 4.2). At 42 DAT, there was a decrease in stem thickness which could be explained by water shortages during the power failure which occurred for a period of a day. Usually at that stage, the canopy of the plant is vigorous and photosynthates are evenly distributed to various parts of the plant especially fruits. Studies conducted by Gallardo *et al*. (2006), reflected that there was an increase in stem diameter on young plants and the slow growth was observed on mature plants.

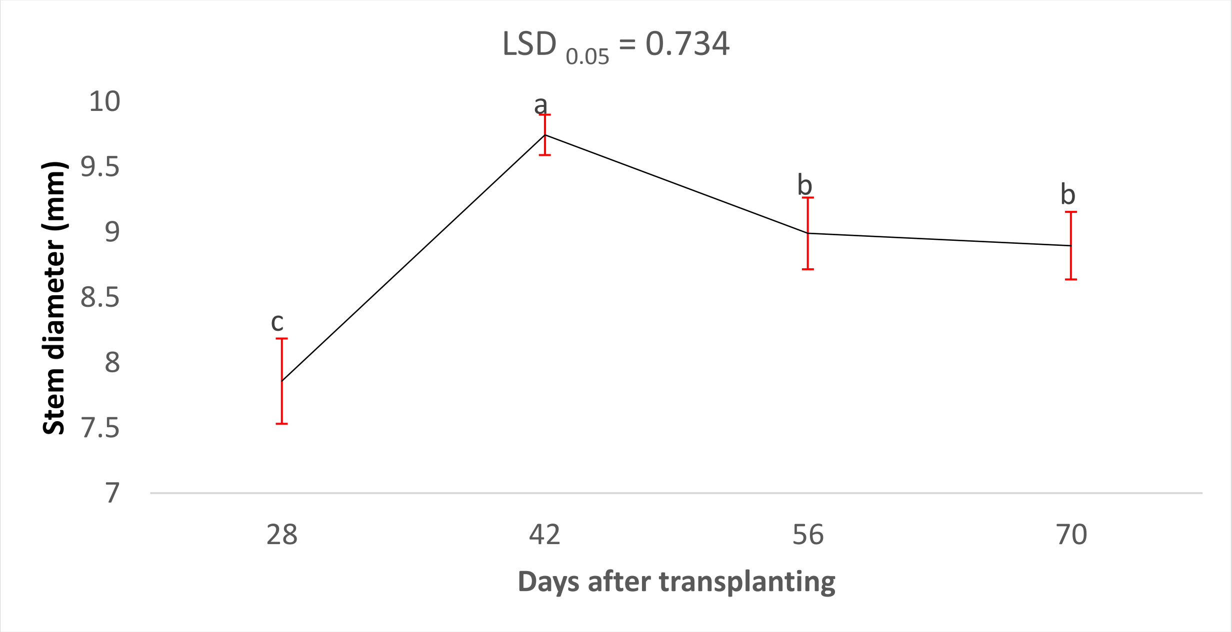

Figure 4.2 Effect of number of days after transplanting on stem diameter.

4.1.3 Number of leaves

The results (Figure 4.3) indicated that there was a significant difference from DAT from 28 to 70 DAT. The decrease in the number of leaves might be due to a power failure which affected the supply of water and nutrient to the plants 48 DAT.

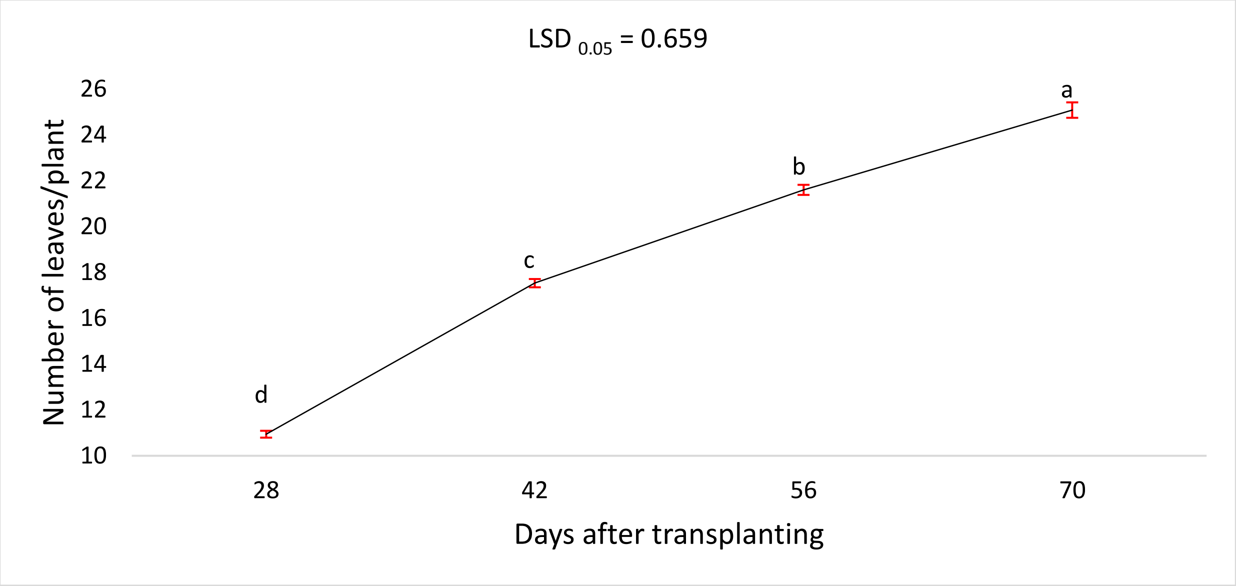

Figure 4.3 Effect of number of days after transplanting on number of leaves.

A study conducted by Logendra *et al*. (2001) reported that an increase in the number of leaves elevated the photosynthetic reaction and increased carbohydrates. As has been seen, there were water shortages caused by a power failure. There was significant increase in number of leaves with an increase in number of DAT.

4.1.4 Leaf length

There was significant increase in leaf length from 28 to 48 DAT (21-26 cm) with no further significant increase in leaf length after 42 DAT (Figure 4.4). However, there was no significant difference amongst the six different particle sizes of sawdust (Appendix A, Table 1A).

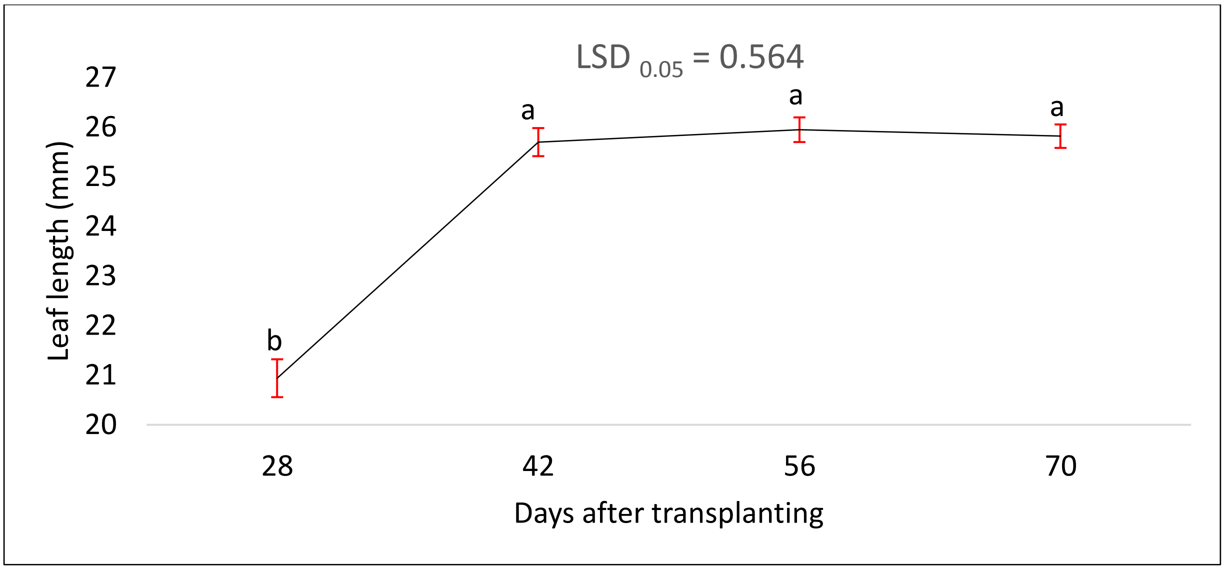

Figure 4.4 Effect of number of days after transplanting on leaf length.

4.1.5 Leaf width

Figure 4.5 shows that leaf width was significantly high at 56 and 70 DAT. During flowering the carbohydrates might have been distributed to the reproductive parts of the plant, which slowed down plant growth in terms of plant height, stem diameter and number of leaves.

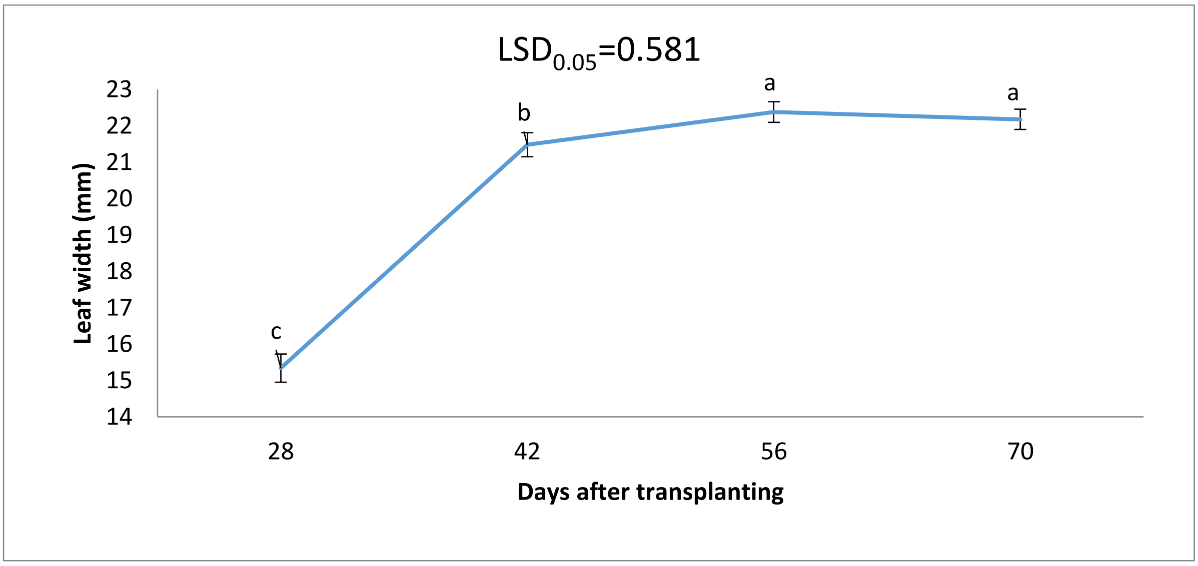

Figure 4.5 Effect of number of days after transplanting on leaf width.

A study conducted by Jankauskienė *et al*. (2010) to estimate the effect of rockwool and coconut fiber substrates on productivity and quality of tomato hybrids ‘Raissa’ and

‘Admiro’ demonstrated that the plant height and leaf number was dependent both on the substrate used and on the hybrid itself. Tomatoes grown in a coconut fiber substrate were 8.1–9.2% higher (insignificant difference) compared with the plants grown in rockwool. In this study the particle sizes did not influence the growth parameters i.e. plant height, stem diameter, number of leaves per plant, leaf length and width. (Appendix 1A).

4.2 Yield parameters

Yield parameters in this case included marketable yield, number and mass of marketable fruits, total and unmarketable yield per plant.

4.2.1 Number and mass of medium sized fruits

A tendency towards a high number of medium sized fruits was observed with CF and F particle sizes while the least number was recorded on M and MF (Figure 4.6).

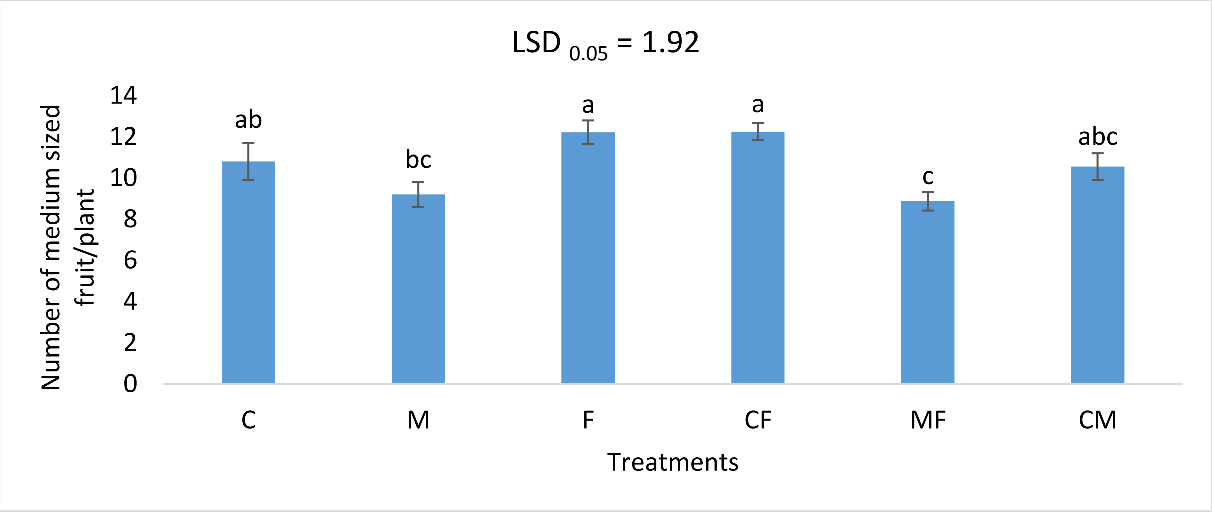

Figure 4.6 Effect of sawdust particle size on number of medium sized fruit. Particle sizes of sawdust: C = coarse, M = medium, F = fine, CF = 50:50% (coarse: fine), MF = 50:50% (medium: fine), CM = 50:50% (coarse: medium).

The particle size of sawdust significantly produced low medium sized fruit mass at MF, although it did not differ significantly with CM and M particle sizes (Figure 4.7).

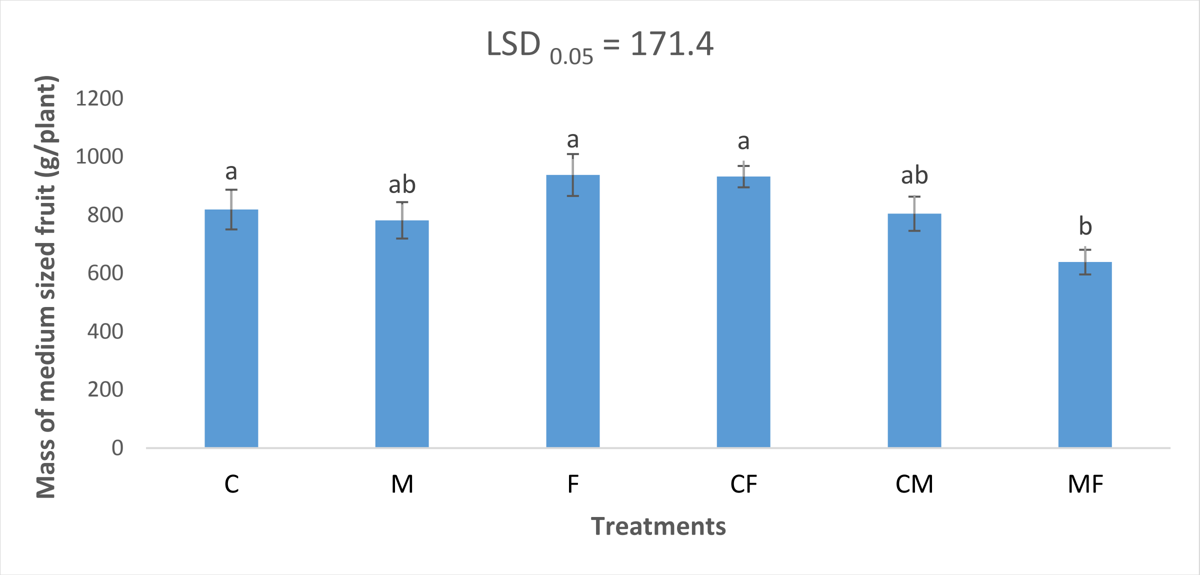

Figure 4.7 Effect of particle sizes on the number of medium sized tomato fruits. Particle sizes of sawdust: C = coarse, M = medium, F = fine, CF = 50:50% (coarse: fine), MF = 50:50% (medium: fine), CM = 50:50% (coarse: medium).

4.2.2 Total, marketable and unmarketable yield

The results demonstrate that the particle size of sawdust did not have a significant effect on marketable yield, total yield or unmarketable yield (Table 4.1, Appendix 2A). However, there was increased tendency towards high yield at treatment CF and F compared to other treatments. The number of marketable fruits was significantly improved at CF and F, although there was no significant difference compared to C.

Ortega-Martinez *et al*. (2010) conducted a study to evaluate four substrates with the mixing ratio of (1:1) i.e. sawdust, compost of sheep manure, red volcanic rock and agricultural soil. The findings were that the sawdust mixture (sawdust and compost of sheep manure) was outstanding in all measured variables including tomato fruit mass and yield. The argument with other reports (Jankauskienė *et al*., 2010; Tzortzakis & Economakis, 2008) is that substrates with different mixtures produce better yield and quality of tomatoes than a pure growing medium.

Table 4.1 Effect of different particle sizes of sawdust on tomato yield

Treatment	Marketable yield/plant (g)	Number of marketable fruits	Total yield (g/plant)	Unmarketable yield (g/plant)
C	2280	27.98 ab	2589	308.9
CF	2475	30.38 a	2823	347.5
CM	1957	25.40 b	2257	299.4
F	2309	29.82 a	2641	331.9
M	2082	25.33 b	2423	340.4
MF	1811	25.15 b	2199	388.0
LSD 0.05	ns	4.16	ns	ns

ns = non-significant; particle sizes of sawdust: C = coarse, M = medium, F = fine, CF = 50:50% (coarse: fine), MF = 50:50% (medium: fine), CM = 50:50% (coarse: medium); LSD = Least significant difference

The findings of this study revealed that fine particle size and the mixture of coarse + fine particle sizes were the treatments that produced better yield than other particle sizes (Table 4.1). Other particle size mixtures such as CM and MF were outperformed by CF and F. This indicates that the correct mixture was a coarse + fine growing medium.

Logendra *et al* (2001), reported that assimilates are elevated with an increased number of leaves which in most instances tends to increase fruit weight and not the fruit number, whereas Maboko and Du Plooy (2008) found that cherry tomato plants pruned to single stem produced large-sized fruit compared to plants pruned to two or three stems which reduced fruit size and increased fruit number. A study conducted by Nzanza (2006) alluded to the fact that the reduced number of fruits was due to high application of CA: Mg ratio fertilizers. Beardsell *et al*. (1979) emphasized that a combination of mixtures possesses both aeration and water holding characteristics respectively which may contribute to crop yield. In this study, CF (coarse + fine particles) improved tomato yield.

4.3 Physiological disorders

Fruit cracking Severe blossom-end rot Blossom-end rot

Figure 4.8 Typical fruit physiological disorders of tomatoes

In this study, physiological disorders that contributed to unmarketable yield were fruits showing incidence of fruit cracking, blossom-end rot (Figure 4.8), blotchy ripening and catface and are regarded as the main physiological disorders that affect tomatoes generally (Nzanza, 2006). The particle size of sawdust did not have an effect on fruit physiological disorders (Appendix A, Table 3A) with the exception of blossom-end rot (Figure 4.9).

Particle size CF produced significantly high fruits with blossom-end rot (Figure 4.9) while there were no significant differences amongst MF, CM, F, M and C treatments. Other reports (Masarirambi *et al*., 2009; Peet, 2009) piloted experiments on the physiological disorders of tomatoes and suggested that several physiological disorders could be side-stepped by choosing resistant cultivars. Nzanza (2006) reported that fruit physiological disorders ultimately affect fruit quality in tomatoes. In this research, the blossom-end rot might be related to water shortages that took place a day after 42 DAT as depicted mostly on the plant growth (Figure 4.1 and 4.5) due to electric failure. Saure (1998) indicated that ca-deficiency causes blossom-end rot and calcium is not easily movable in a plant since it moves through transpiration stream. Failure of the water supply might have exacerbated the incidence of blossom-end rot.

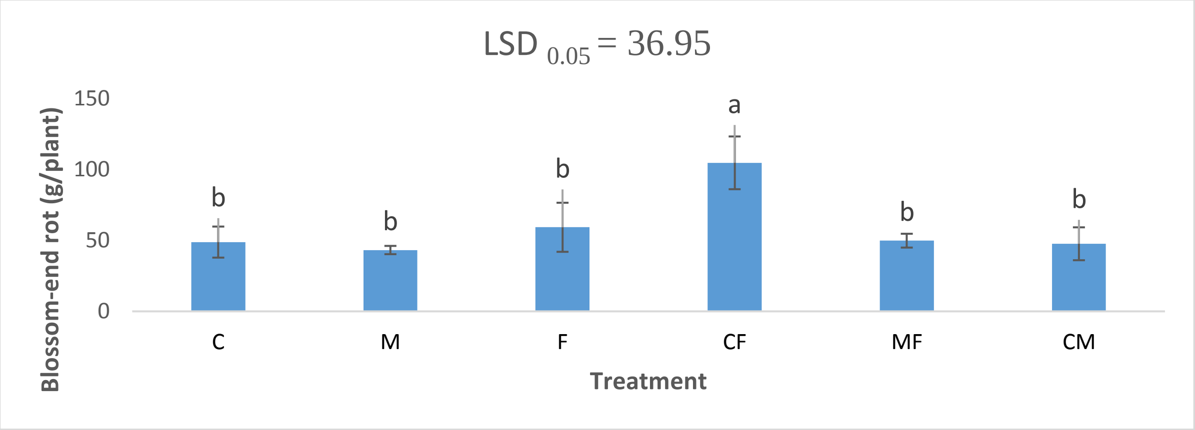

Figure 4.9 Effect of particle size on blossom-end rot per plant. Particle sizes of sawdust: C = coarse, M = medium, F = fine, CF = 50:50% (coarse: fine), MF = 50:50% (medium: fine), CM = 50:50% (coarse: medium).

4.4 Leaf mineral content

The particle size of sawdust did not have a significant effect on leaf mineral content (Appendix A, Table 2A, Table 4.2). However, there was an increased tendency towards leaf nitrogen content with particle size M, while the lowest was evident with CF. The leaf zinc (Zn) content was high on MF and lower at F particle size (Table 4.2).

Table 4.2 Effect of particle size on tomato leaf mineral content

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mn (%)	Zn (mg kg^{-1})
C	3.85	0.70	2.78	5.15	229	25.0
CF	3.06	0.77	2.71	5.18	266	26.7
CM	3.85	0.77	2.97	4.16	192	25.0
F	3.69	0.69	2.69	4.84	246	20.1
M	4.29	0.71	2.67	4.38	206	27.0
MF	3.75	0.83	2.92	4.43	244	35.5
LSD 0.05	ns	ns	ns	ns	ns	ns

ns = non-significant difference; LSD = least significant difference; Particle sizes of sawdust: C = coarse, M = medium, F = fine, CF = 50:50% (coarse: fine), MF = 50:50% (medium: fine), CM = 50:50% (coarse: medium); N = Nitrogen, P = Phosphorus, K= Potassium, Ca= Calcium, Mn = Manganese

These results are contrary to the findings by Nzanza (2006), where blossom-end rot was reported to be a nutritional disorder that could be associated with calcium deficiency, while blotchy ripening could occur as a result of potassium (K) deficiency. In the present study, the disorders could have been caused by factors other than nutrient deficiency as it was not a limiting factor. Park *et al*. (2005) and Saure (2001) suggested that physiological disorders are not always caused by nutrient deficiency. They agreed that other causes could include temperature variation, irregular watering and other environmental factors. However, this investigation did not consider factors other than the effect of sawdust particle size on leaf mineral content.

A study that was conducted by Raja *et al*. (1992) reported that high air-filled porosity (15.7%) in sawdust performed less than that of sand (2.7%) as plants grew better in sand. It appears that the air filled porosity should be at a specific level in order to influence the optimum plant growth.

The above findings are on a par with table 4.1 that shows that CF and F produced high number of marketable fruits, marketable yield and total yield per plant. Fakhrul *et al*. (2013) reported that the growing medium with fine particles retains more water than coarse as its particles occupies large area.

4.5 Fruit mineral content

The mineral content of tomato fruits was tested in order to understand if it is influenced by different particle sizes. The fruit phosphorus content was significantly high at M, although it did not differ significantly with C, CF and MF (Figure 4.10). Fruit moisture and mineral content were not significantly affected by sawdust particle sizes (Appendix A, Table 4A and 4B). The fruit mineral content is determined by the rate at which nutrients are absorbed by plant roots from the growing medium (Sainju et al. 2003). Sainju *et al*. (2003) pointed out that insufficient nutrients in tomato fruits can influence the yield and quality of tomatoes.

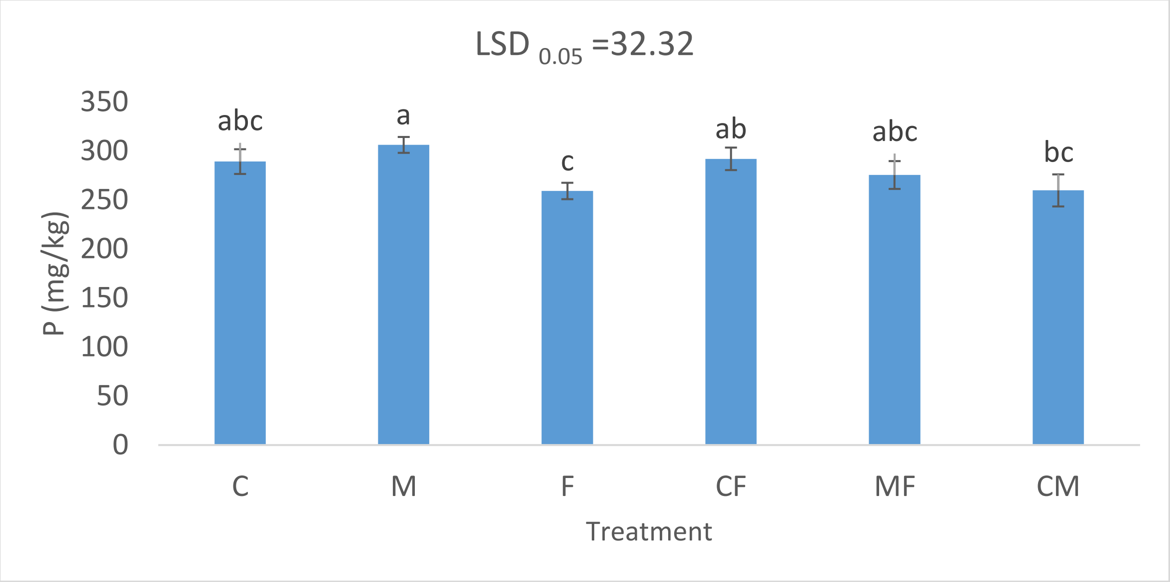

Figure 4.10 Effect of particle size on P fruit content (wet mass basis). Particle sizes of sawdust: C = coarse, M = medium, F = fine, CF = 50:50% (coarse+fine), MF = 50:50% (medium: fine), CM = 50:50% (coarse: medium).

Fine growing media retain moisture better than coarse growing media (coarse and medium) as was explained by Fakhrul *et al*. (2013). However, a few researchers (McDowell and Smith, 1958; Kononova, 1966) suggested a different reason other than substrate texture. Their argument was that a medium with high organic matter and humus has the ability to retain more water and nutrients than a medium with less organic matter.

4.6 Shelf life

Particle sizes of sawdust did not have a significant effect on percentage weight loss at 4th to 20th day of storage. However, the tomato fruits that were harvested from M showed a high tendency of % weight loss than other treatments (Table 4.3). Other reports by Luengwilai *et al*. (2012), and Parker *et al*. (2013) agreed with the opinion that weight loss can also be attributed to temperature variations. However, Parker *et al.* (2013) suggested that ambient humidity could also be a contributing factor to weight loss of tomatoes.

Table 4.3 Percentage weight loss (%) of tomatoes during the storage period of 20 days

Treatment	Weight loss (%)				
	4 days	8 days	12 days	16 days	20 days
C	2.78	6.50	9.12	11.75	13.75
CF	3.92	8.78	11.99	14.94	17.93
CM	3.04	6.99	9.50	11.85	13.92
F	3.22	7.35	10.01	12.73	14.93
M	2.93	6.83	7.35	11.84	14.18
MF	3.43	7.81	10.92	13.94	16.20
LSD 0.05	ns	ns	ns	ns	ns

ns = not significant; LSD = least significant difference; sawdust particle sizes: C = course, M = medium, F= fine, CF = 50:50 % (coarse: fine), MF = 50:50% (medium: fine) and CM = 50:50% (Coarse: medium)

4.7 Physical and chemical properties of sawdust

Table 4.4 below shows the physical and chemical properties of six different particle sizes of sawdust before the experiment. The intention was to determine the change in the physical and chemical properties before and after the experiment.

Table 4.4 Physical and chemical properties of six particle sizes of sawdust before planting

Parameters	C	M	F	CM	CF	MF	Units
Moisture	42.59	12.36	34.16	21.58	23.29	16.79	% (v/v)
NO_3^-	Nd	Nd	Nd	Nd	Nd	1.40	mg/l
NO_2^-	Nd	Nd	Nd	0.20	Nd	1.20	mg/l
Cl^-	19.0	11.8	32.7	9.90	19.9	13.7	mg/l
F^- *	0.40	Nd	0.17	0.70	0.20	1.30	mg/l
SO_4^{-2}	6.60	16.1	30.7	12.20	15.7	14.9	mg/l
PO_4^{-3}	0.04	2.35	3.30	0.35	4.0	0.57	mg/l
HCO_3^-	26.6	23.1	21.0	21.6	30.3	14.9	mg/l
K	31.9	39.5	41.8	36.2	39.9	43.4	mg/l
Ca	7.48	6.36	9.46	5.98	7.79	5.60	mg/l
Mg	3.11	3.33	9.46	2.72	3.53	3.65	mg/l
B	0.10	0.04	0.06	0.06	0.08	0.04	mg/l
Fe	58.6	0.43	0.46	0.64	0.44	0.31	mg/l
Mn	0.10	0.16	0.17	0.28	0.165	0.19	mg/l
Cu	0.01	0.02	0.05	0.01	0.048	0.04	mg/l
Zn	0.01	0.02	0.04	0.01	0.04	0.02	mg/l
WHC **	58.6	52.6	79.10	52.8	64.4	67.80	% (v/v)
Air-Filled Porosity	22.7	31.0	8.10	29.2	13.8	17.10	% (v/v)

Nd = Not detected, WHC = Water holding capacity. C = coarse, M = medium, F= fine, CF = 50:50 % (coarse: fine), MF = 50:50% (medium: fine) and CM = 50:50% (coarse: medium)

4.8 Water holding capacity (WHC)

Water holding capacity was significantly high on fine particle size while poor water holding was found on C and CM (Figure 4.11). The results in figures 4.11 and 4.12, showed a slight tendency towards increased water holding capacity and air-filled porosity (%) compared to fresh sawdust. This could be as a result of sawdust as organic medium which decomposes and increases water retention and reduces air porosity with time. Fine particle size (F) had the highest water holding capacity as the fine particle sizes are closely packed together (Michel, 2010). Coarse and CM particle sizes had poor water holding capacity. Badcock-Walters (2008) suggested that fine growing media hold water for a longer time than media containing medium particle sizes.

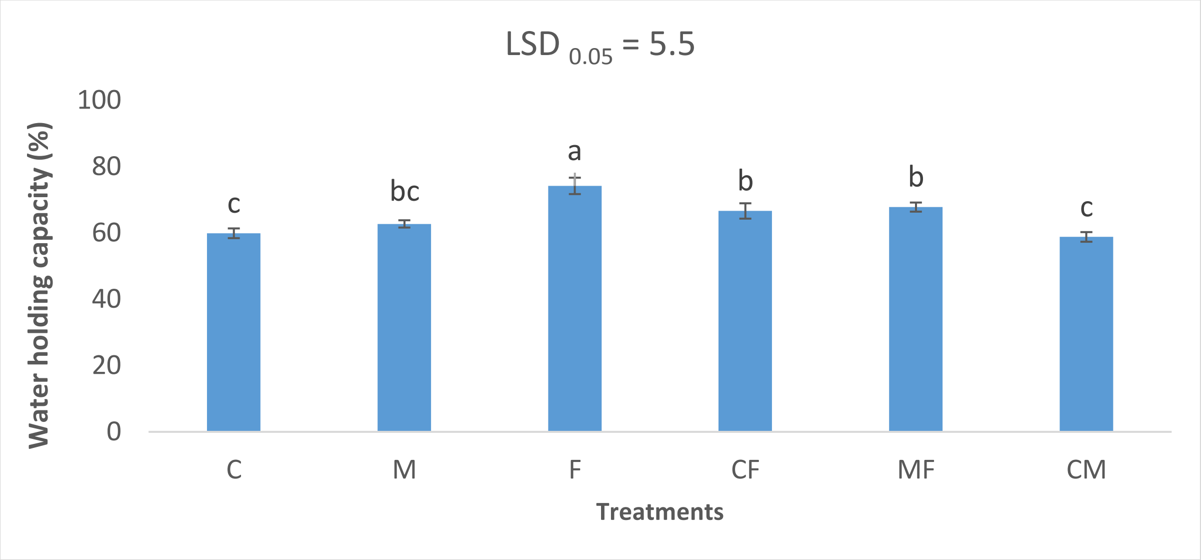

Figure 4.11 Effect of different particle sizes of sawdust on water holding capacity. Sawdust particle sizes: C = coarse, M = medium, F= fine, CF = 50:50 % (coarse: fine), MF = 50:50% (medium: fine) and CM = 50:50% (coarse: medium)

4.9 Air-filled porosity

Air–filled porosity (AFP) means the total percentage of the volume of the medium occupied by the air at end of the free drainage (Raviv *et al*., 2002). Air filled porosity was significantly high on C, M and CM particle size (Figure 4.12). The least AFP was obtained on F particle size.

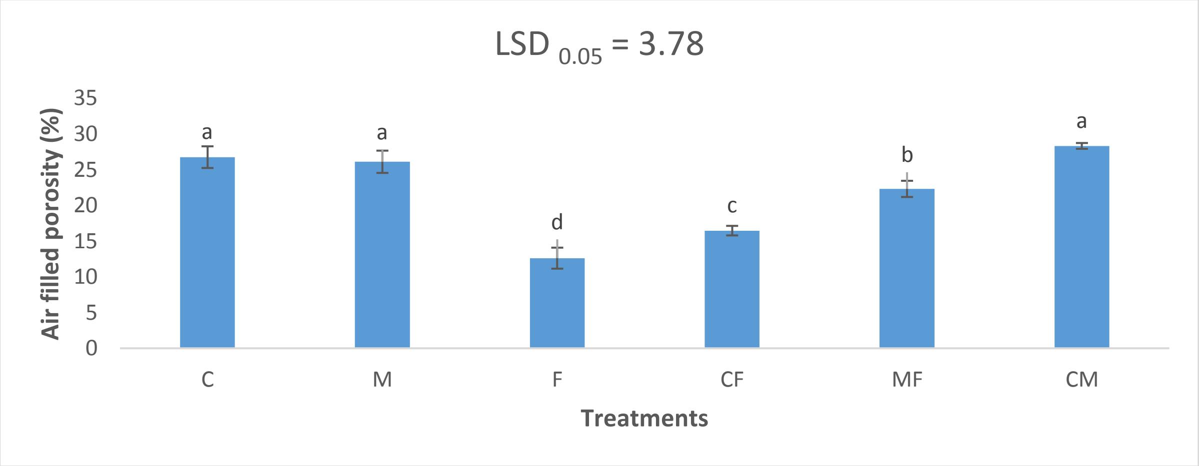

Figure 4.12 Effect of particle size of sawdust on air-filled porosity. Sawdust particle sizes: C = coarse, M = medium, F= fine, CF = 50:50 % (coarse: fine), MF = 50:50% (medium: fine) and CM = 50:50% (coarse: medium).

This means that C, CM and M have higher air-filled porosity than F, MF and CF growing media. For sufficient and free flow of gaseous exchange, drainage and water holding capacity, the proper quantity of macrospores are necessary (Marinou *et al.*, 2013). In this case, the significance of the results regarding air-filled capacity is that treatment CM, C and M had high air-filled porosity and will therefore provide aeration and drainage to plant roots.

Guo *et al*. (2012) also affirmed the notion that aeration is important, as insufficient aeration can lead to anaerobic respiration. The treatment with high air-filled porosity means that it would be ideal to avoid anaerobic conditions. Reports by Anlauf *et al*. (2012) and Guo *et al*. (2012) have a common understanding that physical properties influence water uptake; however, Anlauf *et al*. (2012) further indicated that form and the gradient were contributing factors. Raviv (2014) differed from the above reports due to the fact that physical properties were related to mineral uptake, but it was not clear whether the mineral uptake was also influenced by the water absorption rate. The findings by Heiskanen (1993) emphasized that the growth medium must be maintained at all times to ensure proper growth and quality of the plantings. These results reflected a strong correlation between air-filled porosity and holding capacity (Figure 4.11 and 4.12). In other words, the higher the water retention capacity, the lower the air-filled porosity. A lower AFP of 13 and 16.5% for particle size F and CF respectively, improved tomato yield (Table 4.1).

4.10 Water drainage

Drainage water analysis is important as it provides information on the nutrient status of the substrate at any given time (Bailey *et al*., 1998). Furthermore, drainage water analysis also helps to determine which substrates retain water or nutrients better.

The highest water drainage was obtained at 100 and 111 DAT (Figure 4.13). The mean values were observed to be not significantly different at 64 - 93 DAT; however, results generally showed an increase in drainage water with an increase in number of DAT until 111 DAT. Water application was increased as the plant developed to supply the leaves, flowers and the fruits. At 64 to 93 DAT during the ripening stage, the water was evenly distributed as there was no significant difference amongst the dates. During the ripening stage of the tomato fruit, water was applied consistently to plants as the ripe tomatoes could crack severely (Chrétien and Gosselin, 2000).

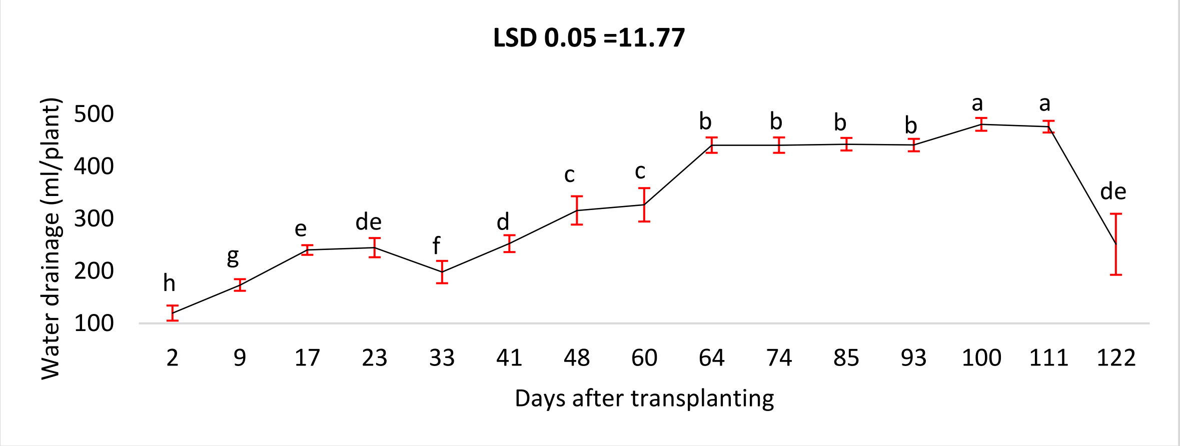

Figure 4.13 Effect of DAT on drainage water

Reports by Vázquez *et al*. (2006), and Mangiafico *et al*. (2009) demonstrated that excessive drainage can result in leaching of nutrients and that can cause deficiency of the essential elements. This will support the findings of Chrétien and Gosselin (2000) that during the ripening stage of tomatoes balanced water distribution is necessary. Particle size of sawdust in this study did not have a significant effect on water drainage.

4.11 Electrical conductivity (EC) of drainage nutrient solution

Electrical conductivity (EC) is the salt content based on the flow of electric current (Richard, 2006). Particle size of sawdust did not have a significant influence on the EC drainage nutrient solution. The highest EC of drainage nutrient solution was obtained at 51 to 54 DAT (Figure 4.14). During the early stages of the plant growth, there was an increase in EC drainage nutrient solution until 54 DAT. The mean values started to drop until 88 DAT. The cause of this increase and the drop of the EC were not identified as the study was not investigating the electric conductivity in this case. However, fresh sawdust might have a low nutrient holding capacity and plants were still too young to have large root systems to increase nutrient absorption.

Tadesse *et al*. (1999), explained that reduced fruit growth and fruit size is due to elevated EC of the nutrient solution. When a growing medium like sawdust is used for a prolonged time, it starts to decompose and increases water retention capacity with time (Niederwieser, 2001). However, a fine growing medium holds water for a longer time than a medium particle sized growing medium (Badcock-Walters, 2008).

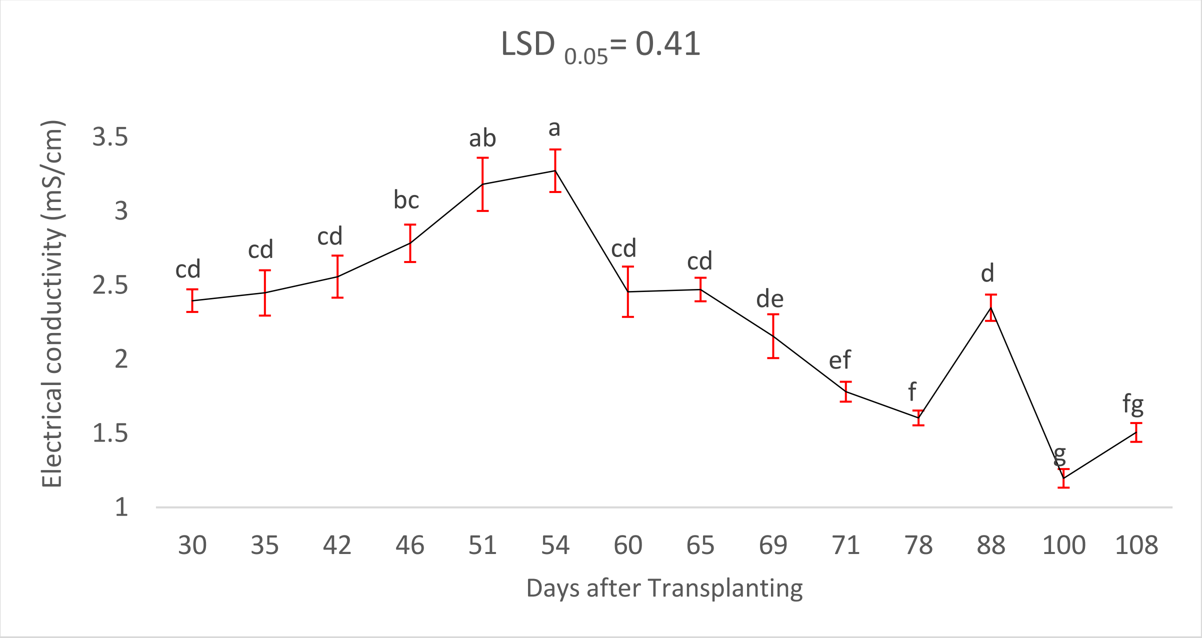

Figure 4.14 Effect of DAT on electrical conductivity of the drainage nutrient solution

The mean difference was obtained by subtracting drainage EC (from planting bag) from incoming EC (irrigation water) of nutrient solution. The EC differences were very high between 51 and 54 DAT and lower after 88 DAT (Figure 4.15). It is evident that at the beginning of transplanting the growing medium was not composted and the roots were still young and less numerous, and this resulted in high EC drainage. At 54 DAT, the EC started dropping until 78 DAT. The rise in EC also occurred again at 88 DAT. The drop might have been influenced by the biogradability of the growing medium. The aim of the study was not to determine factors affecting the drop of EC.

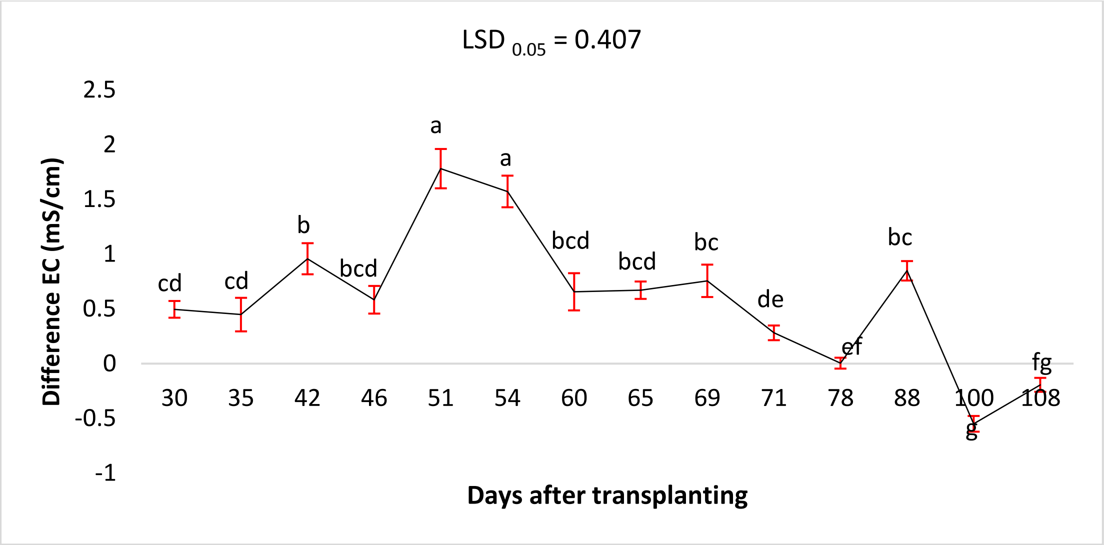

Figure 4.15 Effect of DAT on the differences in EC drainage nutrient solution

A study conducted by Eymar *et al*. (2001) revealed that when a medium was not decomposable, less interaction between the nutrients and the growing medium was experienced and EC was unaffected. Chrétien and Gosselin(2000) illustrated that increased EC of the nutrient solution did not affect growth at the vegetative and reproductive stages; however it can only increase fruit quality of tomatoes and has less effect on yield. This is in contrast to the findings of Tadesse *et al*. (1999).

4.12 pH

The pH is merely a mathematically derived scale relating to the alkalinity and the acidity of the solution (Harris, 1987). Furthermore, the author indicated that impediments in the hydroponic system are expected at above 7.0 and below 4.0 pH level. The pH of the drainage nutrient solution was not significantly affected by particle sizes of sawdust.

In the case of EC, the pH was measured in the water tank before the water reached the growing medium (incoming pH) and even after seepage from the bags containing sawdust (pH of drainage nutrient solution). In this investigation, the pH was not measured to observe its impact on growth, yield and quality of tomatoes, but only to detect if there was a relationship between pH and particle sizes.

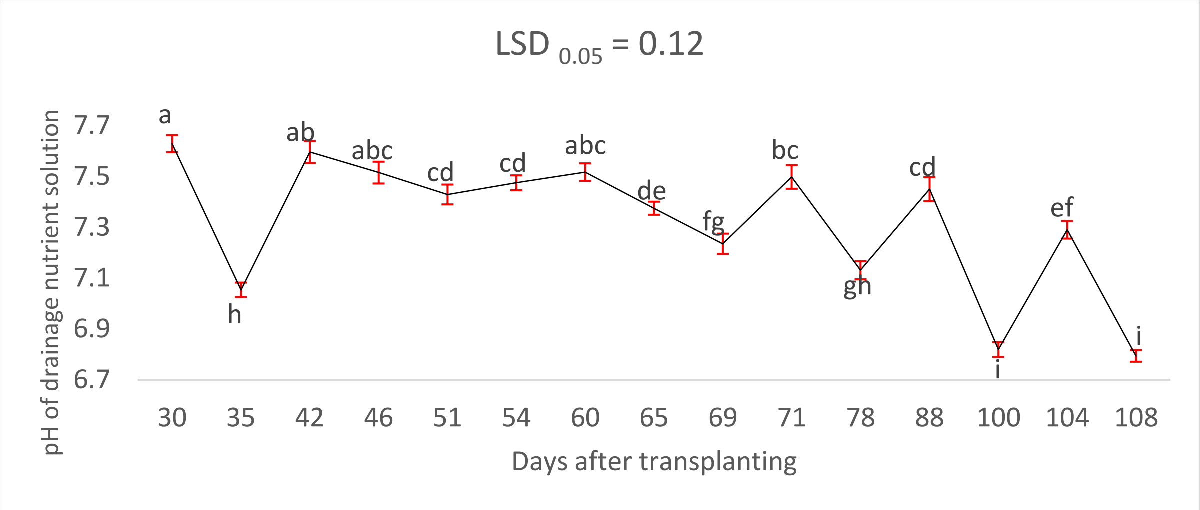

Figure 4.16 Effect of DAT on the pH of drainage nutrient solution

The mean values on the graph recorded at 30, 35, 100 and 108 DAT were significantly different to other DAT (Figure 4.16). There was a relative significant difference from 42 to 88 and 104 days after transplanting. There was a relationship amongst the dates except for 30, 35, 100 and 108 DAT. Generally, the pH of the drainage water was at an average of 7.4.

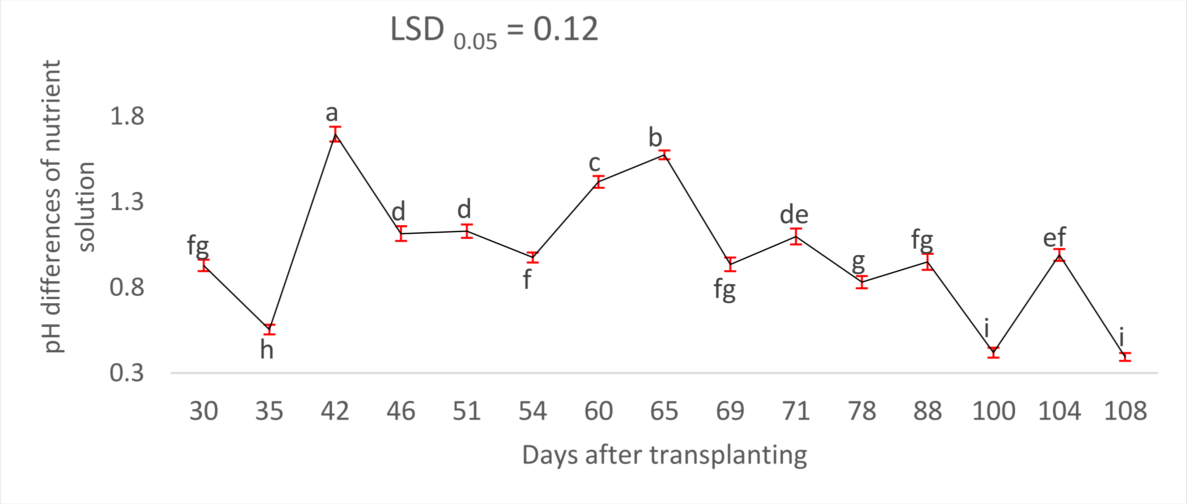

Figure 4.17 Effect of DAT on the pH differences (incoming pH and drainage pH)

Figure 4.17 assumes a haphazard shape with the mean value of 1.696 at 42 days after transplanting. The lowest mean values of 1.419 and 0.394 were recorded at 100 and 108 days after transplanting respectively. A raised pH in the water solution negatively affects the fruit weights and sizes of some fruits (Chrétien and Gosselin, 2000).

Tyson (2008), and Treadwell *et al*. (2010) are in agreement that the pH can negatively affect microbial activity and the assimilation of certain nutrient elements. However, the ideal water pH for hydroponic production is in the range of 5.5-6.5 (Treadwell *et al*., 2010). It seems as if there could be other factors that contributed to elevated pH but which nonetheless did not have any detrimental effects on roots and availability nutrients was not affected.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The texture of the growing medium plays a major role in the production of tomatoes in soilless production. Sawdust is used worldwide mostly near forest areas, because of its affordability and high water holding capacity (Marinou *et al*., 2013). Different particle sizes of sawdust have shown no significant differences in the growth, yield and quality of tomatoes; only mean dates were significant in growth parameters (plant height, stem diameter, numbers of leaves per plant, leaf length and width). The physical and chemical properties did not have a significant effect on hydroponically grown tomatoes.

Generally, the CF and F particle sizes showed improved mass and number of medium sized fruit in comparison with other particle sizes of sawdust. Even though the particle size of sawdust did not have significant effect on total yield and marketable yield, there was a tendency towards increased yield on plants grown in CF followed by F particle sizes. As regards physiological disorders, blossom-end rot was significantly affected by particle sizes of sawdust. Particle size CF produced a significantly high incidence of fruit prone to blossom-end rot compared to other treatments.

The improved yield in CF and F particle size could be explained by the physical properties of the particle sizes of sawdust. The unique physical properties such as aeration, drainage and water-holding capacity that this mixture, CF and F particle sizes of sawdust possesses, contributed to improved yield in hydroponically grown tomatoes. Fine and 50:50% coarse: fine can be regarded as the ideal particle sizes of sawdust as growing media for hydroponically grown tomatoes.

5.2 RECOMMENDATIONS FOR FUTURE RESEARCH

Based on conclusions made from the findings, the study recommends that the coarse+fine (CF) particle sizes of sawdust growing medium be used for commercial tomato production in hydroponics. This is due to the improvement in yield in terms of marketable yield, number of marketable fruits and total yield per plant. CF also proved to be better in terms of physical properties because it had better water holding capacity and was well aerated.

The study will help tomato growers to make informed decisions when selecting sawdust particle sizes in order to produce high yield. There was a change in physical properties depending on the particle sizes of the organic growing medium such as sawdust over time which did not significantly affect yield. It is recommended that further studies be conducted on whether the physical properties of the recommended (coarse+fine) medium can affect yield and quality of hydroponically grown tomatoes when the medium is reused or used over long period.

References

Abbas, S. (2009). Effect of particle size distribution of perlite and organic media on cucumber in hydroponics. *Indian Journal of Horticultural Science*, 66, 326 – 332.

Adriaanse, P. (2013). A comparison of growth media in a controlled environment. MSc. Thesis University of South Africa. School of Ornamental Horticulture. South Africa

ALASA, (1998). Handbook of Feeds and Plant Analysis.

Allaire, S., J. Caron, C. Menard., & M. Dorais. 2004. Growing media varying in particle size and shape for greenhouse tomato. *Acta Horticulturae*, 644,307-311.

Anlauf, R., Rehrmann. P., & Schacht, H. (2012). Simulation of water uptake and redistribution in growing media during ebb-and-flow irrigation. *Journal of Horticultural and Forestry*, 1, 8-21,

Askew, D.J. (1996). Tomato production guideline for the Umlaas river valley area of KwaZulu - Natal: *Department of Horticultural Science*, University of Natal: ISBN 1-86840-203-7.

Badcock-Walters, T. (2008). Cultivating Flavour. 29 Winston, Kloof Road, 3610, South Africa. Lizard’s Leap Press ISBN 978-0-8914173-0-1.

Bailey, D., & Bilderback, T. (1998). Alkalinity control for irrigation water used in nurseries and greenhouses. NC State University. *Hort. Info*. (Available at www2.ncsu.edu/floriculture/)

Beardsell, D.V., Nichols, D.G., & Jones, D.L. (1979). Physical properties of nursery potting-mixtures. *Scientia Horticulturae*, 11 (1), 1–8.

Bunt, A.C. (1988). Media and mixes for container-grown plants. 2nd Ed. Unwin Hymnan Ltd., London, pp 309.

Chrétien, S., & Gosselin, A., & Dorais, M. (2000). High electric conductivity and radiation based water management improve fruit quality of greenhouse tomatoes grown in rock wool. *HortScience*, 25:627-631

DAFF, (Department of Agriculture, Fisheries and Forestry). (2012). A profile of South African tomato market value chain. www.daff.gov/docs/amcp/tomatomvcp (2010) pdf accessed in May 2012.

DAFF, (Department of Agriculture, Fisheries and Forestry). (2011). Hydroponic vegetable production. www.daff.gov/docs/amcp/tomatomvcp (2010) pdf. Accessed in November 2014.

Drzal, M.S., Fonteno, W.C., & Cassel, D.K. (1999). Pore fraction analysis: a new tool for substrate testing, Soil Science Department, North Carolina State University. *Acta Horticulturae*, 481, 43-54.

Dubský, M., & Šrámek, F. (2009). The effect of rockwool on physical properties of growing substrates for perennials. *Horticultural Science*, *36* (1), 38–43.

Eberhardt, T.L., & Min, S. (2007). Biosorbents prepared from wood particles treated with anionic polymer and iron salt: Effect of particle size on phosphate adsorption. *Bioresource Technology*, 99, 626 - 630.

Eymar, E., Oki L.R., & Lieth, J.H. (2001). Continuous measurements of electrical conductivity in growing media using a modified suction probe: Initial calibration and potential usefulness. *Journal of Plant and Soil Science,* 230, 67–75.

FAOSTATS, http//en.wikipedia.org/wiki/tomato accessed in July 2014.

Fakhrul, T., Mahbub, R., & Islam, M. A. (2013). Properties of wood sawdust and wheat flour reinforced polypropylene composites. *Journal of Modern Science and Technology*, 1 (1), 135-148.

Gallardo, M., Thomson, R. B., Valdes, M.C., & Fernandez, M.D. (2006). The use of stem diameter variations to detect plant hwater stress in tomato. Journal of Irrigation Science, 24: 241-255

Guo, R., Li, G., Jiang, T., Schuchardt, F., Chen, T., Zhao, Y., & Shen, Y. (2012). Effect of aeration rate, c/n ratio and moisture content on the stability and maturity of the compost. Bioresource Technology, 112, 171-178.

Hardgrave, M., Harriman, M. (1995).Development of organic substrates for hydroponic cucumber production Acta Horticulturae, 401.26

Harmayani, K.D., & Anwar A, H. M. F. (2012). Adsorption of nutrients from storm water using sawdust. International Journal of Environmental Science and Development, 3, 114-117.

Harris, D., (1974). Hydroponics: The South African guide to the gardening without soil. 4th ed: Keerom Street, Cape Town (South Africa). ISBN 3 60002 366.

Harris, D., (1987). Hydroponics: The South African guide to the gardening without soil. 7th ed: Oswald Pirow Street Foreshore, Cape Town. ISBN 0 86977 283 X.

Heiskanen, J. (1993). Favourable water and aeration conditions for growth media used in a containerized tree seedling production: A review. Scandinavian Journal of Forest Research, 8, 1-4.

Hurd, R.G., Gay, A.P., & Mountifield, A. C. (1979).The effect of partial flower removal on the relation between roots, shoot and fruit growth in the indeterminate tomato. Annals of Applied Biology, 93, 1, 77–89,

http://edis.ifas.ufl.edu/department_horticultural_sciences. October 2014

http://www.retsch.com/ July 2012

http://edis.ifas.ufl.edu/pdffiles/CN/CN00400.pdf (November. 2012)

Ingram, D., Henley, R. W., & Yeager, T.H. (2003). Growth media for container grown ornamental plants. BUL 241, the Environmental and Horticultural Department Florida. Cooperative Extension Service, Institute of Food and Agricultural science, University of Florida, pp.18.

Jankauskienė, J., Brazaitytė, A., & Viškelis, P. (2010). Effect of Different growing substrates on physiological processes, productivity and quality of tomato in soilless culture. Institute of Horticulture, Lithuanian Research Centre for Agriculture and Forestry, *Lithuania Journal of Horticultural Science*, 1 (1), 19-25.

Kononova, M.M. (1966). Soil Organic Matter: It's nature, its role in soil formation and in soil fertility. Second edition, The Academy of Soil Science of the USSR.

Logendra, L.S., Thomas, J., Gianfagna, T.J., David, R., Specca, D.R., Harry, W., & Janes H.W. (2001). Greenhouse tomato limited cluster production systems: crop management practices affect yield. *HortiScience*, 36 (5), 893–896.

Luengwilai, K., Beckles, D.M., & Saltveit, M.E. (2012). Chilling-injury of harvested tomato (*Solanum lycopersicon* L.) micro-tom fruit is reduced by temperature pre-treatments. *Journal of Biological and Technological Science*, 63,123–128.

Maboko, M.M., & Du Plooy, C.P. (2008). Effect of pruning on yield and quality of hydroponically grown cherry tomato (*Lycopersicon esculentum*). *South African Journal of Plant and Soil*, 3 (25), 178-181

Maboko, M. M., & Du Plooy, C. P. (2009). Comparative performance of tomato cultivars in soilless vs. in soil production system. *Acta Horticulturae*, 843, 319-326.

Maboko, M. M., & Du Plooy, C.P. (2013b). Effect of plant spacing and harvesting frequency on the yield of Swiss chard cultivars (*Beta Valgaris* L.) in a closed hydroponic system.). *African Journal of Agricultural Research*, 8 (10), 936-942.

Maboko, M.M., Bertling, I. & Du Plooy, C.P. 2013. Arbuscular mycorrhiza has limited effect on yield and quality of tomatoes grown under soilless cultivation. *Acta Agriculturae Scandinavica,* Section B Soil & Plant Science, 63 (3), 261-270.

Maboko, M.M., & Du Plooy C.P. (2014). Yield of hydroponically grown tomato Cultivars as affected by transplanting stage or direct seeding. *HortScience*, 49, 438-440.

Maharani, R., Yutaka, T., Yajima, T., & Minoru, T. (2010). Scrutiny on physical properties of sawdust from tropical wood species: Effect of different mills and sawdust‘s particle sizes. *Journal of Forestry Research*, 7, (1), 20 - 32.

Mangiafico, S.S., Newman, J., Merhaut, J.D., Gan, J. F., & Wu, B. (2009). Nutrients and pesticides in storm water runoff and soil water in production nurseries and citrus and avocado groves in California. *HortTechnology,* 19, 2, 360-367.

Maragatham, D., & Raj, S.P. (2010). Physical characteristics of coir pith as a function of its particle size to be used as soilless medium. *Journal of Agricultural and Environmental Science*, 8 (4), 431- 437.

Marinou, E., Chrysargyris, A. N., & Tzortzakis, N. (2013). Use of sawdust, coco soil and pumice in hydroponically grown strawberry. *Journal of Plant, Soil and Environmental Science,* 59 (10), 452–459.

Martin, P.N., Gent M.P.N., & Short, M.R. (2012) Effect on yield and quality of a simple system to recycle nutrient solution to greenhouse tomato. *HortScience*, 47, 11, 1641-1645.

Masarirambi M.T., Mhazo, N., Oseni, T.O., & Shongwe, V.D. *(*2009). Common physiological disorders of tomato (*lycopersicon esculentum*) fruit found in Swaziland. *Journal of Agricultural and Social Science*, 5 (4), 123–127.

McDowell, L. L., & Smith G. E., (1958). The Retention and reactions of anhydrous ammonia on different soil types. *Journal of America Soil Science Society*, 22 (1), 38-42.

Michel, J.C. (2010). The physical properties of peat: a key factor for modern growing medium. ISSN – 754x International Mire Conservation Group and international Peat Society, 6 (2), 1-6.

Miller, J.H., & Jones N. (1995). Organic and compost-based growing media for tree seedling nurseries. *Division of Agriculture and Natural Resource Department*, 66 Avenue d'lena, 75116 Paris, France. ISSN: 0253-7494.

Mokrzecka, E. (2000). Effect of substrates with sawdust on yielding of greenhouse tomatoes: Annales Universitatis Mariae Curie Skodowska Sectio EEE, *Horticultura*, 8, 11-18.

Niederwieser, J.G. (2001). Guide to hydroponic vegetable production (2nd edition). Agricultural research Council, Roodeplaat, Vegetable and Ornamental Plant Institute. Pretoria, South Africa, pp, 140.

Nzanza, B. (2006). Yield and quality of tomato as influenced by differential Ca, Mg and K nutrition. MSc. Thesis. University of Pretoria, Department of Plant Production and Soil Science. Faculty of Natural and Agricultural Science, South Africa.

Nurzynski, J. (2013). Yield and quality of greenhouse tomato fruit grown in rape straw substrates. *Acta Scientiarum Polonorum, Hortorum Cultus*, 12, 1, 3-4

Ortega-Martinez, L.D., Sanchez-Olarte, J., Ocampo-Mendoza, J., Sandoval, E., Salcido-Ramos, B.A., & Manzo Ramos, F. (2010). Effect of different substrates on the growth and yield of tomato under greenhouse conditions. Ra Ximhai; 6(3): 339-346.

Parker, R., & Maalekuu, B.K. **(**2013). The effect of harvesting stage on fruit quality and shelf-life of four tomato cultivars. *Journal of Agricultural and Biological Science*, 4 (3), 252-259.

Park, S., Cheng, N.H., Pittman, J.K., Yoo, K.S., Park, J., Smith, R.H., & Hirschi, K.D. (2005). Increased calcium levels and prolonged shelf life in tomatoes epressing arabidopsis H^+/Ca^{2+} transporters[1]. *American Society of Plant Biologists*, 139,1194-1206.

Peet, M.M. 2009. Physiological disorders in tomato fruit development. *Acta Horticulturae* 821:151-160

Raja, H.R.M., Hall, D.A., Hitchon, C.M., & Szmidt R.A.K. (1992). Melon cultivation in sand and hardwood sawdust. Department of Agriculture. *Journal of Horticultural and Plant Breeding,* 15, 217-220.

Raviv, M. (2014). Building and maintaining soil health in the context of organic greenhouses*. Acta Horticulturae*, 104, 1, 79-86

Richard, M.P. (2006). Effect of nursery media particle size distribution on container-grown woody ornamental production, MSc. Thesis, B.S. Louisiana State University.

Rodriguez, J.C., Cantliffe, D.J., & Shaw, N. (2001). Performance of greenhouse tomato cultivars grown in soilless culture in North Central Florida. *Proceedings Florida State of Horticultural Society* (114), 303-306.

RothamStead (2010) http://www.bbsrc.ac.uk/ accessed May 2013.

Sainju, U.M., Whitehead, W.F., and Singh, B.P. (2003). Agricultural management practices to sustain crop yields and improve soil and environmental qualities. *Scientific World Journal*, 3, 768-789.

Samadi, A. (2011). Effect of particle size distribution of perlite and its mixture with organic substrates on cucumber in hydroponics. Journal of Agricultural Science and Technology, 13: 121-129.

Saure, M.C. (2001). Blossom end rot of tomato (*Lycopersicon esculentum mill.)* calcium or stress related disorder. *Scientia Horticulturae*, 90, 193- 208.

Sawan, O. M.M., & Eissa, A.M. (1996). Sawdust as an alternative to peat moss media for cucumber seedlings production in greenhouses. *Acta Horticulturae*, 434,14

Savvas, G., & Gizas, G. (2007). Particle size and hydraulic properties of pumice affect growth and yield of greenhouse crops in soilless culture. *HortScience*, 42, 5: 1274-1280

Shah, M., Khattak, A.M., & Amin, N. (2006). Effect of different growing media on the rooting of *ficus binnendijkii* ‘amstel queen’ cuttings. *Journal of Agricultural and Biological Science* 1, 15-17.

Tadesse, T., Nichols, M.A., Hewett, E.W., & Fisher, K.J. (2001). Relative humidity around the fruit influences the mineral composition and incidence of blossom-end rot in sweet pepper fruit. *Journal of Horticulture and Forestry,* 76, 9-16.

Treadwell, D., Taber, S., Tyson, T., & Simonne, E. (2010). Foliar-applied micronutrients in aquaponics: a guide to use and sourcing1, *Horticultural Sciences Department*, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida.

Tyson, R.V., Simonne, E.R., & Treadwell, D.D. (2008). Reconciling pH for ammonia biofiltration in a cucumber/tilapia aquaponics system using a perlite medium. *HortScience* 43, 3, 719–724.

Tzortzakis, N.G., & Economakis, C.D. (2008). Impacts of the substrate medium on tomato yield and fruit quality in soilless cultivation. *Journal of Horticultural Science 35*, (2): 83–89.

Vano, I., Matsushima, M., Changyuan Tang, C., & Inubushi, K. (2011). Effects of peat moss and sawdust compost applications on N_2O emission and N leaching in blueberry cultivating soils. *Journal of Soil Science and Plant Nutrition*, 57, 2, 348, - 360.

Vázquez, N., Pardo, A. M.L., Suso M.L., & Quemada M. (2006). Drainage and nitrate leaching under processing tomato growth with drip irrigation and plastic mulching. *Journal of Agricultural Science*, 112, 313 – 323.

Walls, I.G. (1987). Concorde gardening: simple growing tomatoes, 2nd ed. Ward Lock Limited, London: ISBN 0-7063-6505-4.

Yoon, H.S., Hwang, Y.H., An, C.G., Hwang, H.J., & Shon, G.M. (2007). Effect of reuse of organic substrate on growth and yield of strawberry in soilless culture. Acta *Horticulturae*, 761.

APPENDIX A

Table 1A. ANOVA table for plant growth parameters

Source of variation	df	Fpr				
		Plant height	Stem diameter	Number of leaves	Leaf length	Leaf width
Rep	3					
Particle size (P)	5	0.312	0.682	0.175	0.596	0.729
Error	15					
Date (D)	3	<0.001	<0.001	<0.001	<0.001	<0.001
P x D	15	0.347	0.747	0.938	0.815	0.850
Error	54					
Total count	95					

Table 2A. ANOVA table for yield (yield parameters)

Source of variation	df	Number of marketable fruits	Marketable yield	Total yield	Unmarketable yield
Rep	3				
Particle size (P)	5	0.046	0.074	0.076	0.846
Error	15				
Total count	23				

Table 2B. ANOVA table for tomato yield (sizes of tomatoes)

Source of variation	df	F pr				
		Extra-Large	Large	Medium	Small	Extra small
Rep	3	0.510	0.485	0.006	0.332	0.189
Particle size (P)	5					
Error	15					
Total count	23					

Table 2C. ANOVA table for tomato yield (Mass of tomatoes)

Source of variation	df	F pr				
		Extra Large Mass	Large Mass	Medium Mass	Small Mass	Extra small Mass
Rep	3					
Particle size (P)	5	0.217	0.251	0.021	0.210	0.215
Error	15					
Total count	23					

Table 3A. ANOVA table for leaf mineral analysis (N=Nitrogen, P=Phosphorus, K=Potassium, Ca=Calcium, Mn= Magnesium, Zn=Zinc)

Source of variation	df	F pr					
		N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Zn(mgkg^{-1})
Rep	3	0.405	0.289	0.819	0.290	0.411	0.087
Particle size	5						
Error	15						
Total count	23						

Table 4A. ANOVA table for fruit mineral content on dry state (P=Phosphorus, K = Potassium, Ca=Calcium, Mn=Magnesium, Zn=Zinc)

Source of variation	df	F pr						
		Moisture (%)	P (mg kg^{-1})	K (%)	Ca (mg kg^{-1})	Mg (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})
Rep	3	0.58	0.47	0.83	0.688	0.545	0.332	0.347
Particle size	5							
Error	15							
Total count	23							

Table 4B. ANOVA table for fruit mineral content on wet state (P=Phosphorus, K=Potassium, Ca=Calcium, Mg=Magnesium, Mn=Magnesium, Zn=Zinc)

Source of variation	d.f	F pr						
		Moisture (%)	P (mg kg $^{-1}$)	K (%)	Ca (mg kg^{-1})	Mg (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})
Rep	3	0.579	0.041	0.52	0.738	0.224	0.305	0.329
Particle size	5							
Error	15							
Total count	23							

Table 5A. ANOVA table for shelf life (%weight loss from 0-20 days)

Source of variation	df	Fpr				
		4 days	8 days	12 days	16 days	20 days
Rep	3	0.275	0.284	276	0.278	0.199
Particle size (P)	5					
Error	15					
Total count	23					