The effect of coir particle size on yield of greenhouse tomatoes (*Lycopersicon esculentum* Mill.)

A thesis presented in partial fulfilment of the requirements for the degree of Master of Science (Horticultural Science) at Massey University, Turitea, New Zealand.

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ABSTRACT

Coir is a relatively new growing media, and little information is known of the relationship between particle size and particle size distribution on crop productivity. Particle size significantly affects the physical properties of coir, particularly the air-water relationships. The objectives are (1) to investigate the relationship water holding capacity has on total yield, fruit number and mean fruit weight of tomato (2) determine whether growth analysis could be used to test treatments prior to full scale growth trials in terms of predicting yields based on small sample sets of limited duration. Two yield trials, summer and winter trials, was designed to compare the yield of a tomato (L*ycopersicum esculentum*) crop grown in coir using a range of particle sizes, while a plant growth analysis was used to compare RGR, LAR, and NAR. Two coir sources were used throughout the trials. One source consisted of seven treatments based on combinations of small (S), medium (M) and large (L) size grade particles. The second source consisted of two ungraded coir products, P1 and P3. Two irrigation (low and high) frequencies were used. The seven treatments were based on particle size with differences in WHC (water holding capacity). A bioassay was used to compare tomato yield and RGR. The physical properties, governed by particle size, have an effect on tomato yield. The average yield for the winter yield trial was 2.14 and 2.38 kg per plant for SG and HK data while the average yield for the summer yield trial was 7.92 and 7.69 kg per plant. An increasing linear relationship exists between WHC and fruit yield per plant, as treatments increase in WHC so do their fruit yield per plant. A relationship was also found between the bioassay and tomato yield trial. Similar to the tomato yield trial, as WHC increased so did the RGR. The relationship between WHC and RGR may have commercial implications for both soilless media manufacturers and growers who require specific physical properties in terms of water and air availability for particular crop types.

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CHAPTER 1: INTRODUCTION

Apart from capital expenditure, soilless media is probably the most important investment a grower in any modern greenhouse industry will have to make. There are a number of media options available through centuries of development. Some options involve the chemical and physical restructure of natural elements: silica and clay; while other options involve the mining of raw materials: peat and perlite. The choice of soilless media, either through the experience of the grower or the culture of the industry, is an important decision which requires thorough consultation. Once the decision is made it will most likely become the standard for the grower for a number of years.

Most studies have focused on comparing properties of different media choices available. Typical details in the study include the chemical characteristics (Evans et al., 1996; Noguera et al., 1997; Noguera et al., 2003), the physical properties (Evans et al., 1996; Noguera et al., 1997; Fornes et al., 2003; Noguera et al., 2003; Prasad & Chualain, 2003; Nelson et al., 2004; Abad et al., 2005; Jeyaseeli & Raj, 2010) while other studies include overall yield/growth trials (Vavrina et al., 1996; Noguera et al., 1997; Arenas et al., 2002; Iwasaki, 2008). Comparisons are made between synthetic, natural or a combination of the two at various ratios. Synthetic options are generally developed for a specific purpose. For example, the high air filled porosity of rockwool results in an ideal environment for commercial horticultural seedling propagation.

A limited number of studies have focused on the fundamental aspects which are common among all natural media types. It may be fair to compare different sources to one another if all producers of coir used the same techniques for processing. In other words, coir producers need to grade their product to similar quality standards in terms of particle size before comparisons can be made. In fact, the majority of what is being compared through previous coir source studies is the processing technique used, thus giving a false indication of coir quality. In addition, results obtained from previous research may become obsolete when processing technique change. Technological advances may enable the coir product to be produced faster regardless of maintaining quality standards, i.e. particle size. Ideally producers of coir would use the same technique regardless of their geographical location.

While the use of a common processing technique is encouraged for coir production, the extraction method used for substrates in general should be based on common physical characteristics. Data obtained using one certain processing technique, over all substrate types, is difficult to compare (Van den Ende, 1971; Raviv & Mordehai, 1988; Warncke, 1990).

Physical properties ultimately determine the suitability of a natural or synthetic resource as a growing medium. The ability of media to retain water, facilitate gas exchange and provide sufficient anchorage for root growth determines the suitability of media for industrial purposes. The physical characteristics controlling water retention and gas exchange are water holding capacity and air filled porosity. Although previous studies have compared water holding capacity and air filled porosity, few have focused on differences within the same medium source. None have compared the effect of these physical properties through yield trials and growth analysis studies.

The objectives of this thesis, using graded coir produced from coconut media, are (1) to investigate the relationship water holding capacity has on total yield, fruit number and mean fruit weight of tomato, (2) determine whether growth analysis could be used to test treatments prior to full scale growth trials in terms of predicting yields based on small sample sets of limited duration (i.e. bioassay).

The limitations of this project is (1) not knowing if the variation in particle size is sufficient in accurately describing physical property relationships (2) the size of the greenhouse restricts the number of blocks available which may negatively impact statistical analysis if variations occur in greenhouse conditions.

CHAPTER 2: LITERATURE REVIEW

2.1 Coconut palm

The coconut palm (*Cocos nucifera*) is monocotyledonous with fine narrow roots which emerge from the base of the swollen stem (Grimwood, 1976). This root system is extremely adaptable to local soil conditions. If the coconut palm is found growing on banks susceptible to flooding, roots are concentrated in a thin layer of soil over a wide area. When grown inland, roots can penetrate at a depth of up to 5m (Grimwood, 1976), below the surface in search of moisture and nutrients.

The coconut is not botanically related to other species and as such said to be monospecific, consisting of tall and dwarf with further division within the dwarf group (fragile or robust trunk). Tall varieties contain both male and female flowers but are said to be cross pollinated due to pollen shedding prior to female flowers forming. Robust dwarf varieties have a flowering habit similar to that of tall varieties. Fragile dwarf variety shed pollen freely and are said to be self-fertilized. Cross pollination occurs between all known varieties (both tall and dwarf) and can produce vigorous and fertile hybrids (Foale, 2005).

The number of coconut varieties is uncertain. According to COGENT (the international coconut genetic resources network) 1416 conserved accessions exist containing characterization data from 22 countries. However, some of this collection may be redundant or genetically very similar (Perera et al., 2003).

Coconut palm is cultivated in many parts of the world. The main producers of coconut are tropical countries such as Indonesia, Philippines and India. Indonesia provides a third of the world's coconuts while globally 62 million tonnes are produced (FAO, 2010). Coconut production of commercial value can generally be found between latitudes 22° North and 22° South (Grimwood, 1976). Coconut palm is found to grow in many parts of world and is not necessarily confined to coastal regions. Coconut groves in India, for example, can be found 80 km away from coastal areas and are still profitable to harvest. The United Republic of Tanzania, located in East Africa, also produce coconuts which can be found 640km away from the coast at an altitude of 900 m above sea level. A correlation exists between latitude and altitude for productive coconut production (Grimwood, 1976). Coconuts grown at the equator can withstand altitudes of 600m above sea level, anything above results in slow growth rate, small fruit and consequently lower yield. Jamaica, latitude 18°N, can only produce coconuts at no more than 120m above sea level (Grimwood, 1976).

Table 1. World top ten countries by coconut production (tonnes).

Country	2005	2010
Indonesia	15240000	20655400
Philippines	12994700	15540000
India	8350000	10824100
Brazil	1952120	2705860
Sri Lanka	2353000	2238800
Thailand	1795270	1298150
Viet Nam	884800	1179900
Mexico	1117000	983000
Papua New Guinea	1032000	902000
United Republic of Tanzania	370000	590000
World	**51155811**	**62451506**

Source: FAO Statistics Division 2012

2.2 Coir

A raw coconut contains the edible copra and protected by husk and skin (Fig.1). The shell contains the coco-water and copra while the husk is made up of 30% fibre and 70% pith on a dry weight basis (van Dam, 2002; van Dam et al., 2003).

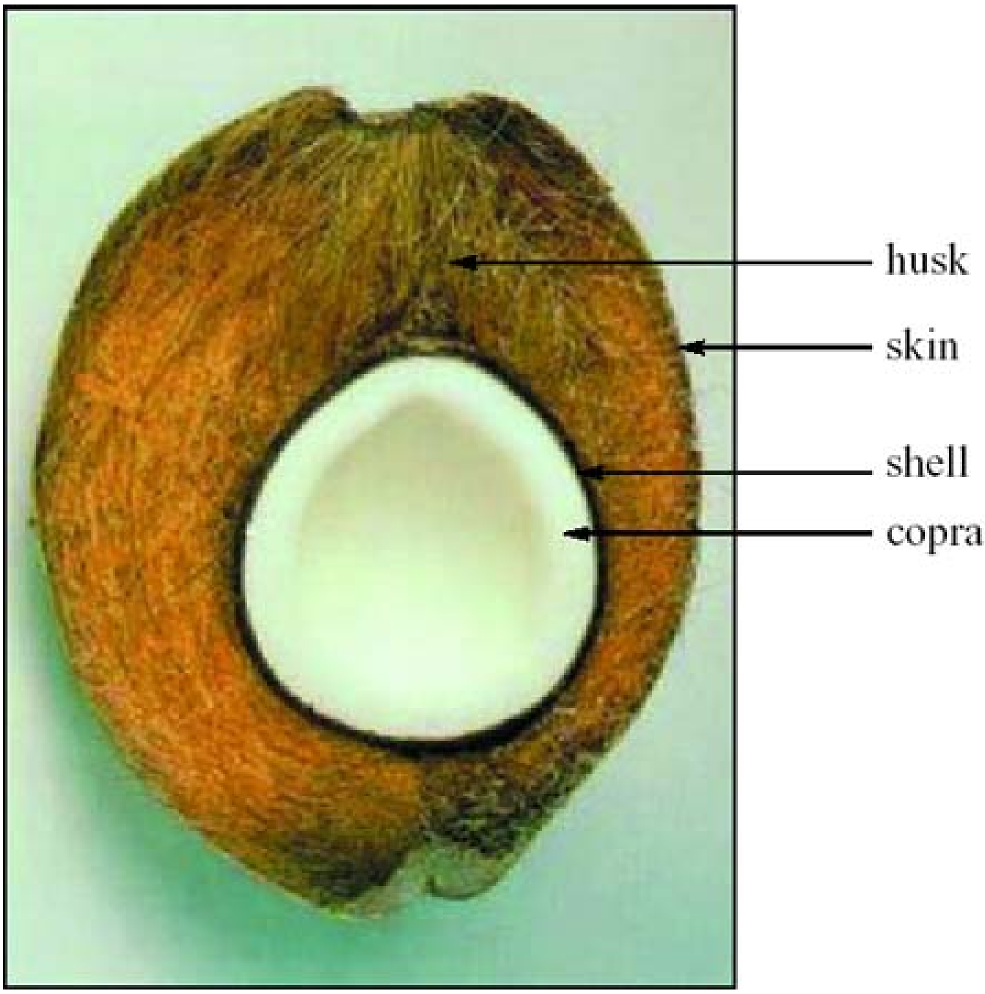

Fig. 1. A cross section of a coconut including the edible fruit (copra). The skin and husk are considered a by-product

Coir, cocopeat, or coir dust is a by-product of the husk fiber extraction process (van Dam, 2002). Coir is the remains left after the extraction of the coconut fruit and long fibrous strands (Fig. 2). The average yield of coir fibre is dependent on geographical location and particular variety of coconut. Sri Lanka and southern India, for example, yield on average 80-90g per husk while Caribbean husks, which are relatively thick, can yield on average 150g fiber per husk (van Dam, 2002).The fibrous strands are processed into saleable products; brushes and brooms, rope and yarn for nets and bags, and padding for mattresses. More innovative applications have also been developed which uses the relatively high lignin content of coir. By the use of heat and pressure, developers were able to bind particles at high density to create board or even 3D molded products without the use of a chemical bonding agent (van Dam et al., 2003).

Fig. 2. Coir, fine mesophyll particles remain after the extraction of long fibrous strands. Particle size depends on how the coir was graded. The sample on the left contains graded coir of inconsistent particle size while the sample on the right has been graded through a sieve of known diameter.

Previously, coir has accumulated at production sites for many years. Recently, however, coir has gained commercial interest as a possible peat substitute. A potential large amount of waste product (coir) may therefore be of horticultural interest. Coir is highly porous with the ability to absorb large quantities of water; more than 50% by weight (van Dam, 2002).

2.3 Physical properties

2.3.1 Bulk density

The bulk density (BD) of a medium is usually defined as its dry weight per unit of volume (Raviv et al., 2002). The volume is measured in a moist state. The unit of measurement is $g.cm^{-3}$. There are a number of methods used to measure the bulk density, although the simple definition of BD should enable any plant scientist to calculate BD. For the purposes of determining the physical characteristics of coir media, the method outlined by De Boodt et al. (1972) was used. However, it is important to note that there are various methods for determining BD for a specific purpose. For example, the method outlined by De Boodt et al. (1972) is primarily used for research purposes while other methods are targeted towards industry to meet specific standards. All methods are based on a common principle: the wet media is allowed to settle or compress in a container of known volume then dried and weighed (Raviv et al., 2002).

Growing media is made up of a number of particle sizes with corresponding packing densities which is due to the particles arrangement in space. Therefore, BD measures the total packing density and not each individual particle size, unless media has been graded that way. Growing media which differ significantly in particle sizes tend to have a higher BD. Together with higher BD "mixed" growing media also have a lower total porosity (TP), water holding capacity (WHC) and air-filled porosity (AFP) compared to a medium with consistent particle size arrangements (Pokorny, Gibson & Dunavent, 1986). BD has different effects on media and consequently their use. For example, in outdoor tree sapling production, a high BD is preferred to help prevent container instability during high winds. In comparison, high intensity greenhouse production, which are irrigated frequently, may become oxygen deficient if hydraulic conductivity and AFP are not high, thus favouring a low BD (Raviv et al., 2002). The production and transportation costs associated with a low BD media (i.e. particles of consistent size) may be cheaper compared to mixing of different media options.

2.3.2 Particle size distribution

Media is composed of three distinct phases: the solid phase, liquid phase and gas/air phase. The solid phase covers the stable component and one that gives substance to the media (Raviv et al., 2002) while the liquid and gas/air phases are linked to each other. The nature of gas/air exchange (AFP) is governed by WHC, and vice versa. The solid phase consists of mineral particles of varying sizes, together with amorphous compounds known as organic matter. This array of mineral particles can be characterised in terms of proportions of different size particles. Therefore the solid phase, including both mineral and organic components, largely determines the nature and behaviour of a soil type/media. Media texture refers to the range of sizes, be that small, medium or large sized particles. Media texture is said to be an intrinsic attribute of media and often characterizes its physical makeup (Raviv et al., 2002).

Particle size distribution methodology involves dividing a media's continuous array of particle sizes into discrete fractions (Raviv et al., 2002). The particle size distribution curve for coir media sourced from Christchurch, but originally from the Philippines, is shown in Fig. 3.

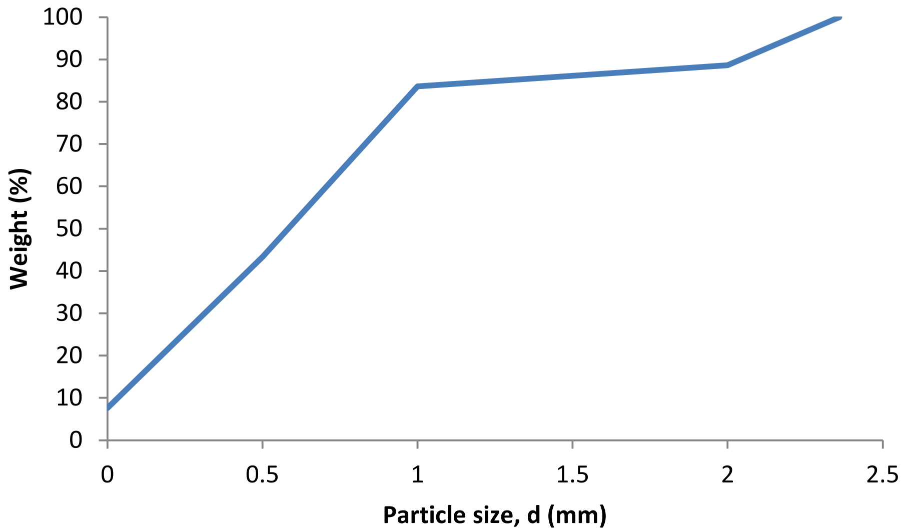

Fig. 3. A cumulative representation of particle size distribution for coir the diameter range of the particles (d).

Note that the graph gives a cumulative representation: the reason being that this representation is said to be useful in determining the hydraulic properties of a growing media. The shape of the curve helps determine water retention and hydraulic conductivity characteristics (Raviv et al., 2002). Information gathered from the graph includes the grading pattern (i.e. whether the media contains distinct groups of particles of uniform shape or whether particles sizes are more-or-less continuous). A poorly graded media is said to be dominant in particular particle sizes and represented by a staircase looking distribution curve while a well graded media is characterised by a smooth flattened distribution curve (Raviv et al., 2002). Comparing coir's particle size distribution curve (Fig. 3) to scoria (Fig.4) one can assume that this particular source of coir is poorly graded compared to RTM scoria.

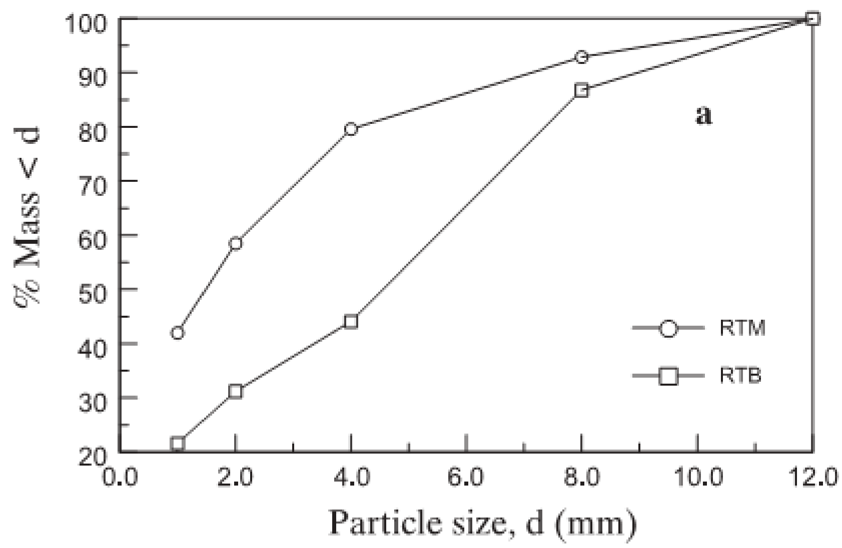

Fig. 4. Particle size distribution for RTB and RTM scoria (Tuff). Source data from Raviv et al., (2002), originally from Wallach et al., (1992a). RTM and RTB is red tuff graded to particle size 0 to 8mm. RTM is naturally sieved while RTB is crushed from larger particle sizes before being graded.

2.3.3 AFP

The amount of air, as a volumetric percentage remaining in media, after gravitational drainage, is called the air-filled porosity (AFP). An ideal AFP provides an environment where adequate oxygen is provided for respiration while enabling the release of CO_2. Media aeration is absolutely vital for normal plant function to occur (Raviv et al., 2002). Dissolved oxygen is located in the thin layer of water surrounding active roots (boundary layer), thus root function is dependent on a supply of gas exchange between the liquid and gas phase of media. Stagnant water does not contain enough dissolved oxygen (Raviv et al., 2002) for normal root function to occur. The same can be said when media, placed in pots, is left in an environment where the bottom section of the pot is constantly saturated, thus restricting the free flow of oxygen in and around the roots.

Most media mixes have an AFP of between 10% and 30%, depending on the container size and frequency of irrigation. Ideal AFP will also depend on the operation involved. For example, the ideal AFP environment for rooting of cuttings should be greater than 20% while an AFP lower than 10% is said to be adequate for deep containers containing slow growing tree saplings (Raviv et al., 2002). As with all container grown plants, one needs to be aware that roots tend to grow gravitropically thus possibly forming a dense layer of roots at the bottom of the container. If water remains perched, the free flow of oxygen is restricted. Raviv, Lieth, Burger & Wallach (2001) highlights the important fact that although AFP may be adequate, reduction in plant performance may be due to the perched water table that exists at the bottom of the container.

2.3.4 Soil plant atmosphere

Water status is characterised by the amount of water and energy state present (Or and Wraith, 2002) in a given soil or media. Water in media or soil is subject to a number of forces which affect its potential energy (EQ.1). The main forces acting on pure water (water potential) are pressure potential, osmotic potential and matric potential (Or and Wraith, 2002; Lai and Shukla, 2004; Kirkham, 2005; Miyazaki, 2006; Hillel, 2008).

$$\Psi_w = \Psi_p + \Psi_o + \Psi_m \qquad \textbf{EQ.1}$$

Pure water is water in which the free energy is not reduced by solute molecules and therefore has a high potential for energy transfer. Pure water is given a zero value at standard elevation and temperature (Hillel, 2008). Forces act on pure water resulting in a change in water status from zero to either positive or negative. Soil water is normally given a negative value because of the forces described below.

Once water is drained due to gravity (i.e. field capacity), the remaining water is subject to a number of forces, which reduce the water potential. From the point of view of plant-soil relationships these forces can be split into two;

1. The media environment (i.e. the water potential before entering the root hairs) which involves the matric potential.
2. The root environment where osmotic potential and pressure potential become important for the flow of solutes through a differentially permeable membrane (e.g. of the root hairs).

Pressure potential involves the pressure exerted on cell walls (turgor pressure) due to the difference in solute concentration between cells, or a cell and the soil solution. If one cell has an increased concentration of solutes and the neighbouring cell a decreased concentration, a pressure difference will exists between the two cells at equilibrium. This pressure is due to the differential nature of cell membrane which allow the flow of water between cells, via osmosis. Pressure potential, within a cell, is given a positive value (i.e. the cell is turgid and has turgor pressure).

Osmotic potential involves the relationship between soil water and solute content (Or and Wraith, 2002; Lai and Shukla, 2004; Hillel, 2008; Nobel, 2009). It is important to note that osmotic potential is relevant when considering uptake of soil water across a differentially permeable membrane (Lai and Shukla, 2004; Hillel, 2008), such as the cell plasma membrane which transmits water more readily that solutes (i.e. is differentially permeable). Therefore osmotic potential is particularly important in uptake of water and nutrients by roots (Hillel, 2008) and of no use when only considering flow of liquid in a soil (Or and Wraith, 2002). The presence of solutes (salts) also lowers vapour pressure and at extreme levels can increase viscosity and density of soil water (Hillel, 2008). Greater solute concentration produces a more negative osmotic potential and thus a more negative water potential.

Matric potential involves relationships between soil water and soil particles (Kirkham, 2005; Miyazaki, 2006) which exist only in unsaturated soils (Lai and Shukla, 2004). This interaction usually occurs in soils between groundwater and surface level (Miyazaki, 2006). This interaction reduces the potential energy of soil water because of surface tension, adhesion and cohesion forces between soil particles and soil water (Or and Wraith, 2002; Lai and Shukla, 2004; Miyazaki, 2006). Adhesion forces between liquid and solid phases are due to van der Waals forces and cohesion forces by hydrogen bonds forming in the liquid phase. Due to the decrease in potential energy, matric potential is given a negative value. Previously, matric potential was known as capillary potential due to water rising and falling in capillary tubing due to changes in surface tension (Kirkham, 2005).

Hydraulic conductivity in soil or media is related to the resistance from soil particles when water flows through pore spaces (Miyazaki, 2006). Hydraulic conductivity is highly affected by texture and structure. The conductivity of sand containing large pores is much greater compared to clay containing small pores despite total porosity being greater in clay soils (Hillel, 2008). By far the most variation exists in disturbed soil types (Kirkham, 2007) and possibly soilless media with varying particle size. In other words hydraulic conductivity expresses a rate at which water is able to move across a soil matrix. Conductivity can also be used to denote how open or closed stomata are stomata (stomatal conductance) which are affected by water potential at the root tip.

Water flow, flux, or rate of transport is largely determined by hydraulic conductivity and difference in water potential (EQ.2) or water flow can be determined by hydraulic conductivity divided by resistance (EQ.3). For example, the flow of water in soils is governed by hydraulic conductivity and differences in water potential (mainly matric potential). The flow of solutes at the root tip (cell) is governed by hydraulic conductivity (or resistance, the reciprocal of conductivity) and differences between pressure potential and osmotic potential (i.e. the difference in water potential). Thus differences in water potential are the driving force and the amount of water that actually flows depends on the hydraulic conductivity, or its reciprocal, the resistance.

$$Water\ flow = hydraulic\ conductivity\ \times difference\ in\ water\ potential \quad \textbf{EQ.2}$$

OR

$$Water\ flow = \frac{difference\ in\ water\ potential}{resistance} \quad \textbf{EQ.3}$$

According to the laws of thermodynamics, regardless of pressure, osmotic, matric or gravitational potential, flow will begin at a region of high potential energy and flow to an area of lower potential energy, until a state of equilibrium is reached. Osmotic potential, pressure potential and matric potential are factors which govern this energy transfer which results in either an increased or decreased uptake of water by root hairs and are therefore important factors limiting plant growth.

2.3.5 Water release/retention curves

The traditional method for measuring the water release/retention curve involves the establishment of a series of equilibriums between water in a substrate, at known depths to generate pressure (i.e. 10, 20, 50 cm, etc.). The media (wetted) is placed in hydraulic contact with a body of water separated by a porous plate (Fig. 5).

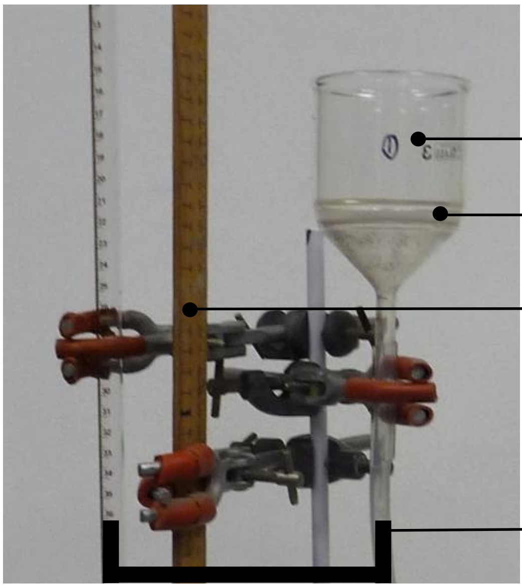

Fig. 5. The apparatus used to determine the water release curve (Heins apparatus). The funnel (substrate container) is part of a system which connects to a measuring tube via a plastic tube. A ruler is included to work out the hydraulic head.

At equilibrium, at a known depth, the volumetric water content (ϴ) is paired with the matric potential (Ψ), i.e. the pressure in the body of water and the gas phase in the substrate. The two points, ϴ and Ψ, forms a point in the water release curve (Raviv et al., 2002). Each point in the curve represents a specific matric potential. It is the combination of ϴ and Ψ points, at different depths, which make up the curve. The curve created for media is said to be intrinsically different compared to field soils, mainly due to a low depth range which exists in container media (Raviv et al., 2002). As matric potential decreases from 0 cm, water begins to empty from large pores and a point is reached where water is subsequently replaced by air, known as the air-entry point. As most container used for soilless cultures range in height from 5 to 20 cm, having an air entry point in this range will mean the media remains saturated. This anaerobic condition, i.e. shortage of oxygen, can result in reduced root, and consequently shoot growth. Continuous anaerobic conditions will ultimately lead to plant death. However, it has been shown that the air entry point is much lower in soilless containers than in soils even to the point where it is considered zero due to this value being so small. A noticeable difference can be observed when comparing sand to tuff (Fig. 6). This sharp decrease in water content, observed in tuff, is consistent with a low air-entry value compared to that of sand where consistent vertical points are observed prior to the air entry point (i.e. 10 cm). The difference in air entry points can be explained by their special displacement in space. Sand quartz are regular and smooth compared to tuff particles which are rough and irregular (Raviv et al., 2002).

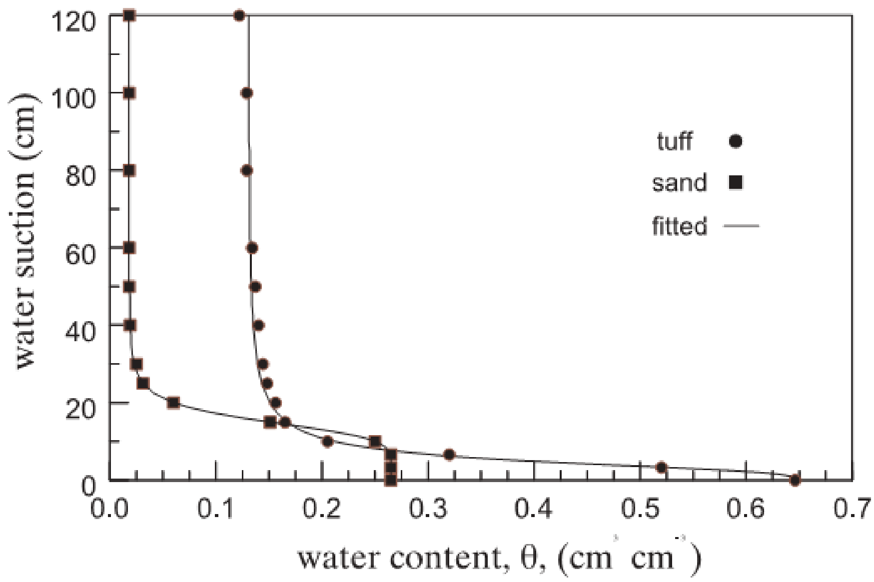

Fig. 6. Water retention curves for both tuff and quartz sand with a similar particle size fraction of 1-1>2mm. Source data from Raviv *et al.,* (2002), originally from Wallach *et al.,* (1992a).

As mentioned earlier, larger particle sizes drain water faster compared to smaller particle sizes, but this is by no means the only indication for differences in water release curves. For example, when 1-1>2mm fractions for both tuff and sand were measured, although particle sizes are similar, there is a distinct difference in their water release curves (Fig. 6). Tuff porosity (0.58 $cm^3.cm^{-3}$) is much higher than sand porosity (0.20 $cm^3.cm^{-3}$). The difference in porosity can be explained by inner micro-porosity. Tuff consists of rough and irregular particle sizes while sand has smooth and regular particles (Chen, Banin & Ataman, 1980). The shape of a water release curve is governed by;

- Particle size distribution
- Characteristics of the media (i.e. shape, porosity)
- Air-entry points (initial vertical and subsequent horizontal shape)

2.4 Tomato physiology and greenhouse productivity

2.4.1 Hybrid Seed

Tomato seed measures 3 to 5 mm in size, silky and flat in appearance and cream to light brown in colour. The seed contains a large embryo surrounded by a relatively small amount of endosperm (Jones, 2008).

Hybrid seed production has become increasingly important in recent years due to its favourable characteristics over traditional breeding methods. The first hybrid cultivar “Single Cross” appeared in 1946 which combined favourable characteristics from both parents yet were able to segregate in the progeny (Lindhout, 2005). Segregation of traits discourages seed production by the grower. This feature enables breeders to protect their cultivars, and as such, is the only producer of that specific line. Heterosis is what truly sets hybrids apart from any other breeding technique. This biological phenomenon appears in the offspring of two parents which have been chosen for their particular trait of interest. The offspring (F1) will not only inherit the chosen traits but are also become more productive and adaptive than the parents (Lindhout, 2005). Although hybrid seeds are more expensive, growers accept the price increase as almost all fresh market tomatoes are hybrids and use for processing tomatoes is increasing (Lindhout, 2005).

2.4.2 Nutrition

Soilless systems, such as rockwool and cocopeat, usually receive their nutrition through drip irrigation. Using this method, nutrients are injected into the irrigation line (fertigation) from at least two separate stock tanks. The reason nutrients are separated, is to prevent the precipitation of calcium phosphate and calcium sulphate. In larger greenhouse operations, a third tank containing acid may be added to control pH. Some growers may even go as far as including six or more stock tanks to better control their nutrient solution (Peet & Welles, 2005).

2.4.3 Controlling growth

Apart from controlling nutrient levels to avoid deficiencies, controlling the balance between vegetative and generative growth is equally important (Peet & Welles, 2005). Due to the amount of energy and resources invested in a greenhouse crop, it is essential to cover such costs with tomato product and not excessively vegetative growth. A well balanced plant is defined as one which has a thick stem, dark green leaves as well as large, closely packed flower clusters which set well (OMAFRA, 2001). There are a number of ways to help control the balance of tomato crops including EC, water supply, the ratio of nitrogen to potassium in the nutrition feed, as well as a number of environmental controls. A number of unfavourable conditions reduce vegetative growth and steer the crop towards generative growth;

- High salinity in the root-zone, infrequent irrigation, and low volumes of irrigation reduces water availability to plant roots; which decreases overall growth rate, steering the plant towards generative growth.
- High temperature and low relative humidity also decreases the availability of water.

2.4.4 Cultural practices

Keeping a tomato crop profitable requires a number of practises which need to be completed on a regular basis (Fig. 7). The aim of these practises is to keep the crop in high fruit production. The severity of these practises will change depending in the cultivar and characteristics of the plant (Jones, 2008) as well as environmental conditions such as light levels, ventilation and humidity.

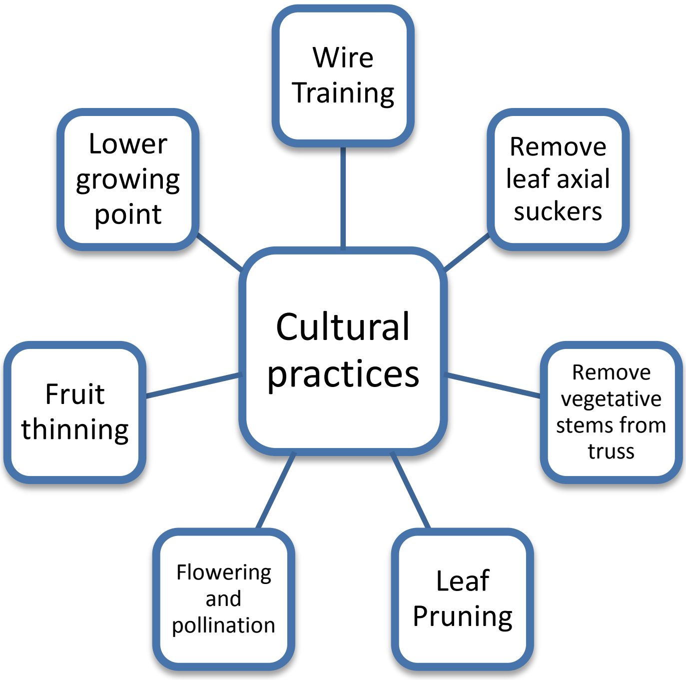

Fig. 7. An overview of common cultural practices which need to be performed regularly to ensure optimum production.

2.4.4.1 Wire training

A set of wires are usually located horizontally above the growing area. These wires are used as supports on which lengths of string are hung vertically and tied to the base of the plant using a non-slip loop (Hickman, 1998; Peet & Welles, 2005). Wire training involves twisting the stem or apex of the tomato plant around the string to support the plant as it grows taller. An alternate method involves clipping the stem (Hickman, 1998) around the string every 18cm (Peet & Welles, 2005). This practise needs to occur regularly to prevent stem curvature which may disturb plant spacing.

The high-wire training system is the most commonly used training system in The Netherlands and northern USA allowing one crop to be carried over several seasons (Peet & Welles, 2005). This system allows the growing point or apex to remain at peak height combining the yield-improving advantages of maximum light interception of young leaves as well as constant labour requirements. The fruit can be harvested and the leaves pruned easier at this constant height.

2.4.4.2 Lower growing point

The main requirement for the high-wire training system is lowering the growing point, via a winding hook placed on the wire above (Peet & Welles, 2005). As plants grow taller the extra length of stem lies along the floor; at this stage all fruit and leaves have been removed. This system allows for continuous cropping through multiple seasons. In northern Europe and in the USA it is not uncommon to continue cropping from December of one year to November of the next (Peet & Welles, 2005.

Crop topping is commonly used when a termination date is set. In general the crop is topped 5-8 weeks prior to termination and remaining flowers removed a week later. Flowers or small fruit are removed at this stage to ensure the 6-9 weeks required for full fruit maturity. When topping, it is good practise to leave 2 sets of leaves over the last truss. This ensures some shade for tomatoes which in theory should reduce the incidence of sun scald. Some growers suggest that leaves above fruit also increase transpiration which reduces the risk of fruit cracking and russeting (Peet & Willits, 1995).

2.4.4.3 Remove side shoots

Removal of leaf axial suckers is particularly important in an indoor crop where plant density, together with leaf area, needs to be maintained. Leaf axial suckers redistribute energy (nutrients) from the growing apex and therefore decrease crop productivity. Side shoots should ideally be removed before 5cm in length as shoots above this length will become tougher and thus harder to remove (Hickman, 1998). Allowing leaf axils to continue growing may also slowly change the tomatoes growth habit from being indeterminate, which is required in greenhouse production, to determinate which is preferred for outdoor processing tomato and not for indoor greenhouse production. The same reasoning is valid for removing vegetative stems from fruit trusses as localised nutrient distribution is preferred. Care needs to be taken not to accidentally remove the main stem when pruning side shoots. If this happens a side shoot can replace the main stem. However, yield may be affected and harvesting delayed (Peet & Welles, 2005). Although side shoots are usually removed, there are circumstances where they are encouraged to grow. For example when a gap is formed by removing a neighbouring plant, for whatever reasons (i.e. disease), a side shoot is encouraged to grow and fill the gap. This technique is an important tool in The Netherlands for optimising fruit load and crop yield (De Koning, 1994).

2.4.4.4 Leaf pruning

Leaf pruning involves the removal of leaves below the oldest fruit truss. There are a number of reasons why this practise is encouraged. Leaves can be either sources of energy or sinks of energy. Once leaves have contributed adequate carbohydrates to the crop, they begin to turn brown. At this point the leaves, which are turning brown, may still remain alive but at the expense of much needed energy to the remaining growing parts. Typically all leaves below the first fruit truss are removed (Peet & Welles, 2005). Leaf pruning also improves air circulation and light penetration in higher leaves. Disease, pests and beneficial plant predators also affect the timing and extent of leaf pruning. Older leaves are more susceptible to disease, such as botrytis. If botrytis is found in leaves they should be removed from the greenhouse immediately. Whitefly larvae, which may be present on old leaves, can be removed by leaf pruning. If beneficial predators are used, the timing of whitefly infested leave removal is important. Beneficial predators parasitize whitefly pupae and if pruned will remove the predators from emerging. At times, leaf pruning represents a trade-off between emergence of whitefly and control by beneficial predators (Peet & Welles, 2005).

2.4.4.5 Fruit thinning

Fruit thinning is a technique used to balance fruit load by increasing fruit size and fruit quality (Peet & Welles, 2005). Limiting the number of fruit per truss helps maintain uniform fruit size (CVPG, 2002). Small and misshapen fruit are removed to increase the size of the remaining fruit on the truss and remove those fruit which otherwise would not grow to marketable size. In most cases fruit are thinned to four per truss (proximal fruit). The exact number left on the truss depends on a number of factors such as cultivar, the natural number that form on a truss, growing conditions and most importantly the fruit size the market demands (Peet & Welles, 2005; Coolong, 2012). A common example is 'Beefsteak' tomatoes where traditionally only 18 fruit should be on the plant at any time. The technique used for large sized fruit cultivars involves, pruning the first three trusses to a maximum of eight to nine fruit, followed by four fruit per truss for the remaining trusses. This technique needs to be flexible as fruit load may require more or less fruit per truss, depending on growing conditions. Thinning of trusses may only require the removal of flowers before fruit development occurs while at other times misshapen fruit only need to be removed (Peet & Willits, 1995).

2.4.5 Flowering

Unlike the wild self-incompatible Lycopersicon species, which have their style extended well above the anther and therefore rely on cross-pollinators, cultivated tomatoes have their style and anther at similar lengths which aid self-pollination (Jones, 2008). As described by botanists, tomato flowers are perfect as they possess male parts (anthers) and female parts (stigma, style, and ovary), meaning that each flower is capable of pollinating itself (Myers, 2006).

Although tomato flowers are said to be self-pollinators they do however require some mechanical means of disturbing the flowers to complete pollination (Jones, 2008). Complete pollination helps to ensure round fruit development; limiting the occurrence of physiological disorders such as "puffiness" when a number of seed cavities (ovules) are empty due to improper fertilisation (Salveit, 2005; Jones, 2008). Mechanical disturbance can be natural as with insects or by electric vibrators. Flowers which are not correctly pollinated may abort and not produce any fruit. Flower abortion may also be due to adverse environmental conditions such as low light levels as well as stress conditions, such as drastic changes in temperature, moisture, nutrition and disease. Plant density has also shown to affect the rate of flower abortion: At five plants per m^2

no flower loss was recorded, compared to 30 plants per m^2 where up to 90% flower abortion occurred (Jones, 2008).

Electric vibrators may successfully be used in smaller indoor tomato operations but become increasingly labour intensive as the operation increases in size. Other than labour costs, the vibrator may itself damage the skin of the newly developed tomatoes if not handled correctly. Bumblebees are a more efficient cost effective method of pollinating indoor tomato crops. They are able to work over the usual nine to five work day that a labourer would be required. The number and frequency of hives required is determined by the size of the operation as well as the duration of the flowering period. A reputable supplier is vital as bumblebee vitality may reduce crop load. Bumblebees can however damage fruit in the same way that an electric vibrator can, due to insufficient flowers for all bumblebees to work on (Jones, 2008).

2.4.6 Harvesting

The timing and manner in which fruit is harvested depends on the target market. The varies choices include;

- Market
  - Harvest each tomato individually as they ripen
  - Harvest the entire truss of tomatoes
- Timing
  - Harvest at the breaker stage
  - Harvest as late as possible

The above timing strategy will depend on whether the tomato product is destined for the local market or destined for overseas markets. Another option is tomatoes which have been trained as truss tomatoes which usually receive a higher premium. The quality and superior taste of truss tomatoes have been attributed to the length they remain on the vine. In some varieties, such as Beefsteak, the calyx is removed to prevent puncturing the delicate fruit skin (Peet & Welles, 2005). However there are dangers of removing the calyx prior to correct maturation, as it is a potential entry point for disease as well as dehydration.

Production potential heavily depends on a number of factors;

- Soil or soilless based: Soil based operations are generally those who do not supply to the same markets as their dominant soilless competitors. Instead they are sold to a niche market locally as organically produced. Although yields for soil based operations are generally lower compared to soilless operations, their input and operating costs are significantly lower.
- High vs. low light environments: The amount of available sunshine hours together with the position of the sun in the sky are two important aspects to consider when positioning an indoor tomato crop.
- Cropping period: Adopting a method which allows for continuous growth through a number of seasons increases overall crop yield. The duration of the cropping period will depend on a number of factors such as costs, labour availability and market demand, among others.
- Supplementary lighting: Additional lighting is generally required for operations that choose to crop over an extended period of time. At some stage of the operation, generally at low light levels, supplementary lighting as required to maintain the light requirement component of the operation.
- CO_2 enrichment: The addition of CO_2 can improve crop yield. A number of factors, including cost, timing and duration, need to be investigated prior to implementation.
- Cultivar selection: The advancement in parent line selection in hybrid tomato production means that yield and quality of tomatoes are improving: resistance to disease, a limited pest problems and adverse weather conditions. Although seed of these hybrid cultivars is expensive, they do offer the grower lower costs over the production period.

2.4.7 Defects (physiological disorders)

2.4.7.1 Cracking

Cracking refers to the rapid influx of water and solutes into fruit when ripening or other factors reduce the elasticity of the tomato skin (Peet, 1992). Concentric circles or radical cracks may also appear from the stem to the blossom end (Salveit, 2005). Some varieties of tomato have excellent crack resistance compared to others. Cracking is said to increase with the number of fruit per cluster as well as increased watering frequency (Peet & Willits, 1995). As with most other physiological disorders, cracking occurs due to stress invoked on the plant. As such, constant soil moisture should be maintained to avoid variations in plant moisture stress (Jones, 2008; Salveit, 2005). Cracking can further be avoided by making sure that calcium nutrition is adequate and by selecting crack resistant cultivars (Salveit, 2005).

2.4.7.2 Misshapen fruit, catface & puffiness)

Misshappen fruit is commonly caused by incomplete or partial pollination. Incomplete pollination causes differential growth of various parts of the fruit resulting in misshapen fruit (Salveit, 2005). Examples of misshapen fruit include catface, puffiness and general non round fruit.

Catface is characterised where fruit do not have a smooth round appearance. Locules in the fruit produce a convoluted shape due to differential growth. This disorder it thought to be due to incomplete pollination of all seed cells (ovules). The cause of catface is partly due to low temperatures (<12.7°C) and cloud cover during flowering and fruit set (Jones, 2008).

Puffiness, also known as boxiness, or hollowness is a disorder characterised by one or more locules being empty of some or all seed tissue (Salveit, 2005; Jones, 2008). Affected fruit appear normal, although they are less dense than normal fruit, and can be separated by floating in water. A flat spot usually forms above the affected area. This disorder usually appears in early-season tomato crops or fruit which have been harvested early (Salveit, 2005; Jones, 2008). Improper pollination causing incomplete locule development is mainly due to unfavourable conditions, such as high (>32.2°C) or low (<14.4°C) temperatures, low light and excessive nitrogen fertilization (Jones, 2008).

2.4.7.3 BER (Blossom End Rot)

Blossom end rot (BER), if left untreated, can be the most destructive physiological disorder which affects tomato crops. Affected fruit are easily spotted. This disorder can affect young fruit as well as larger, more developed fruit. In both cases the blossom end of the fruit begins to turn brown, spreading its way towards the calyx end of the fruit. In young fruit the affected area first appears water soaked followed by a colour change from brown to black. Older fruit typically follow the same changes as in young fruit, with the addition of accelerated ripening above the affected area from green to red. The term “rot” does not accurately describe this physiological disorder as no pathogenic organism is involved (Snowdon, 1990).

The cause of BER has been under scrutiny for over a century. The first documented incidence of BER occurred in 1896 (Selby, 1896; cited in Saure, 2001). The main cause of BER, which has received much attention, is said to be the insufficient supply of Ca^{2+} to the site of the physiological disorder, the fruit. The limited supply of Ca^{2+} to the fruit may be attributed to (Ho et al., 1992);

1. Light and temperature at the fruit itself. Gibberellin activity increases with high temperatures and high irradiance and low RH increases stress (Nilsen and Orcutt, 1966, cited in Saure, 2001)
2. Inadequate xylem tissue development in fruit. Plants grown in high conductivity results in greatly reduced water uptake, suggesting an increased resistance in xylem transport within the fruit (Ehret & Ho, 1986).
3. Competition between leaves, shoot and fruit for available Ca^{2+}.

A review by Saure (2001) suggests that Ca^{2+} deficiency is not the primary factor for the onset of BER. It is proposed that two equally important factors are responsible for BER symptoms;

1. The crop is highly susceptible to various stresses due to an increase in physiologically active gibberellins (GA), resulting in a decrease in Ca^{2+}. Rapid growth has been attributed to an increase in GA and an external application of GA has shown to increase the occurrence of BER. The application of GA inhibitors has resulted in an increase in Ca^{2+}. The uptake and transportation of Ca^{2+} has shown to relate to GA levels. Ca^{2+} is known to protect cell membrane integrity while GA has shown to do the opposite.
2. A specific stress, such as water deficits, high salinity or high NH_4^+ activity causes cell membranes to deteriorate and subsequent loss of turgor.

To summarise, BER is a complex physiological disorder which is not fully understood. There is no simple cause of BER symptoms but rather a combination of high GA and low Ca^{2+} levels in susceptible cell membranes which can result in a loss of turgor and leakage of solutes, together with adverse environmental conditions (specific stresses) which causes the disintegration of cell membranes (Saure, 2001).

There are several causes of BER. The main cause is calcium deficiency coupled with moisture stress as a trigger (Pill et al., 1978). Grierson and Kader (1986) found that the calcium concentration in affected fruit was 0.08% while unaffected fruit had a calcium concentration of 0.12%. Calcium is relatively immobile in plants. Fruit develop fast and require an increased amount of energy and nutrition compared to other sinks in the plant. As such, fruit will show signs of calcium deficiency. The level of calcium required during fruit growth favours the development of BER (Ho, 1999).

BER increases with fruit thinning (Dekock et al., 1982). While fruit thinning increases fruit size, rapidly developing fruit are more susceptible to BER. This may be due to an excess hormone supply from the roots to the developing fruit.

Other disorders

Sun scald and russeting are other physiological disorders which may impact on the quality of tomatoes. The most sensitive green and ripening fruit exposed to direct sunlight for a prolonged period of time are most vulnerable to sun scald (Salveit, 2005; Jones, 2008). Affected fruit appear translucent; thin walled and a netted appearance. Development and quality of fruit decrease as the internal temperature of fruit increases (Salveit, 2005) by more than 10°C, compared to the ambient temperature (Jones, 2008). The appearance of russeting is similar to that of cracking. Russeting is characterised by numerous fine cracks which appear on the surface (Salveit, 2005) rather than limited large cracks. Russeting may also appear as brownish scarring on the fruits surface, giving it a rough cloudy appearance. Increased greenhouse humidity is said to be the cause of this disorder (Jones, 2008).

2.4.8 Pest and Disease

The use of chemicals in food production is perceived to be a danger to public health. Regardless of the legitimacy of this claim, the fact is that the industry has moved towards methods which are deemed “healthy”, and as such biological control methods are becoming the standard. Biological pest control has a long history of investigation and development. One predator which is becoming popular to control whitefly in the greenhouse is *Encarsia formosa* (Ferguson, 1996; Smith, 1993; Stephens, 1997).

Successfully implementing biological control agents rely on factors involving greenhouse management, timing, and subsequent monitoring. Optimum humidity and temperature, for predator and pest, are factors which affect their efficacy. Introducing predators prior to pest infestation is vital in maintaining a sustainable balance between pest and plant.

As with any pest problem, a combination of controls is usually implemented to prevent population explosions. One simple addition to biological control is the addition of plants for the sole purpose of attracting pest, as opposed to the value crop. Plants are removed and replaced as required.

Apart from biological and chemical controls, another innovative method gaining ground in pest control is the use of trichomes as a defence mechanism in *Lycopersicon* species. Trichomes are small epidermis cells which protrude from leaves and plant parts (Schilmiller et al., 2008). Glandular and non-glandular trichomes are prominent features of the foliage and stems (Kennedy, 2003). These trichomes range in size, shape and morphology from silk like protrusions called seed trichomes to others which appear on the leaves surface as bumps (Schimiller et al., 2008). There are four common types of trichomes in *Lycopersicon* species (Luckwill, 1943). Of the four, type four and type six are associated with high levels of arthropod control (Fig. 8).

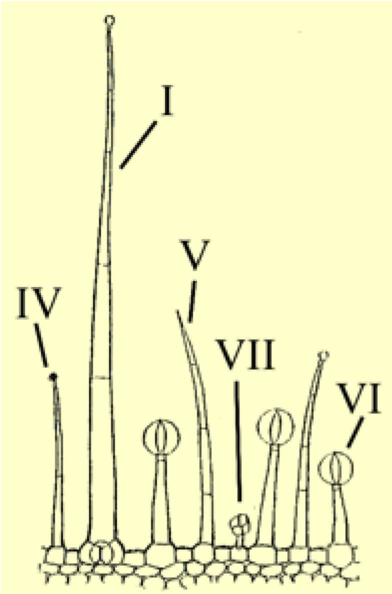

Fig. 8. Solanaceous species, including Tomato, produce a variety of trichomes on the surface of leaves, stems and flowers parts. Type four and type six trichomes are associated with high anthropod control.

Proteinase inhibitor proteins are known to interfere with herbivore physiology by preventing proteinases from being digested. These inhibitors accumulate in plant tissues naturally in flowers and responsively in leaves due to wounding or insect feeding (Schilmiller et al., 2007). Apart from proteinase inhibitors, trichomes from many species of *Solanum* also produce significant levels of polyphenol oxidase (Yu et al., 1992). Polyphenol oxidase studies have uncovered a number of functions including insect and pathogen defence (Myers, 2006). Trichomes therefore do not only provide a physical barrier but also a chemical barrier (proteinase inhibitor and polyphenol oxidase) to some plant pests.

Sanitation and cultural practises should not be overlooked. The best pest and disease program is prevention rather than controlling after an infestation. Simple techniques include:

- Keep the greenhouse floor clean by removing plant tissue, such as suckers, leaves and unmarketable fruit.
- Restrict foot traffic access into the greenhouse.

- Maintain working tools through sterilising.
- Using plastic gloves during pruning and fruit picking.
- Remove all weeds growing along the edges of the greenhouse.
- Don’t use the greenhouse to store or grade fruit.

2.5 Growth Analysis

2.5.1 Introduction

Total biomass production, biomass partitioning and fruit content (dry matter) determines the yield of a tomato crop. Not only do these attributes affect yield but also fruit quality (taste and size) which affects product price (Heuvelink & Dorais, 2005). Photosynthesis is the major driver in biomass production. Light interception greatly determines the rate of photosynthesis which varies with leaf area. Although measuring leaf area is a good indicator of biomass production, it is important to note that high biomass production does not necessarily result in high yields.

Plant growth analysis refers to quantitative methods used to describe and interpret the performance of plant systems under controlled, natural, or semi-natural environments. These methods includes a number of primary data recordings, such as weights, areas, volumes and/or the contents of plant components, to investigate the inner workings of whole plants or crops (Hunt, 2003). In this context “growth” refers to an irreversible change in time. These changes may most often be due to size (mass, volume, etc.) or number.

Two approaches to plant growth analysis have evolved. The “classical” approach involves a series of infrequent harvests. These harvests are large, destructive and usually consist of many replicates. The second of the two approaches, “functional” approach, involves frequent measurements taken over a greater period of time with less replication of measurements. Due to restrictions on both time and space it is said the experimenter is often forced to choose between the two approaches. A decision needs to be made in advance as experimental design depends on which approach is used (Hunt, 2003).

Classical experiments have shown that both annual and perennial growth raised under productive systems (Hunt, 2003) follow the same typical pattern. Changes in total dry weight vary considerably over the course of growth, especially in the first phase of development (Hunt, 1978). Recording changes, in total dry weight, on an arithmetic scale does not show visible differences in the first phase of development. For this reason, data is often transformed to natural logarithms to greater emphasise differences in growth and therefore used to calculate RGR, etc

2.5.2 Absolute growth rate (AGR)

Absolute growth rate (AGR) is defined as the net gain in weight over a period of time, irrespective of the initial weight of the plant. It is very possible for two plants being measured, although one has an initial weight of 1g and the other 10g, to have the same AGR (Hunt, 1978). AGR is the simplest measure of plant growth rate (Hunt, 2003). Measuring AGR is commonly used in systems where the initial weight of the plant is of no importance. In most other applications, however, a more useful measure of performance is required which include the initial weight. Relative growth rate (RGR) is commonly used for such applications.

2.5.3 RGR

The RGR (Relative growth rate) was originally termed "efficiency index" as it expresses growth in terms of increase in weight per unit of size (Hunt, 2003). This concept can easily be explained in financial terms. The amount of interest gained on an investment can be interpreted as the AGR while the amount of interest gained, taking into account capital invested, can be seen as RGR. Therefore, RGR expresses the relationship between initial plant weight, final plant weight and the period of growth (Hunt, 1978).

RGR can be expressed either as an instantaneous or a mean value. West, Briggs & Kidd (1920a) who suggested the name "relative growth rate" explained that RGR could not always be regarded as a constant value as the value can change depending on the different stages of plant growth. For this reason, the term "specific growth rate" was used for the instantaneous value (iRGR). Calculating the mRGR (mean RGR) or iRGR are both useful and have their purposes (Hunt, 1978).

The equation used for determining instantaneous RGR;

$$iRGR = \frac{1}{W} \times \frac{dW}{dt}$$

The equation used for determining mean (between two time periods) RGR;

$$mRGR = \frac{lnW_2 - lnW_1}{t_2 - t_1}$$

Where W = Biomass dry weight
t = Time

RGR can also be calculated if both the "photosynthetic term", NAR (net assimilation rate) and "morphogenic term", LAR (leaf area ratio) are known (Hunt, 1982);

2.5.4 NAR

Net assimilation rate (NAR) can be viewed as the difference between total photosynthesis and total respiration. In other words, NAR represents the plant's net photosynthetic effectiveness in obtaining light, assimilating CO_2 and accumulating photoassimilates. Variations in NAR can be attributed to differences in, plant architecture and light interception, respiration rate, photosynthetic activity of leaves and storage capacity of sinks, among others (Kriedermann et al., 2003).

The equation used for determining instantaneous NAR;

$$iNAR = \frac{1}{A} \times \frac{dW}{dt}$$

The equation used for determining mean (between two time periods) NAR;

$$mNAR = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{lnA_2 - lnA_1}{A_2 - A_1}$$

Where W = Biomass dry weight

A = Leaf area

t = Time

2.5.5 LAR

Leaf area ratio (LAR) can be defined as the proportion of biomass invested in leaf area or more simply the "leafiness" of the plant (Kriedermann et al., 2003). In financial terms LAR can be described as the balance between income and expenditure (Hunt, 2003).

LAR can further be broken down into the leaf weight ratio (LWR) and specific leaf area (SLA). LWR refers to the ratio of leaf dry weight over total plant dry weight while SLA refers to the ratio of leaf area over leaf dry weight (Heuvelink & Dorais, 2005). In other words SLA is an index which describes the relative thickness of a leaf while LWR is an index which describes the overall leafiness of a plant (Hunt, 2003). Variations in SLA usually contribute to variations in LAR (Hunt, 1982).

The equation used for determining instantaneous LAR;

$$iLAR = \frac{A}{W}$$

The equation used for determining mean (between two time periods) LAR;

$$mLAR = \frac{1}{2}\left(\frac{A_1}{W_1} + \frac{A_2}{W_2}\right)$$

Where W = Biomass dry weight

A = Leaf area

NAR and LAR are mutually dependent (Fig. 9), resulting in a negative correlation (Thornly & Hurd, 1974; Bruggink & Heuvelink, 1987). Therefore LAR = RGR/NAR and/or RGR = NAR X LAR. More explicitly RGR = NAR X LWR X SLA.

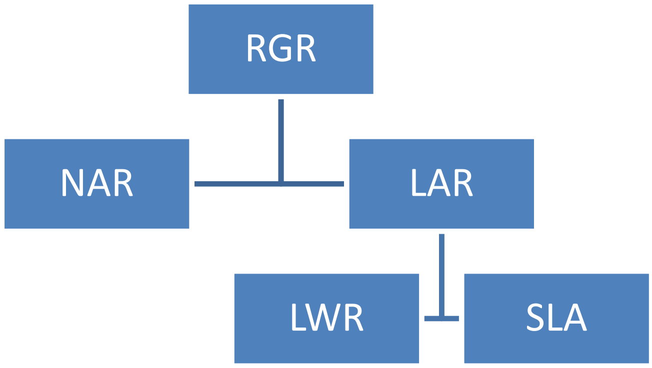

Fig. 9. The relationship between growth parameters RGR (relative growth rate), LAR (leaf area ratio), LWR (leaf weight ratio) and SLA (specific leaf area).

2.5.6 Summary

Plant growth analysis has proved highly effective when studying a plants reaction to environmental conditions. The following summary highlights the terminology, units and functional definition commonly used in plant growth analysis to accurately quantitate differences in plant growth performance (Table 2).

Table 2. A reference of terminology, functional definition and corresponding units commonly used in plant growth analysis. Adapted from Kriedermann et al., 2003.

Terminology	Units	Functional definition
AGR	g. week^{-1}	Source strength Sink strength
NAR	g.cm^{-2} (leaf). week^{-1}	Rate of weight gain per unit leaf area. Source activity Dry matter production efficiency
RGR	g.g^{-1}. week^{-1}	Sink activity
LAR	cm^{-2}. g^{-1}	Ratio of leaf area to total plant weight
SLA	cm^{-2}. g^{-1}	Ratio of leaf area to leaf weight
LWR		Ratio of leaf weight to total plant weight

CHAPTER 3: MATERIALS AND METHODS

3.1 Potting material

3.1.1 Size grade sourced coir

Gropac coir needed to be processed in order to separate particle sizes. The following process was undertaken to fully break up the coir from a state of compression;

1. Compressed coir was placed in a 50l plastic container together with water at room temperature and allowed to fully saturate for 24 hours, allowing particle sizes to fully expand and separate from one another.
2. The hydrated coir was then oven dried at 60°C, for 48 hours or until media fell apart to the touch, to allow all water to evaporate. Once fully dried, the coir expanded in the order of 300%.
3. The oven dried coir media was placed on a vibrating sieve shaker, separating the media into 3 grades, namely S(small), M(Medium), and L(Large) with corresponding sizes <0.85mm, 0.85-1.40mm, 1.40-2.36mm.

Once the coir was initially processed a further 3 size grades were created by mixing 1:1 ratios of S, M, and L. A seventh grade was created by mixing at a ratio of 1:1:1. The 7 final size grades are namely:

1. S = 100% Small
2. M = 100% Medium
3. L = 100% Large
4. SM = 50% S and 50% M
5. SL = 50% S and 50% L
6. ML = 50% M and 50% L
7. SML = 33% S and 33% M and 33% L

3.1.2 Hong Kong (HK) sourced coir

Two samples of coir, P1 and P3, were provided by GTL (Green Terra Firma) based in Hong Kong. These two grades of coir where used and labelled as the Hong Kong (HK) sourced coir. This coir was provided as compressed coir blocks and processed using the same method described in Chapter 3.1.1. The coir was provided pre-graded and as such were not processed further into specific size grades.

For the purpose of size grade distribution, a sample of P1 and P3 was graded to determine the particle size makeup of the pre-graded coir.

3.1.3 Physical properties of coir

The physical properties of size grade sourced coir and Hong Kong sourced coir. Relevant physical properties include water holding capacity and air filled porosity.

Table 3. Physical properties of size grade and Hong Kong sourced coir. Properties include mean values for water holding capacity (WHC) and air filled porosity (AFP) and significant differences (95% CI). Source Duggan-Jones(2011)

Treatment	Water holding capacity (WHC)	Air Filled Porosity (AFP)
<u>Size grade source</u>		
S	87.61 ^{a}	9.87 ^{e}
M	65.17 ^{d}	24.64 ^{c}
L	41.36 ^{f}	48.69 ^{a}
SM	86.11 ^{a}	10.75 ^{e}
SL	75.28 ^{c}	21.83 ^{c}
ML	49.81 ^{e}	40.36 ^{b}
SML	80.35 ^{b}	17.28 ^{d}
<u>Hong Kong source</u>		
P1	75.53 ^{a}	9.40 ^{d}
P3	38.03 ^{de}	52.62 ^{a}
C	49.57 ^{c}	42.26 ^{b}
P1C	64.63 ^{b}	21.43 ^{c}
P3C	36.60 ^{e}	53.39 ^{a}
P1P3	46.06 ^{cd}	40.54 ^{b}
P1P3C	45.88 ^{cd}	41.79 ^{b}

Means with the same letter are not significantly different (95% confidence interval).

3.1.4 Facilities

The greenhouse facilities used for both yield trials were situated at the PGU (Plant Growth Unit) at Massey University, Turitea, Palmerston North. The greenhouse measured 6m x 15m. An environment control system regulated the temperature between 18°C and 22°C through venting and heating. Two sets of irrigation lines were placed in parallel throughout the greenhouse allowing for easy implementation of either irrigation treatment (Fig. 10). Pressure regulators were placed between the main irrigation tubes and spaghetti tubing, from which drip irrigators were attached. The two irrigation treatments were controlled by Dosatron irrigation controllers. Air-pressure controlled vents were located along the sides of the greenhouse and at the roof peak.

The greenhouse facilities used for the growth analysis (bioassay) was also situated at the PGU and consisted of an ebb and flow irrigation system located within a propagation house. The EC was maintained at 2.2 using a standard all round nutrient solution. The propagation house was also used to propagate tomato seedlings for the two tomato yield trials. A larger ebb and flow system was used with a standard A and B solution (Table. 4) and an EC of 1.8 was maintained throughout propagation.

A hive of bumblebees was introduced to the greenhouse every 6 weeks during flowering to facilitate pollination. During the winter yield trial, bumblebees were introduced between fungicide sprays to prevent killing the population. As no sprays were used during the second yield trial, bumblebees remained in the greenhouse throughout flowering until population numbers declined.

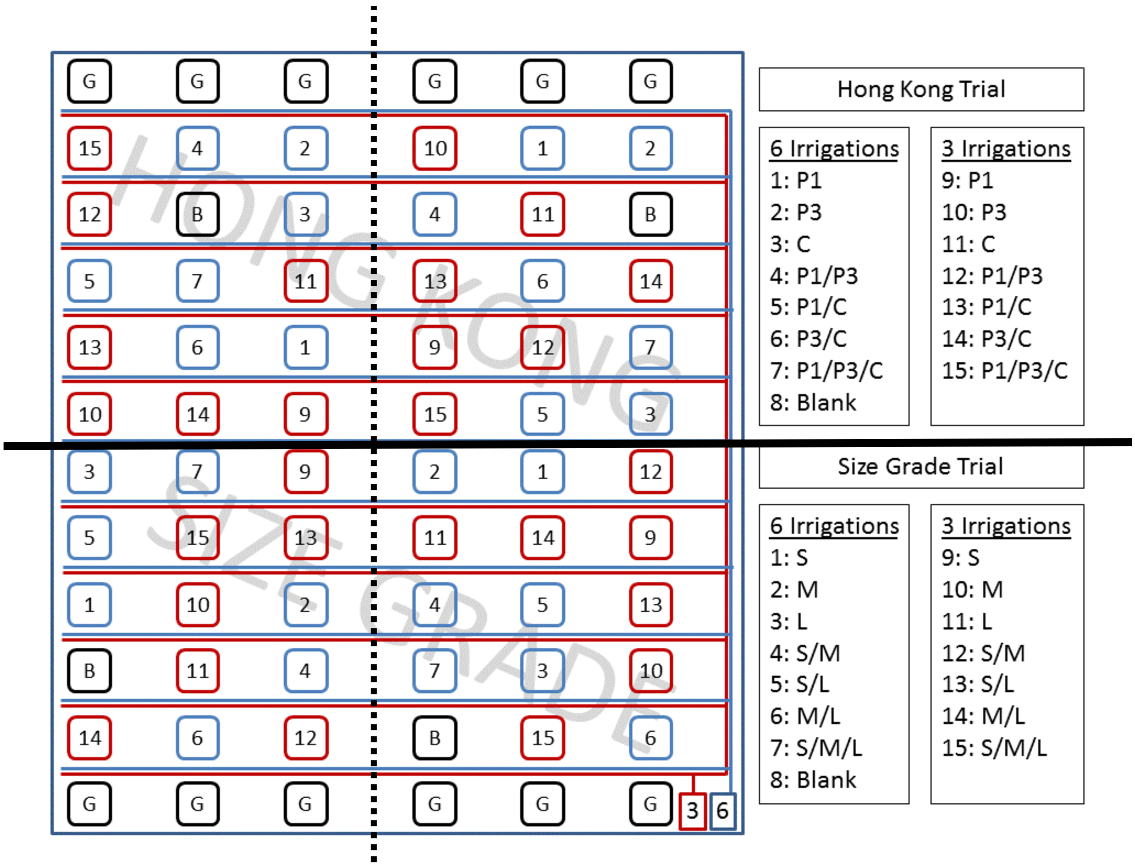

Fig. 10. The greenhouse layout used for the two tomato yield trials. The upper half consists of the Hong Kong trial while the bottom half the Size Grade trial. The layout consists of 2 irrigation frequencies (6 irrigations and 3 irrigations). Guard rows (G) were placed on either end of the greenhouse. Blanks (B), containing ungraded coir, where added to fill the couple of gaps in both trials.

Table 4. The recipe used for the standard A and B nutrient solution. Ingredients were diluted into 200l plastic containers from which 20l containers were used for the A and B solution for the summer yield trial.

Ingredient	Weight (g)
A solution	
Calcium Nitrate	19800
Potassium Nitrate	13160
B solution	
Magnesium Sulphate	9940
Mono Potassium phosphate	5410
Iron chelate	600
Manganese Sulphate	100
Zinc Sulphate	7
Copper Sulphate	6
Boric Acid	36
Ammonium Molybdate	1.6

3.2 Winter yield trial

The first tomato yield trial was conducted during the autumn/winter months of 2011. Tomato (*Lycopersicum esculentum*) cv. Moneymaker were sown on 11 February 2011 in a polystyrene transplant tray containing rockwool plugs covered in fine vermiculite and subsequently placed on an ebb and flow system. Seedlings were allowed to stretch before inverting and placing them into larger Grodan Rockwool cubes to improve stability.

Once seedling reached approximately 15cm in height, on 13 March 2011, they were moved to the greenhouse where they were placed on the processed coir bags. Peters® "Allrounder" nutrient solution (20+9+17+TE), diluted into 40L buckets, was injected via a Dosatron to maintain an EC of 3.5 through drip irrigation systems over two irrigation treatments, High and Low. Both treatments supplied equal quantity of solution within a 12 hour period. The High solution was irrigated twice as often as the Low solution. Irrigation lines were installed in row spacing's of 1m while pressure compensators and drip irrigators were attached at each plot (Fig. 10).

The experimental design was a randomised complete block with 2 plots, 2 blocks, 2 irrigation treatments and 7 size grade treatments. Each plot contained 2 plants.

A total of 11 harvests were taken on a weekly basis, commencing on the 6th June, 2011. Statistical analysis involved ANOVA and two-way interaction tests (see section 3.6

Chemical sprays were used to control whitefly (*Trialeurodes vaporariorum*) and powdery mildew. Calcium Chloride ($CaCl_2$) spray was used to reduce the occurrence of blossom end rot.

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3.3 Summer yield trial

The second tomato yield trial was conducted during the spring/summer months of 2011/2012. Tomato (*Lycopersicum esculentum*) cv. Albaron seeds were sown on 2 August 2011 in a polystyrene transplant tray containing rockwool plugs covered in fine vermiculite and subsequently placed on an ebb and flow system. Seedlings were 2 weeks old and allowed to stretch before inverting and placing them into larger Grodan Rockwool cubes to improve stability.

Once seedling reached approximately 15cm in height, on 26 August 2011, they were moved to a greenhouse where they were placed on processed coir bags. An A and B standard tomato solution (Table. 4), injected via a Dosatron to maintain an EC of 2.2 through the drip irrigation system, was used. Two irrigation treatments, High and Low, were used. Due to an error the low irrigation treatment received 3 times more solution within a 12 hour period than originally intended. The high treatment was irrigated twice as often as the low irrigation.

The experimental design was a randomised complete block with 2 replications, 2 blocks, 2 irrigation treatments and 7 size grade treatments. Each plot consisted of 2 plants.

Tomatoes were picked, on average, twice a week. Harvest frequency depended on the particular phase of development (three phases observed in sigmoidal cumulative yield). Harvesting took a total of 13 weeks, commencing on the 17 November, 2011. Statistical analysis involved ANOVA and two-way interaction tests (see section 3.6).

No chemical sprays were used throughout the growth of the summer yield trial. Powdery mildew did not appear due to improved ventilation and weather conditions. Natural predators (*Encarsia formosa*) were used to control whitefly; three tags were added to the greenhouse per month. As a consequence, bumblebees used to aid pollination, were able to remain in the greenhouse throughout flowering.

3.4 Growth Analysis 1: Tall vs Short Pots

Growth analysis 1 was conducted to investigate the effect of pot height on the growth of tomato seedlings growing in the 7 size grades of coir. Tomato (*Lycopersicum esculentum*) cv. Moneymaker seeds were sown on 4 October 2011 in a seedling tray consisting of a bark based potting mix. The seed tray was hand watered above with water. Once seedling reached their first true leaves (approximately 1 week) they were pricked out and placed 5 per pot. The first harvest took place 1 week after transplanting and the second harvest a week later. Two pot heights were used containing equal volumes of graded coir. An "all round" nutrient solution was used in the ebb and flow on which the pots were placed.

The experimental design was a randomised complete block with 2 blocks, 2 pot heights and 7 size grade treatments. Statistical analysis involved ANOVA and two-way interaction tests (see section 3.6).

3.5 Growth Analysis 2: Tall Pots only

Growth analysis 2 was conducted to investigate the effect taller pots had on the 7 size grades. Tomato (*Lycopersicum esculentum*) cv. Moneymaker seeds were sown on 7 November 2011 in a polystyrene tray consisting of a rockwool plugs on which the seed was placed covered in course vermiculite. The polystyrene tray was then placed on an ebb and flow system using an "all round" nutrient solution. Once the first true leaves appeared the rockwool plugs were individually planted into tall pots containing the graded coir. Overhead irrigation took place in the morning to fully saturate pore spaces while the ebb and flow system sub irrigated at midday and late afternoon.

The experimental design was a randomised complete block with 2 plots, 4 blocks, 1 pot height and 8 size grade treatments. Statistical analysis involved ANOVA tests (see section 3.6 .

3.6 Data collection and analysis

Data collection for the winter yield trial consisted of;

1. Number of saleable fruit,
2. Fresh weight of saleable fruit,

Data collection for the summer yield trial consisted of;

3. Number of saleable fruit,
4. Fresh weight of number of saleable fruit,
5. Number of reject and/or blossom end rot fruit,
6. Fresh weight of reject and/or blossom end rot fruit.

The following variables were collected during both the growth analysis trials;

1. Plant Number
2. Leaf area (measured in cm^{-2})
3. Dry weight (g) for;
    a. Leaves
    b. Stems
    c. Roots (attempted but unsuccessful)

Data analysis involved using a spreadsheet package for data entry, data manipulation and graphing. A more powerful package was required for linear modelling and subsequent ANOVA (analysis of variance). The spreadsheet package used for data entry was Microsoft Excel© 2010. R, a free software environment for statistical computing and graphics, was used as the preferred statistical package. A two-way ANOVA test and LSD t test was completed for both the winter yield and summer yield trials. Interactions between particle size and irrigation treatment were tested. The relationship between particle size and pot size were tested using two-way ANOVA for growth analysis 1 while a single ANOVA test was used to compare particle size in growth analysis 2. A telephone directory was used to randomly allocate plots for the two tomato yield trials while a random number generator package was used in statistical package R for the growth analysis trials. An example of statistical output can be seen in Appendix. 1.

CHAPTER 4: RESULTS

4.1 Size grade physical properties summary

The physical properties of size grade sourced coir and Hong Kong sourced coir are given in Table. 5 with relevant physical properties including water holding capacity and air filled porosity.

Table 5. Physical properties of size grade and Hong Kong sourced coir. Properties include mean values for water holding capacity (WHC) and air filled porosity (AFP) and significant differences (95% CI). Source Duggan-Jones(2011)

Treatment	Water holding capacity (WHC)*	Air Filled Porosity (AFP)*
Size grade source		
S	87.61 [a]	9.87 [e]
M	65.17 [d]	24.64 [c]
L	41.36 [f]	48.69 [a]
SM	86.11 [a]	10.75 [e]
SL	75.28 [c]	21.83 [c]
ML	49.81 [e]	40.36 [b]
SML	80.35 [b]	17.28 [d]
Hong Kong source		
P1	75.53 [a]	9.40 [d]
P3	38.03 [de]	52.62 [a]
C	49.57 [c]	42.26 [b]
P1C	64.63 [b]	21.43 [c]
P3C	36.60 [e]	53.39 [a]
P1P3	46.06 [cd]	40.54 [b]
P1P3C	45.88 [cd]	41.79 [b]

Means with the same letter are not significantly different (95% confidence interval).

4.2 Hong Kong (HK) size grade

A size grade distribution was conducted on two coir grades, P1 and P3, provided from Hong Kong (Fig. 11). P1 size grade consisted of a large percentage of particles smaller than 2.80mm with a peak in size 0.85mm to 1.70mm. The percentage of particles larger than 1.70mm decreased continuously before containing no particles larger than 4.00mm. P3 size grade contained a low percentage of particles smaller than 1.70mm. Particles larger than 1.70 increased sharply until reaching a peak size grade of 2.36mm from where the percentage of larger particles decreased. P3 size grade contained particles larger than 4.00mm while P1 size grade contained particles smaller than 0.25mm.

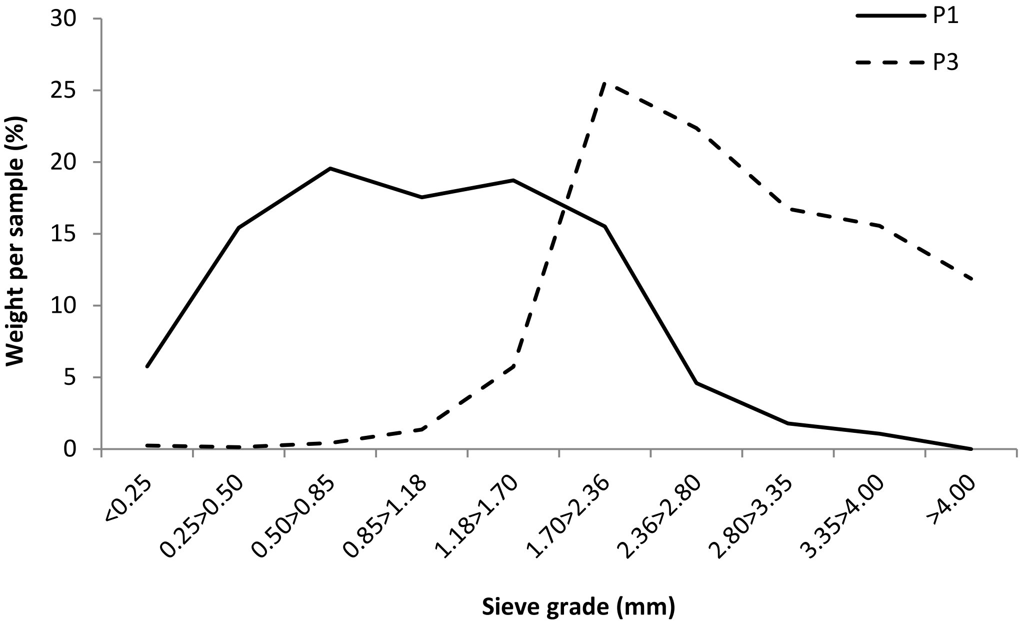

Fig. 11. Size grade distribution graph for Hong Kong (HK) sample set.

4.3 Winter yield trial

4.3.1 Total yield (HK)

Total yield per plant varied between 2.12kg and 2.93kg over 7 size grade treatments showing no significant differences between either coir size grades or irrigation treatments (Table. 6). There was no relationship between total yield and water holding capacity (Fig. 12).

Table 6. Total yield per plant over 2 irrigation treatments including their means and LSD (95% CI).

Treatment	6 Irrigations (kg/plant)	3 Irrigations (kg/plant)	Mean* (kg/plant)
P1	2.30	2.44	2.37 [a]
P3	2.59	2.36	2.47 [a]
C	2.12	2.37	2.25 [a]
P1P3	2.38	2.35	2.36 [a]
P1C	2.37	2.44	2.40 [a]
P3C	2.13	2.16	2.15 [a]
P1P3C	2.36	2.93	2.65 [a]
Mean	2.32	2.43	2.38

Means with the same letter are not significantly different (95% confidence interval).
*LSD = 0.85

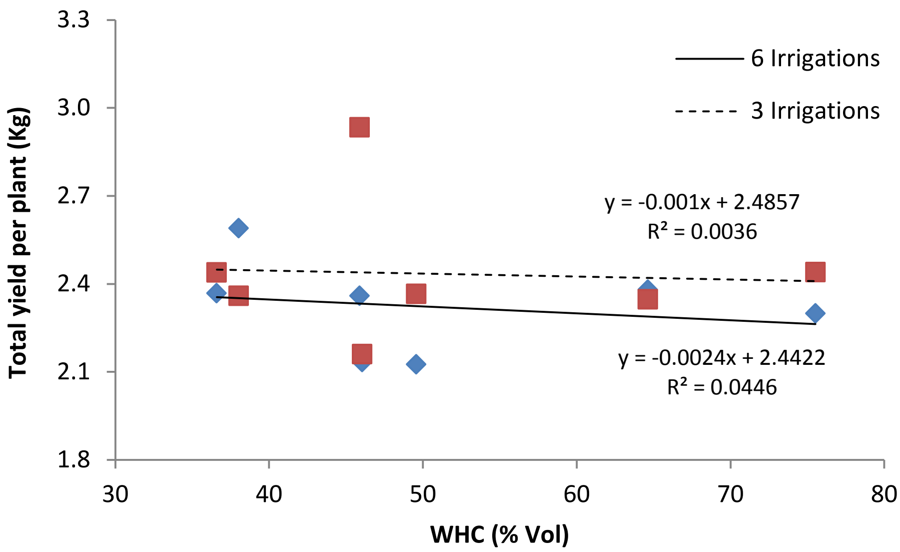

Fig. 12. Relationship between WHC (water holding capacity) and total yield obtained per plant between two irrigation treatments.

4.3.2 Fruit number (HK)

Fruit number per plant varied between 32.50 and 45.00 over 7 size grade treatments showing no significant differences between either coir size grades or irrigation treatments (Table. 7). There was no relationship between fruit number and water holding capacity (Fig. 13).

Table 7. Fruit number per plant over 2 irrigation treatments including their means and LSD (95% CI).

Treatment	6 Irrigations (Number)	3 Irrigations (Number)	Mean* (Number)
P1	36.00	42.00	39.00 [a]
P3	38.00	34.00	36.00 [a]
C	32.50	33.25	32.88 [a]
P1P3	35.75	35.00	35.38 [a]
P1C	34.25	40.00	37.13 [a]
P3C	34.50	34.00	34.25 [a]
P1P3C	39.75	45.00	42.38 [a]
Mean	35.82	37.61	36.71

Means with the same letter are not significantly different (95% confidence interval).
*LSD = 13.70

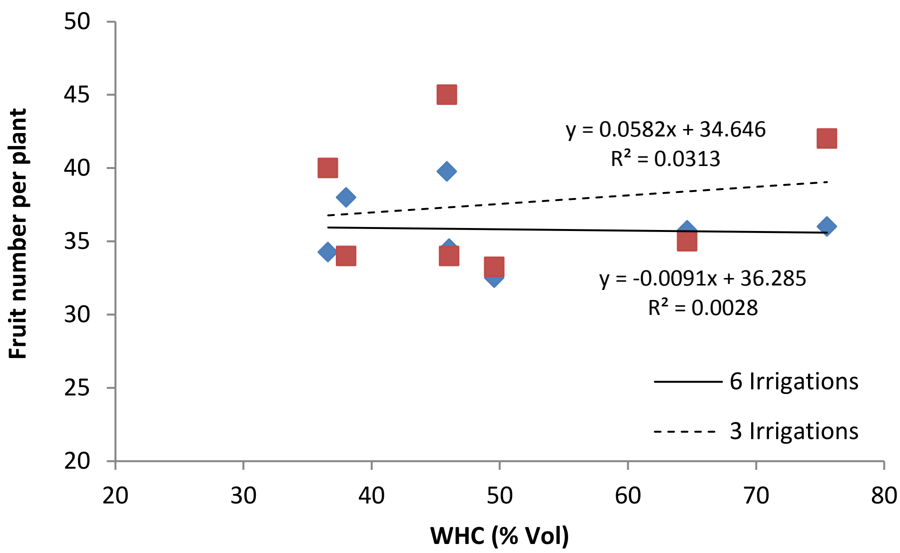

Fig. 13. Relationship between WHC (water holding capacity) and fruit number obtained per plant between two irrigation treatments.

4.3.3 Mean fruit weight (HK)

Mean fruit weight ranged between 58.0g and 71.0g over 7 size grade treatments showing no significant differences between either coir size grades or irrigation treatments (Table. 8). There was no relationship between mean fruit weight and water holding capacity (Fig. 14).

Table 8. Mean fruit weight per plant over 2 irrigation treatments including their means and LSD (95% CI).

Treatment	6 Irrigations (g)	3 Irrigations (g)	Mean* (g)
P1	64.4	58.0	61.2 [a]
P3	69.5	67.9	68.7 [a]
C	64.2	71.0	67.6 [a]
P1P3	65.5	65.6	65.5 [a]
P1C	69.8	63.2	66.5 [a]
P3C	61.5	61.7	61.6 [a]
P1P3C	60.3	64.4	62.4 [a]
Mean	65.0	64.6	64.8

Means with the same letter are not significantly different (95% confidence interval).
*LSD = 7.62

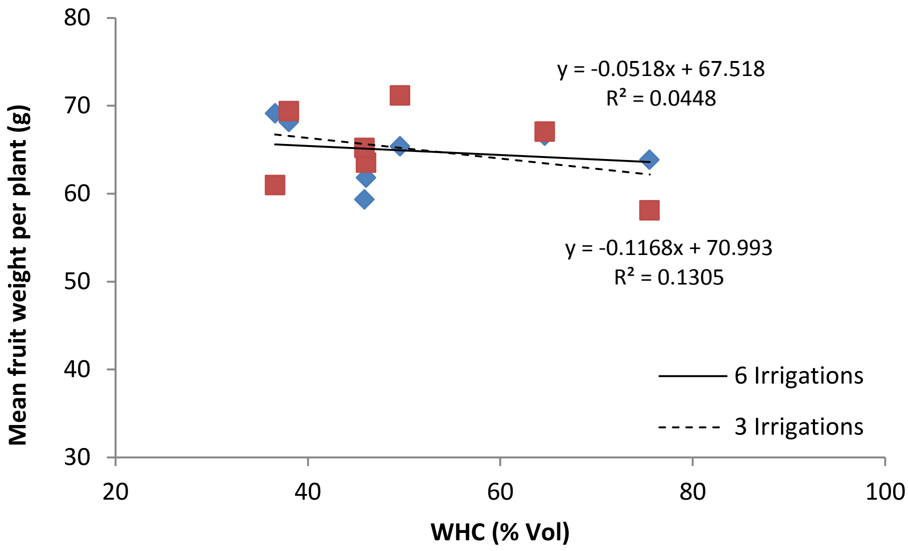

Fig. 14. Relationship between WHC (water holding capacity) and mean fruit weight per plant between two irrigation treatments.

4.3.4 Total yield (SG)

Total yield per plant varied between 1.58kg and 2.58kg over 7 size grade treatments showing no significant differences between either coir size grades or irrigation treatments (Table. 9). There was no relationship between total yield and water holding capacity (Fig. 15).

Table 9. Total yield per plant over 2 irrigation treatments including their means and LSD (95% CI).

Treatment	6 Irrigations (kg/plant)	3 Irrigations (kg/plant)	Mean* (kg/plant)
S	1.83	2.35	2.09 [a]
M	2.39	1.79	2.09 [a]
L	2.15	2.31	2.23 [a]
SM	2.41	2.58	2.49 [a]
SL	1.67	2.35	2.01 [a]
ML	1.58	2.32	1.95 [a]
SML	2.21	2.03	2.12 [a]
Mean	2.03	2.25	2.14

Means with the same letter are not significantly different (95% confidence interval).
*LSD = 0.65

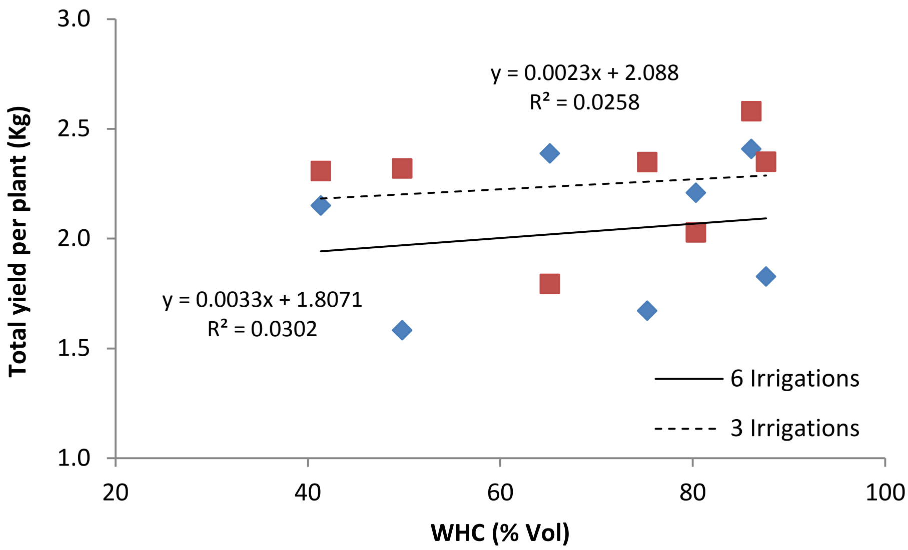

Fig. 15. Relationship between WHC (water holding capacity) and total yield obtained per plant between two irrigation treatments.

4.3.5 Fruit number (SG)

Fruit number per plant varied between 31.00 and 47.25 over 7 size grade treatments showing no significant differences between either coir size grades or irrigation treatments (Table. 10). There was no relationship between fruit number and water holding capacity (Fig. 16).

Table 10. Fruit number per plant over 2 irrigation treatments including their means and LSD (95% CI).

Treatment	6 Irrigations (Number)	3 Irrigations (Number)	Mean* (Number)
S	32.50	46.00	39.25 [a]
M	42.25	31.00	36.63 [a]
L	40.00	47.25	43.63 [a]
SM	40.75	46.75	43.75 [a]
SL	35.50	43.00	39.25 [a]
ML	24.75	45.00	34.88 [a]
SML	39.00	38.50	38.75 [a]
Mean	36.39	42.50	39.45

Means with the same letter are not significantly different (95% confidence interval).
*LSD = 12.79

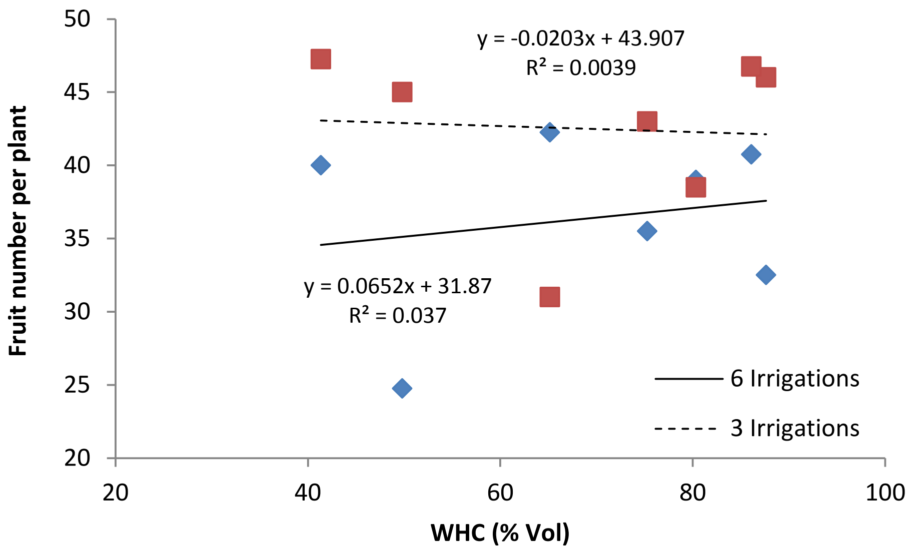

Fig. 16. Relationship between WHC (water holding capacity) and fruit number obtained per plant between two irrigation treatments.

4.3.6 Mean fruit weight (SG)

Mean fruit weight ranged between 48.6g and 71.5g over 7 size grade treatments showing no significant differences between either coir size grades or irrigation treatments (Table. 11). There was no relationship between mean fruit weight and water holding capacity (Fig. 17).

Table 11. Mean fruit weight per plant over 2 irrigation treatments including their and LSD (95% CI).

Treatment	6 Irrigations (g)	3 Irrigations (g)	Mean* (g)
S	56.3	50.4	53.4 [a]
M	56.9	57.5	57.2 [a]
L	54.8	48.6	51.7 [a]
SM	58.0	55.3	56.6 [a]
SL	50.1	53.9	52.0 [a]
ML	71.5	50.0	60.7 [a]
SML	59.1	54.1	56.6 [a]
Mean	58.1	52.9	55.5

Means with the same letter are not significantly different (95% confidence interval).
*LSD = 11.02

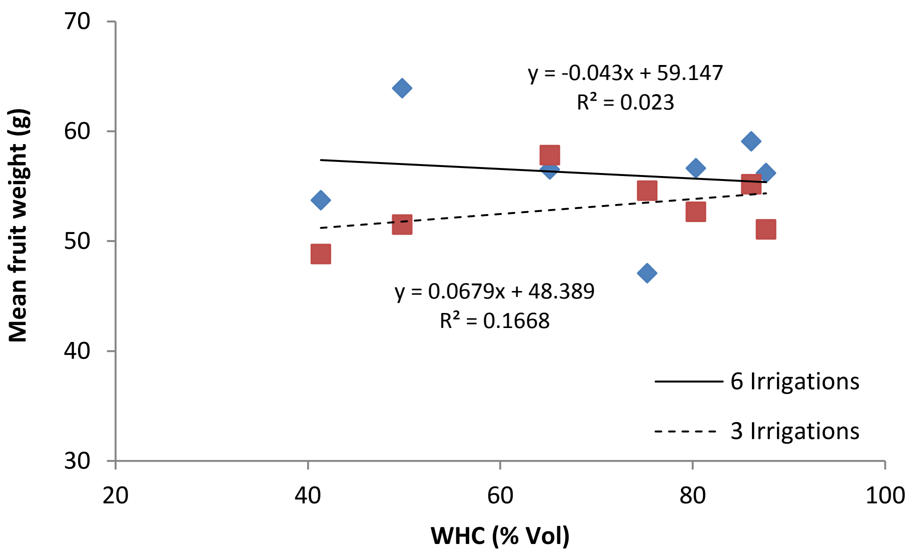

Fig. 17. Relationship between WHC (water holding capacity) and mean fruit weight per plant between two irrigation treatments.

4.4 Summer yield trial

4.4.1 Total yield (HK)

Total yield per plant varied between 6.26 kg and 9.07 kg over 7 coir treatment sizes (Table 12). Treatment P1 was significantly different to other treatments with a mean total yield of 8.40 kg/plant. There was also a significant difference between irrigation treatments when comparing slopes (Fig. 18). The 3 irrigation treatment produced a greater yield with an average of 8.52 kg/plant compared to the 6 irrigation treatment of 6.85 kg/plant. Irrigation treatments had similar increasing trends; as WHC increased total yield increased. The 6 irrigation treatment had a greater slope of 0.6306 compared to the 3 irrigation treatment which had a slope of 0.0829.

Table 12. Total yield per plant over 2 irrigation treatments including their means and LSD (95% CI).

Treatment	6 Irrigations (kg/plant)	3 Irrigations (kg/plant)	Mean* (kg/plant)
P1	7.74	9.07	8.40 [a]
P3	6.75	8.42	7.58 [b]
C	6.73	8.66	7.70 [b]
P1P3	7.09	8.26	7.67 [b]
P1C	6.80	8.64	7.72 [b]
P3C	6.26	8.96	7.61 [b]
P1P3C	6.62	7.67	7.14 [b]
Mean	6.85	8.52	7.69

Means with the same letter are not significantly different (95% confidence interval).
*LSD = 0.66

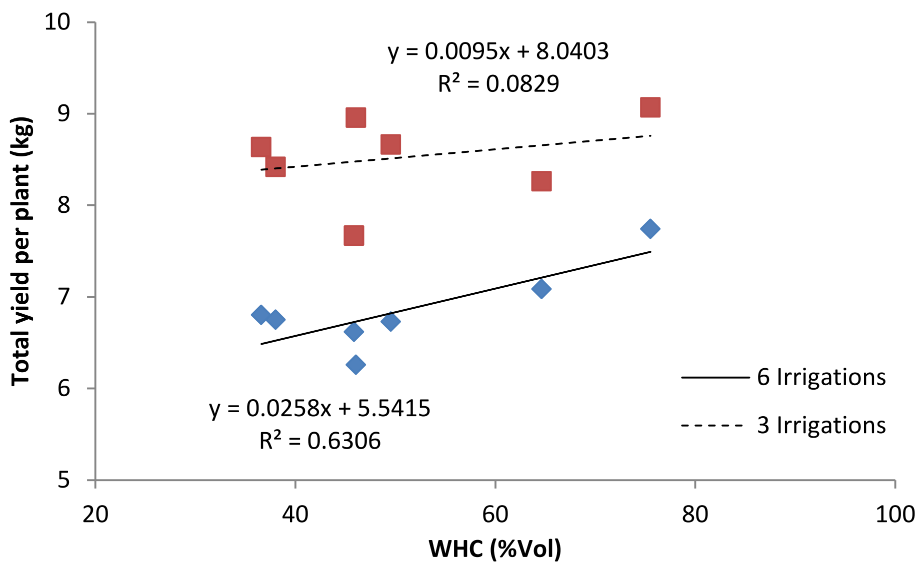

Fig. 18. Relationship between WHC (water holding capacity) and total yield obtained per plant between two irrigation treatments.

4.4.2 Fruit number (HK)

Fruit number per plant varied between 58.75 and 77.00 over seven coir treatment sizes (Table 13). There was a significant difference between size grade treatments with P1 producing the greatest mean number of 76.38 fruit per plant. There was also a significant difference between irrigation treatments when comparing slopes (Fig. 19) The three irrigation treatment produced more fruit per plant with an average of 72.07 compared to the six irrigation treatment which had an average of 66.39. Irrigation treatments had similar increasing trends; as WHC increased total yield increased. The six irrigation treatment, with a slope of 0.2798, was greater than that of the three irrigation treatment which had a slope of 0.0397.

Table 13. Fruit number per plant over two irrigation treatments including their means and LSD (95% CI).

Treatment	6 Irrigations (Number)	3 Irrigations (Number)	Mean* (Number)
P1	75.75	77.00	76.38 [a]
P3	60.25	73.50	66.88 [b]
C	67.75	75.75	71.75[ab]
P1P3	65.75	66.75	66.25 [b]
P1C	71.50	70.75	71.13[ab]
P3C	58.75	71.00	64.88 [b]
P1P3C	65.00	69.75	67.38 [b]
Mean	66.39	72.07	69.23

Means with the same letter are not significantly different (95% confidence interval).
*LSD = 7.68

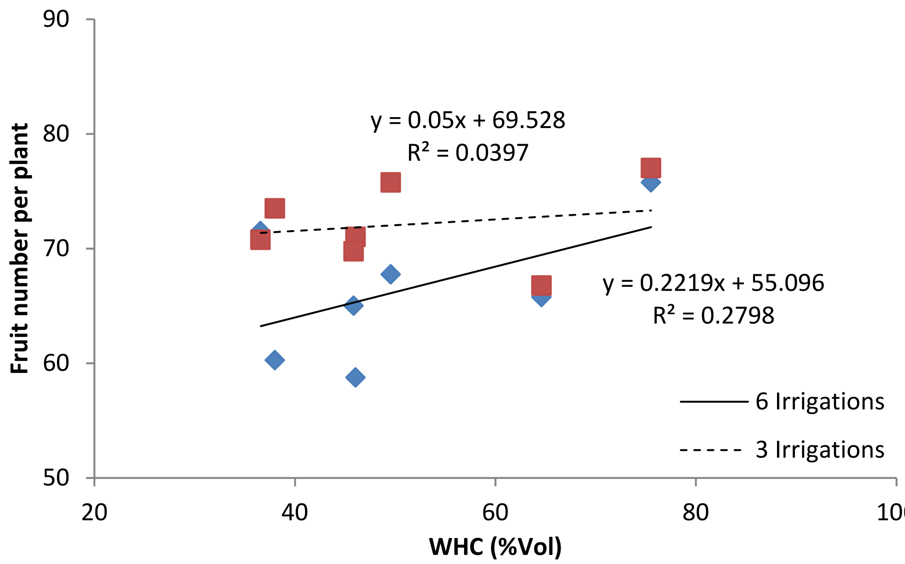

Fig. 19. Relationship between WHC (water holding capacity) and fruit number obtained per plant between two irrigation treatments.

4.4.3 Mean fruit weight (HK)

Mean fruit weight ranged between 95g and 126g over 7 coir treatment sizes (Table 14). There was a significant difference in treatment P3C with the highest mean fruit weight of 117g/plant compared to C and P1P3C with the lowest mean fruit weight of 107g/plant and 106g/plant. There was also a significant difference between irrigation treatments. The three irrigation treatment produced a larger mean fruit weight with an average of 118g compared to 104g for the 6 irrigation treatment. Both irrigation treatments had a slight increasing trend being almost parallel to one another (Fig. 20).

Table 14. Mean fruit weight per plant over 2 irrigation treatments including their means and LSD (95% CI).

Treatment	6 Irrigations (g)	3 Irrigations (g)	Mean* (g)
P1	102	118	110[ab]
P3	112	115	113[ab]
C	99	114	107[b]
P1P3	108	124	116[ab]
P1C	95	122	108[ab]
P3C	108	126	117[a]
P1P3C	102	110	106[b]
Mean	104	118	111

Means with the same letter are not significantly different (95% confidence interval).
*LSD = 10.34

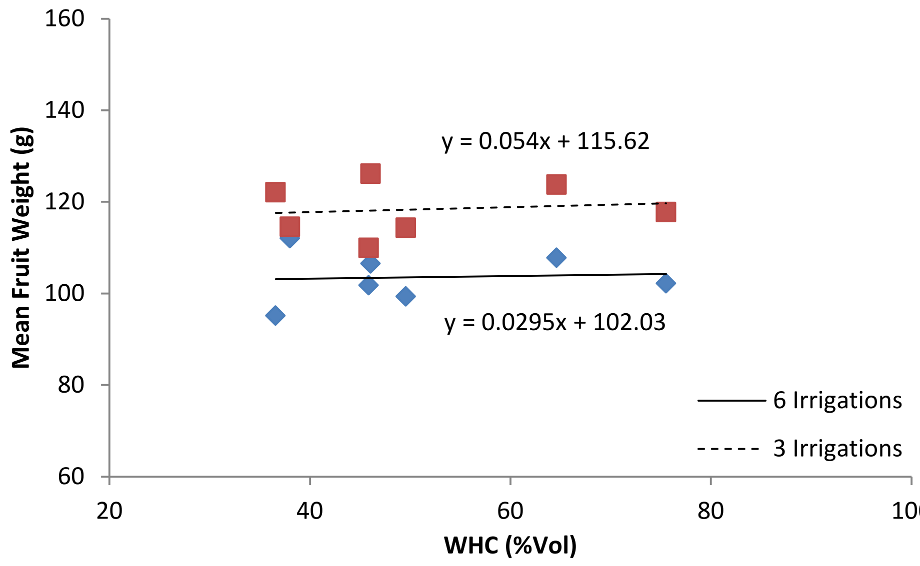

Fig. 20. Relationship between WHC (water holding capacity) and mean fruit weight per plant between two irrigation treatments.

4.4.4 Total Yield (SG)

Total yield per plant varied between 6.18kg and 9.21kg over 7 coir treatment sizes (Table. 15). Treatment L was significantly different from most treatment with the lowest mean total yield of 6.79 kg/plant. There was also a significant difference between irrigation treatments when comparing slopes (Fig. 21). The 3 irrigation treatment produced a greater yield with an average of 8.74 kg/plant compared to the 6 irrigation treatment of 7.10 kg/plant. Irrigation treatments had similar trends; as WHC increased total yield increased. The 3 irrigation treatment had a slightly greater slope of 0.5334 compared to the 6 irrigation treatment with slope 0.3429.

Table 15. Total yield per plant over 2 irrigation treatments including their means and LSD (95% CI).

Treatment	6 Irrigations (kg/plant)	3 Irrigations (kg/plant)	Mean* (kg/plant)
S	7.41	8.90	8.15 [a]
M	7.17	8.79	7.98 [ab]
L	6.18	7.39	6.79 [b]
SM	7.00	9.13	8.07 [a]
SL	7.60	9.21	8.40 [a]
ML	7.26	8.89	8.08 [a]
SML	7.05	8.90	7.98 [ab]
Mean	7.10	8.74	7.92

Means with the same letter are not significantly different (95% confidence interval).
*LSD = 1.19

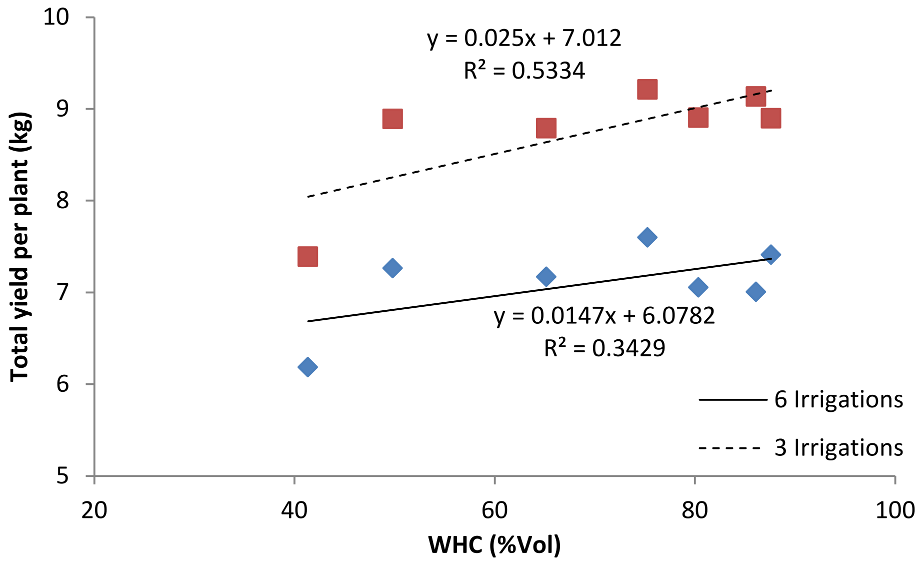

Fig. 21. Relationship between WHC (water holding capacity) and total yield obtained per plant between two irrigation treatments.

4.4.5 Fruit number (SG)

Fruit number per plant varied between 60.00 and 84.25 over 7 coir treatment sizes (Table. 16). There was a significant difference between size grade treatments with L producing the lowest mean number of 61.38 fruit per plant. There was no significant difference between irrigation treatments. Both irrigation treatments had increasing trends; as WHC increased, the number of fruit produced increased (Fig. 22). The 3 irrigation treatment, with a slope of 0.6344, was greater than that of the 6 irrigation treatment which had a slope of 0.0346.

Table 16. Fruit number per plant over 2 irrigation treatments including their means and LSD (95% CI).

Treatment	6 Irrigations (Number)	3 Irrigations (Number)	Mean* (Number)
S	78.00	84.25	81.13 [a]
M	76.25	74.00	75.13 [ab]
L	60.00	62.75	61.38 [c]
SM	69.50	79.00	74.25 [ab]
SL	76.50	80.75	78.63 [ab]
ML	80.75	77.00	78.88 [ab]
SML	64.25	76.00	70.13 [bc]
Mean	72.18	76.25	74.21

Means with the same letter are not significantly different (95% confidence interval).
*LSD = 10.09

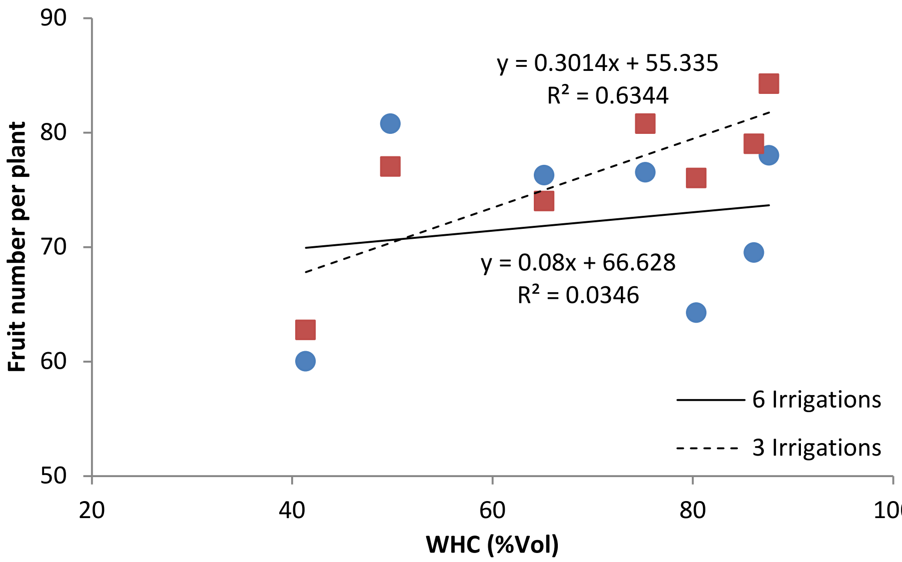

Fig. 22. Relationship between WHC (water holding capacity) and fruit number obtained per plant between two irrigation treatments.

4.4.6 Mean fruit weight (SG)

Mean fruit weight ranged between 90g and 120g over 7 coir treatment sizes (Table. 17). There was no significant difference between size grade treatments. There was, however, a significant difference between irrigation treatments when comparing slopes (Fig. 23). The 3 irrigation treatment produced a larger mean fruit weight with an average of 115g compared to 99g for the 6 irrigation treatment. Irrigation treatments had opposite trends. The 6 irrigation treatment had an increasing slope while the 3 irrigation treatment had a decreasing slope when plotted against WHC.

Table 17. Mean fruit weight per plant over 2 irrigation treatments including their means and LSD (95% CI).

Treatment	6 Irrigations (g)	3 Irrigations (g)	Mean* (g)
S	95	106	100 [a]
M	94	120	107 [a]
L	104	117	111 [a]
SM	101	116	108 [a]
SL	100	114	107 [a]
ML	90	116	103 [a]
SML	110	117	114 [a]
Mean	99	115	107 [a]

Means with the same letter are not significantly different (95% confidence interval).
*LSD = 17.75

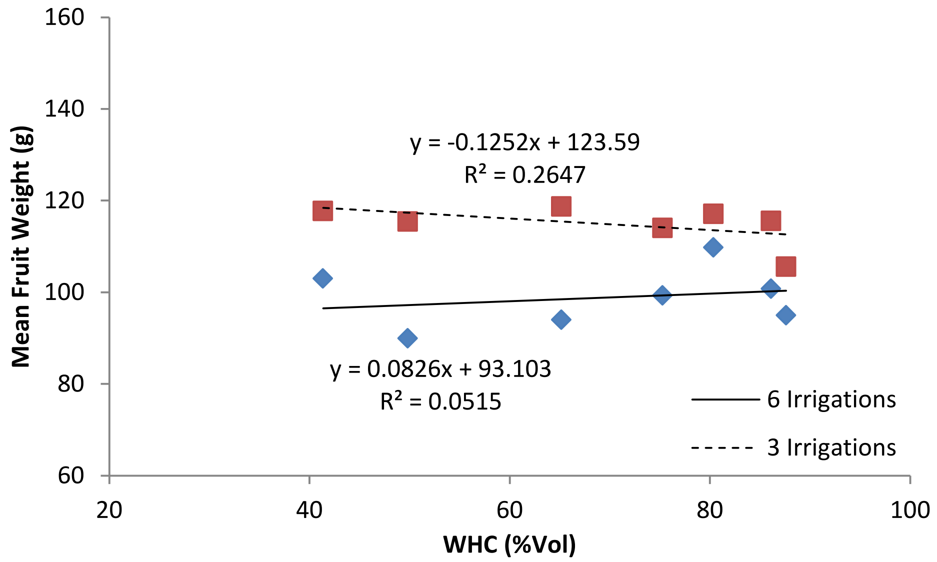

Fig. 23. Relationship between WHC (water holding capacity) and mean fruit weight per plant between two irrigation treatments.

4.4.7 Cumulative Yield (HK)

The sigmoidal curve show 3 phases, a rapidly increasing phase (P1), a linear phase or grand period of growth (P2), and a declining phase (P3) (Fig. 24). Phase 1 extends up until day 36 Phase 2 (P2) continued for the following 7 days. The final phase 3 occurs for the remainder of the trial. Both irrigation treatments have very similar trends up until day 50 where the 6 irrigation treatment gains yield at a faster rate compared to the 3 irrigation treatment.

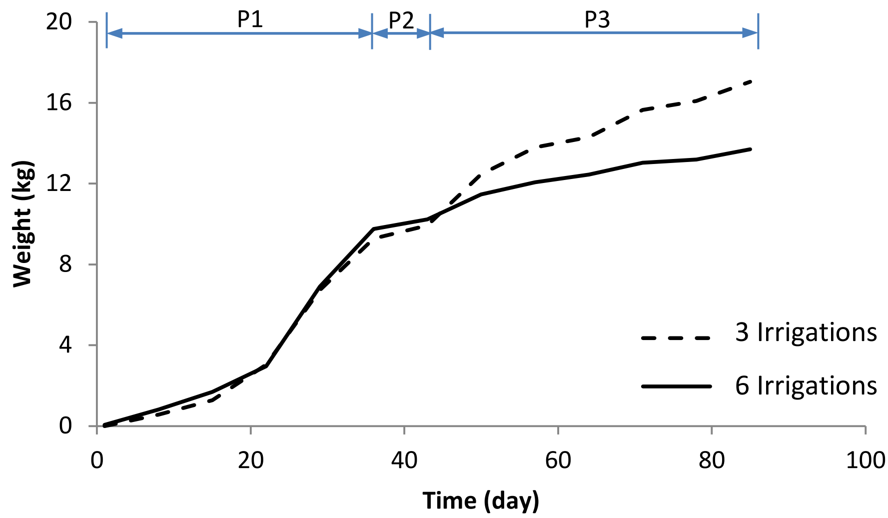

Fig. 24. A sigmoidal yield curve over 85 days between 2 irrigation treatments. The sigmoidal curve indicates 3 distinct phases. Phase 1 (P1) rapidly increases until day 36 where, phase 2 (P2), a grand period of growth or linear phase is reached. This linear phase continues until day 43 where phase 3 (P3) is reached where cumulative yield declines.

4.4.8 Cumulative Yield (SG)

The sigmoidal curve show 3 phases, a rapidly increasing phase (P1), a linear phase or grand period of growth (P2), and a declining phase (P3) (Fig. 25). Phase 1 extends up until day 36 Phase 2 (P2) continued for the following 7 days. The final phase 3 occurs for the remainder of the trial. Both irrigation treatments have very similar trends up until day 50 where the 6 irrigation treatment gains yield at a faster rate compared to the 3 irrigation treatment.

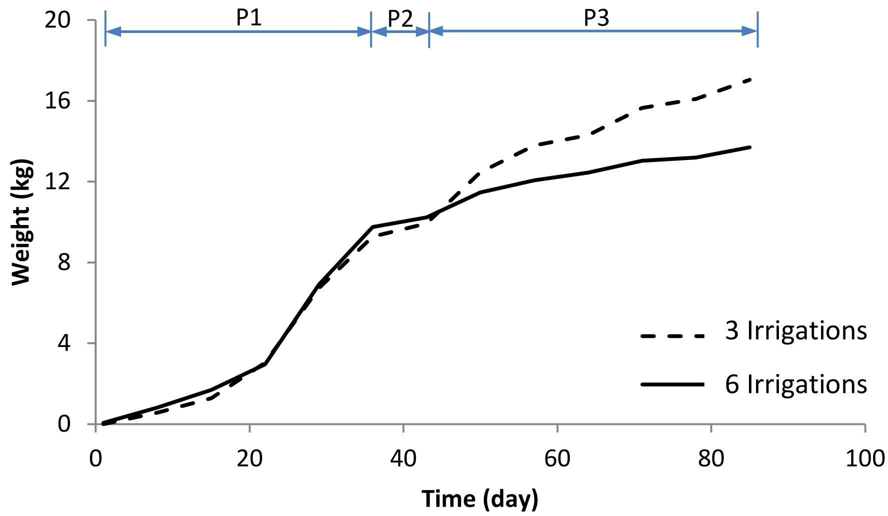

Fig. 25. A sigmoidal yield curve over 85 days between 2 irrigation treatments. The sigmoidal curve indicates 3 distinct phases. Phase 1 (P1) rapidly increases until day 36 where, phase 2 (P2), a grand period of growth or linear phase is reached. This linear phase continues until day 43 where phase 3 (P3) is reached where cumulative yield declines.

4.4.9 Time to 50% total harvest (HK)

The median (Q2) measures the time it takes the crop to complete 50% of its total harvest. Q2 duration took a minimum of 25.6 days and a maximum of 36.2 days over seven coir treatment sizes (Table. 18). There was a significant difference in treatment P3 taking fewer days to reach Q2 duration compared to P1C. There was also a significant difference in irrigation treatments when comparing slopes (Fig.26). The six irrigation treatment took 6 fewer days to reach its median 30 days. The high irrigation treatments increased slightly as WHC increased while the opposite for the low irrigation treatment.

Table 18. The median (Q2) of total yield per plant between 7 size grade and 2 irrigation treatments, with an LSD of 4.05.

Treatment	6 Irrigations (days)	3 Irrigations (days)	Mean* (days)
P1	28.4	32.6	30.5[ab]
P3	25.6	33.4	29.5 [b]
C	28.6	32.4	30.5[ab]
P1P3	27.4	35.2	31.3[ab]
P1C	32.2	34.8	33.5 [a]
P3C	29.8	36.2	33.0[ab]
P1P3C	30.4	30.9	30.7[ab]
Mean	28.9	33.6	31.3

Means with the same letter are not significantly different (95% confidence interval).
*LSD = 4.05

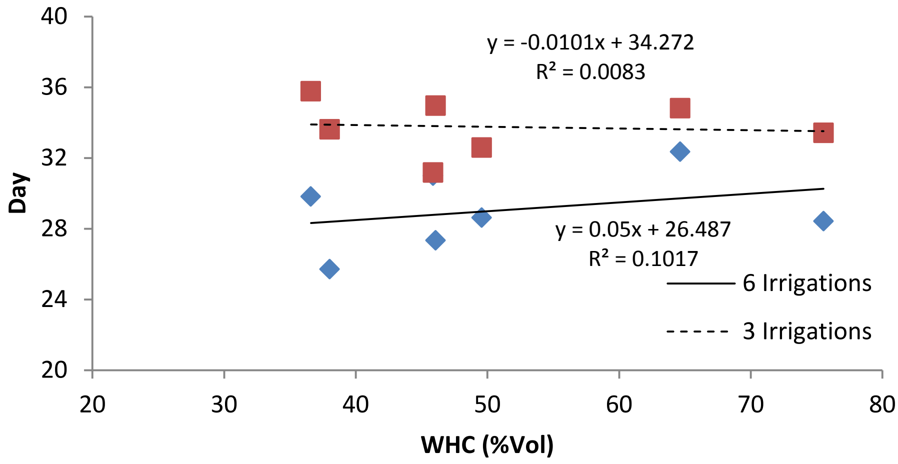

Fig. 26. Comparing the relationship between water holding capacity (WHC) and the days taken to complete the median (Q2) over 2 irrigation treatments. The median measures the time taken to complete 50% of total yield.

4.4.10 Inner quartile range (HK)

The inner quartile range (IQR) measures the time it takes between the lower quartile (Q1) and upper quartile (Q3). IQR duration took a minimum of 17.1 days and a maximum of 30.4 days over 7 coir treatment sizes (Table 19). There was no significant difference between size grade treatments. There was however a significant difference in irrigation treatments when comparing slopes (Fig. 27). The six irrigation treatment took nine fewer days to complete the inner quartile range. The high irrigation treatments increased slightly as WHC increased while the opposite for the low irrigation treatment.

Table 19. The inner quartile range (IQR) of total yield per plant between 7 size grade and 2 irrigation treatments, with an LSD of 4.80

Treatment	6 Irrigations (days)	3 Irrigations (days)	Mean* (days)
P1	23.6	28.0	25.8 [a]
P3	19.2	30.4	24.8 [a]
C	17.5	26.5	22.0 [a]
P1P3	17.2	26.7	22.0 [a]
P1C	20.0	30.4	25.2 [a]
P3C	17.1	29.8	23.4 [a]
P1P3C	17.6	25.8	21.7 [a]
Mean	18.9	28.2	23.6

Means with the same letter are not significantly different (95% confidence interval).
*LSD = 4.80

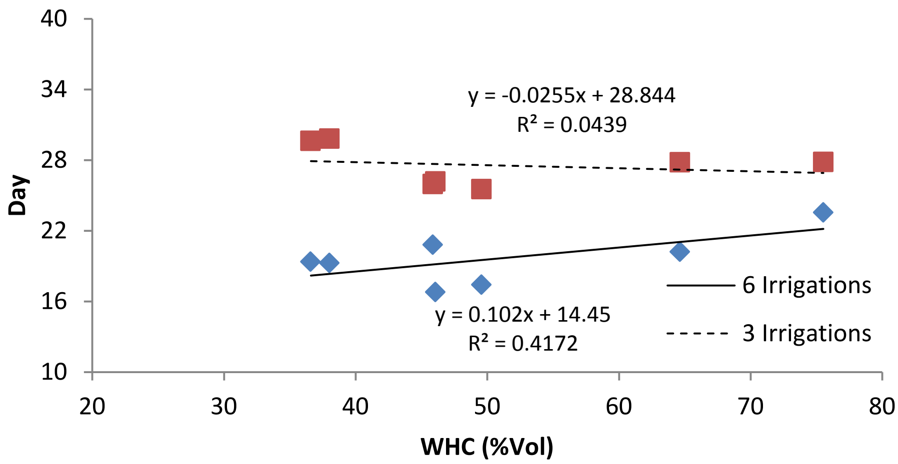

Fig. 27. The inner quartile range (IQR) comparing water holding capacity (WHC) and the days taken using 2 irrigation treatments. IQR measures the difference between Q1 and Q3 which accounts for the middle 75% of total yield.

4.4.11 Time to 50% total harvest (SG)

The median (Q2) measures the time it takes the crop to complete 50% of its total harvest. Q2 duration took a minimum of 28.0 days and a maximum of 40.0 days over 7 coir treatment sizes (Table. 20). There was a significant difference in treatment L taking fewer days to reach Q2 duration compared to ML and SML. There was also a significant difference in irrigation treatments when comparing slopes (Fig.28). The six irrigation treatment took seven fewer days to reach its median 30 days. Both irrigation treatments had similar increasing trends with the days required to complete Q2 increasing with increasing WHC.

Table 20. The median (Q2) of total yield per plant between 7 size grade and 2 irrigation treatments, with an LSD of 5.06.

Treatment	6 Irrigations (days)	3 Irrigations (days)	Mean* (days)
S	31.6	36.8	34.0[ab]
M	28.3	36.5	32.5[ab]
L	28.0	32.4	30.2[b]
SM	29.1	39.7	34.7[ab]
SL	32.1	38.6	35.2[ab]
ML	31.8	40.0	35.7[a]
SML	31.2	39.5	35.5[a]
Mean	30.3	37.1	28.6

Means with the same letter are not significantly different (95% confidence interval).
*LSD = 5.06

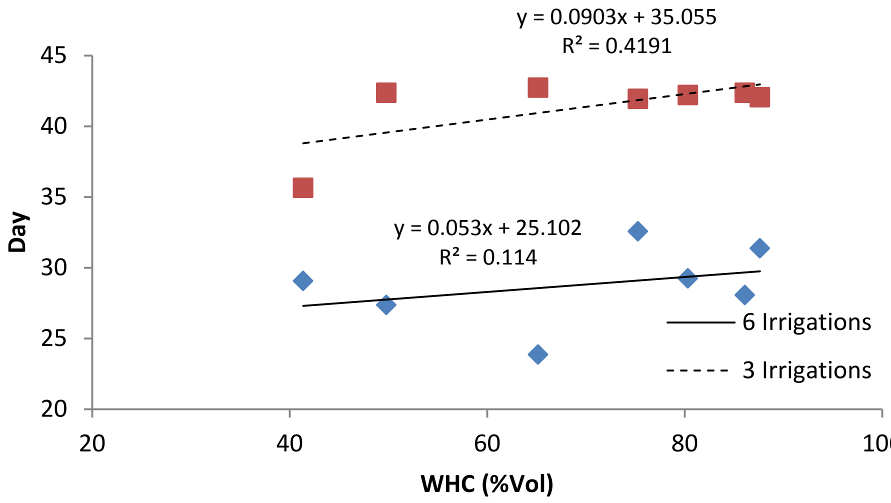

Fig. 28. Comparing the relationship between water holding capacity (WHC) and the days taken to complete the median (Q2) over 2 irrigation treatments. The median measures the time taken to complete the 50% of total yield.

4.4.12 Inner quartile range (SG)

The inner quartile range (IQR) measures the time it takes between the lower quartile (Q1) and upper quartile (Q3). IQR duration took a minimum of 19.0 days and a maximum of 34.6 days over 7 coir treatment sizes (Table 21). There was a significant difference in treatment ML requiring additional days to reach IQR duration compared to L and SM (Table. 21). There was also a significant difference in irrigation treatments when comparing slopes (Fig. 29). The six irrigation treatment took eight fewer days to complete the IQR. Both irrigation treatments had similar increasing trends with the days required to complete IQR decreasing with increasing WHC.

Table 21. The inner quartile range (IQR) of total yield per plant between 7 size grade and 2 irrigation treatments, with an LSD of 6.53

Treatment	6 Irrigations (days)	3 Irrigations (days)	Mean* (days)
S	22.4	29.6	26.0[ab]
M	19.0	34.1	26.6[ab]
L	21.8	24.0	22.9[b]
SM	19.5	27.0	23.2[b]
SL	23.5	33.3	28.4[ab]
ML	27.6	34.6	31.1[a]
SML	20.0	29.3	24.7[ab]
Mean	22.0	30.3	26.1

Means with the same letter are not significantly different (95% confidence interval).
*LSD = 6.53

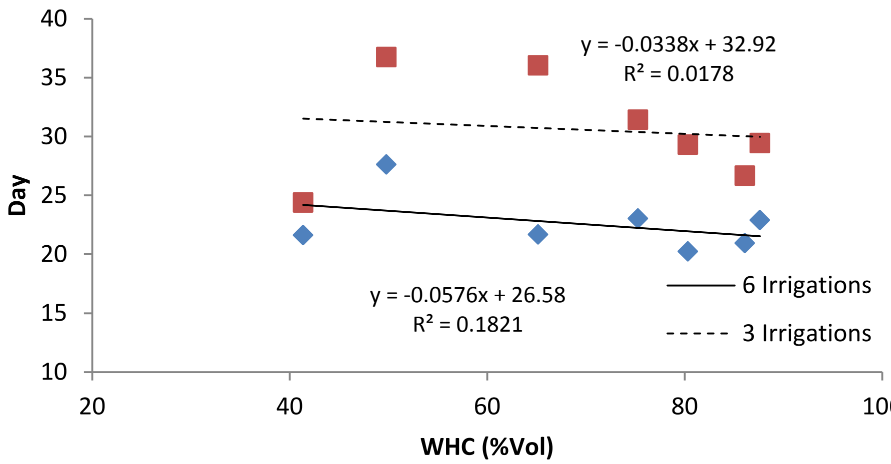

Fig. 29. The inner quartile range (IQR) comparing water holding capacity (WHC) and the days taken using 2 irrigation treatments. IQR measures the difference between Q1 and Q3 which accounts for the middle 75% of total yield.

4.5 Growth Analysis 1 (HK)

4.5.1 Relative growth rate (RGR)

Relative growth rate varied between 0.266 $g.g^{-1}.day^{-1}$ and 1.657 $g.g^{-1}.day^{-1}$, over 7 size grade and 2 pot height treatments (Table. 22). There was a significant difference in size grade treatments. P1 and P3 had a lower mean RGR compared to all other treatments except C. The short pot treatment produced a much lower RGR, almost half that of the tall pot treatment. Both pot size treatments had similar increasing trends; as treatments increased in WHC the RGR increased (Fig. 30).

Table 22. The relationship between relative growth rate (RGR) on both coir and pot height treatment. Pot treatments contained the same volume with tall pots being twice the height of the short pot.

Treatment	Short pot ($g.g^{-1}.day^{-1}$)	Tall pot ($g.g^{-1}.day^{-1}$)	Mean* ($g.g^{-1}.day^{-1}$)
P1	0.266	0.854	0.560 [b]
P3	0.611	0.546	0.578 [b]
C	0.697	1.138	0.917 [ab]
P1P3	1.013	1.261	1.137 [a]
P1C	0.687	1.657	1.172 [a]
P3C	0.707	1.513	1.110 [a]
P1P3C	0.651	1.466	1.059 [a]
Mean	0.662	1.205	0.933

Means with the same letter are not significantly different (95% confidence interval).
*LSD = 0.45

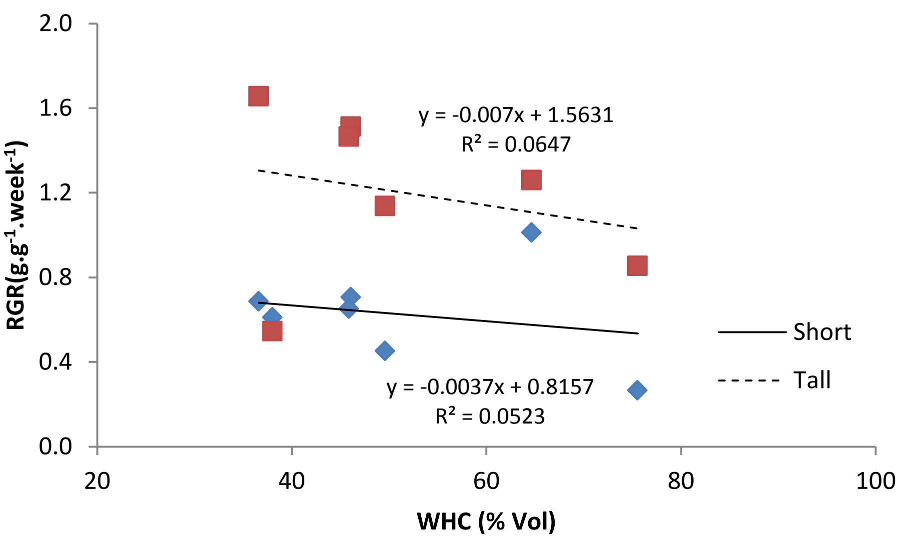

Fig. 30. The relative growth rate (RGR) for two pot treatments (short and tall) over 7 coir treatments.

4.5.2 Leaf area ratio (LAR)

Leaf area ratio (LAR) ranged between 102.5 and 243.1 $cm^{-2}.g^{-1}$, over 7 size grade and 2 pot height treatments (Table. 23). There was a significant difference in P3C producing a larger LAR compared to P1, P3, and C treatments. There was no significant difference in pot height treatment (Fig. 31).

Table 23. The relationship between leaf area ratio (LAR) on both coir and pot height treatment. Pot treatments contained the same volume with tall pots being twice the height of the short pot.

Treatment	Short Pot ($cm^{-3}.g^{-1}$)	Tall Pot ($cm^{-3}.g^{-1}$)	Mean* ($cm^{-3}.g^{-1}$)
P1	126.3	131.6	128.9 b
P3	180.5	102.5	141.5 b
C	154.4	138.9	146.6 b
P1P3	158.2	174.0	166.1 ab
P1C	215.1	142.7	178.9 ab
P3C	243.1	190.9	217.0 a
P1P3C	156.4	135.6	146.0 b
Mean	176.3	145.2	160.7

Means with the same letter are not significantly different (95% confidence interval).
*LSD = 55.41

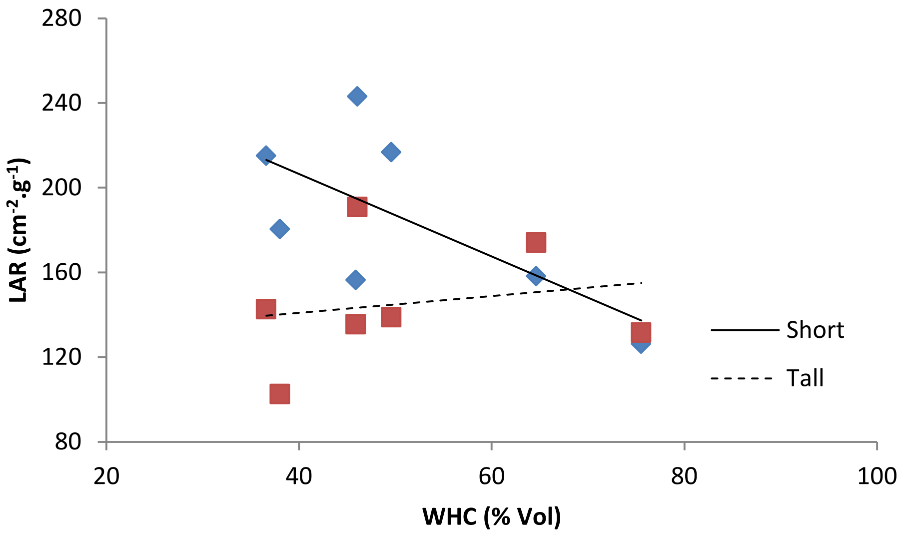

Fig. 31. Leaf area ratio (LAR) for two pot treatments (short and tall) over 7 size grade treatments.

4.5.3 Net assimilation rate (NAR)

Net assimilation rate (NAR) ranged between 2.21 $g.m^{-2}.week^{-1}$ and 11.78 $g.m^{-2}.week^{-1}$, over 7 size grade and 2 pot heights (Table. 24). There was a significant difference in both coir and pot size treatment. The main difference was P1C which gained a higher NAR compared to P3C, P1 and P3. There was also a significant difference between pot height treatments when comparing slopes (Fig. 32). Short pots produced a much lower NAR compared to tall pot treatments.

Table 24. The relationship between net assimilation rate (NAR) on both coir and pot height treatment. Pot treatments contained the same volume with tall pots being twice the height of the short pot.

Treatment	Short Pot ($g.m^{-2}.week^{-1}.10^{-3}$)	Tall Pot ($g.m^{-2}.week^{-1}.10^{-3}$)	Mean* ($g.m^{-2}.week^{-1}.10^{-3}$)
P1	2.21	6.42	4.31 ^{cd}
P3	3.37	5.10	4.24 ^{d}
C	4.41	8.39	6.40 ^{abc}
P1P3	6.44	7.21	6.83 ^{ab}
P1C	3.40	11.78	7.59 ^{a}
P3C	2.94	8.10	5.52 ^{bcd}
P1P3C	4.06	10.74	7.40 ^{ab}
Mean	3.83	8.25	6.04

Means with the same letter are not significantly different (95% confidence interval).
*LSD = 2.38

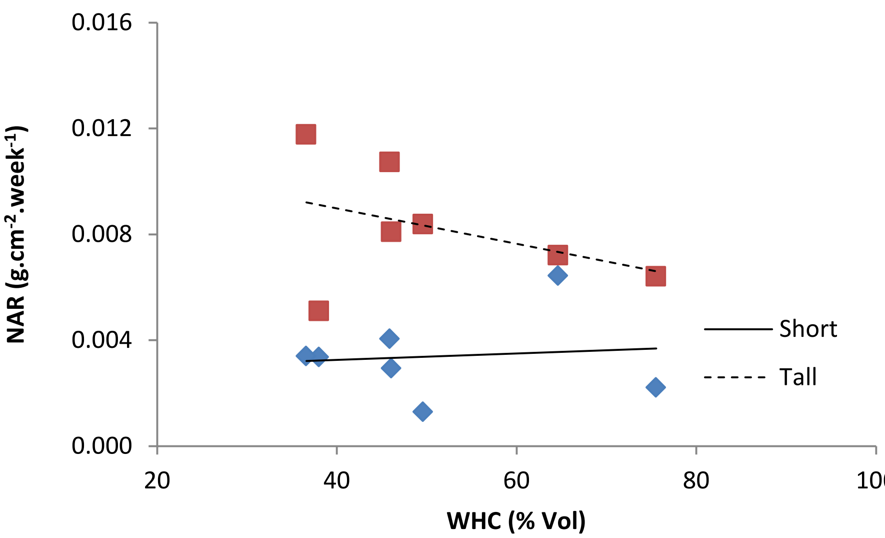

Fig. 32. The net assimilation rate (NAR) for two pot treatments (short and tall) over 7 coir treatments.

4.6 Growth analysis 1 (SG)

4.6.1 Relative growth rate (RGR)

Relative growth rate varied between 0.289 $g.g^{-1}.day^{-1}$ and 1.174 $g.g^{-1}.day^{-1}$, over 7 size grade and 2 pot height treatments (Table. 25). There was a significant difference in size grade treatments. The greatest difference was between S which produced the greatest RGR and L which produced the lowest RGR. There was no significant difference in pot height treatment (Fig. 33).

Table 25. The relationship between relative growth rate (RGR) on both coir and pot height treatment. Pot treatments contained the same volume with tall pots being twice the height of the short pot.

Treatment	Short Pot ($g.g^{-1}.day^{-1}$)	Tall Pot ($g.g^{-1}.day^{-1}$)	Mean* ($g.g^{-1}.day^{-1}$)
S	1.174	0.796	0.985 [a]
M	0.461	0.531	0.496 [bc]
L	0.635	0.289	0.462 [c]
SM	0.637	0.326	0.482 [bc]
SL	0.478	0.742	0.610 [bc]
ML	0.672	0.832	0.752 [abc]
SML	0.815	0.833	0.824 [ab]
Mean	0.696	0.621	0.659

Means with the same letter are not significantly different (95% confidence interval).
*LSD = 0.34

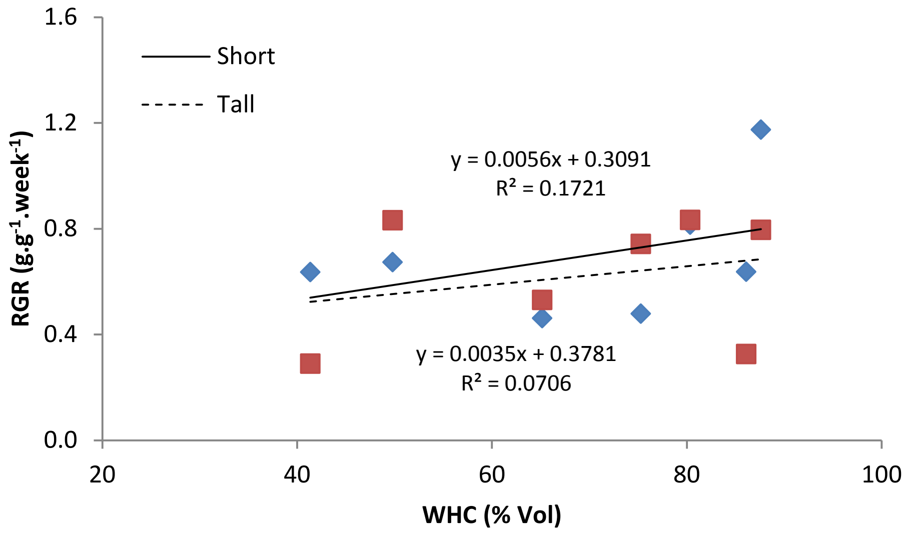

Fig. 33. The relative growth rate (RGR) for two pot treatments (short and tall) over 7 coir treatments.

4.6.2 Leaf area ratio (LAR)

Leaf area ratio (LAR) ranged between 115.6 $cm^{-2}.g^{-1}$ and 183.2 $cm^{-2}.g^{-1}$, over 7 size grade and 2 pot height treatments (Table. 26). There was a significant difference in M and L producing a lower LAR compared to SL, ML and SML treatments. There was no significant difference in pot height treatment (Fig. 34).

Table 26. The relationship between leaf area ratio (LAR) on both coir and pot height treatment. Pot treatments contained the same volume with tall pots being twice the height of the short pot.

Treatment	Short Pot ($cm^{-2}.g^{-1}$)	Tall Pot ($cm^{-2}.g^{-1}$)	Mean* ($cm^{-2}.g^{-1}$)
S	170.0	132.2	151.1^{ab}
M	136.7	129.4	133.0^{b}
L	152.3	115.6	134.0^{b}
SM	168.5	143.0	155.7^{ab}
SL	176.6	163.4	170.0^{a}
ML	183.2	148.2	165.7^{a}
SML	163.1	182.2	172.7^{a}
Mean	164.3	144.9	154.6

Means with the same letter are not significantly different (95% confidence interval).
*LSD = 30.07

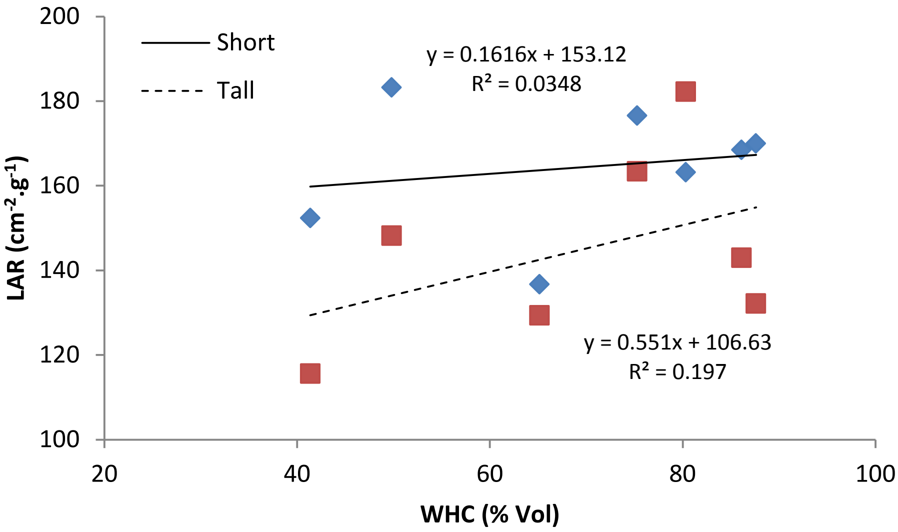

Fig. 34. Leaf area ratio (LAR) for two pot treatments (short and tall) over 7 size grade treatments.

4.6.3 Net assimilation rate (NAR)

Net assimilation rate (NAR) ranged between 2.28 $g.m^{-2}.week^{-1}$ and 6.86 $g.m^{-2}.week^{-1}$, over seven size grade and two pot heights (Table. 27). There was a significant difference in both coir and pot size treatment. The main difference was S which gained a higher NAR compared to M, L and SM. There was no significant difference in pot height treatment (Fig. 35).

Table 27. The relationship between net assimilation rate (NAR) on both coir and pot height treatment. Pot treatments contained the same volume with tall pots being twice the height of the short pot.

Treatment	Short Pot ($g.m^{-2}.week^{-1}.10^{-3}$)	Tall Pot ($g.m^{-2}.week^{-1}. 10^{-3}$)	Mean* ($g.m^{-2}.week^{-1}. 10^{-3}$)
S	6.86	5.78	6.32 a
M	3.29	4.11	3.70 bc
L	4.12	2.44	3.28 bc
SM	3.68	2.28	2.98 c
SL	2.69	4.52	3.61 bc
ML	3.68	5.60	4.64 ab
SML	4.99	4.58	4.78 ab
Mean	4.19	4.19	4.19

Means with the same letter are not significantly different (95% confidence interval).
*LSD = 1.60

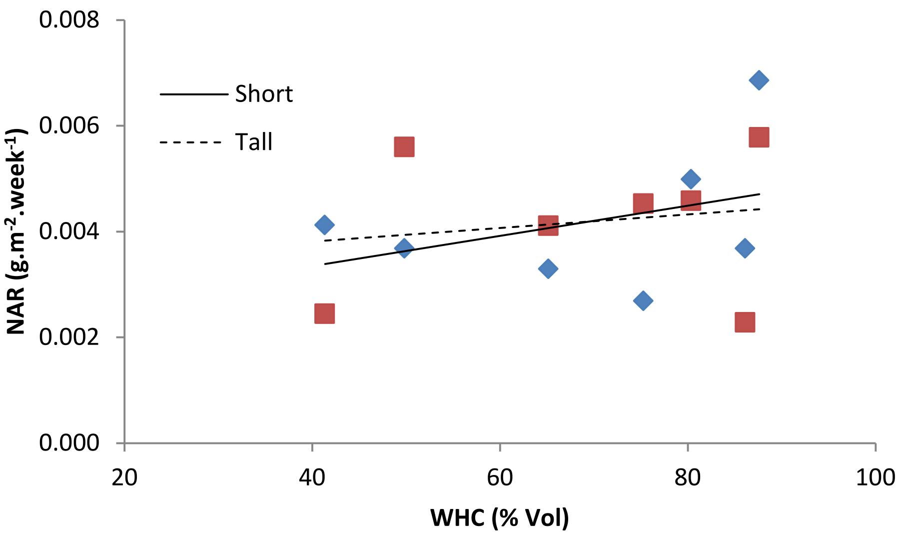

Fig. 35. The net assimilation rate (NAR) for two pot treatments (short and tall) over 7 coir treatments.

4.7 Growth Analysis 2 (SG)

4.7.1 Relative growth rate (RGR)

Relative growth rate varied between 1.073 $g.g^{-1}.day^{-1}$ and 1.399 $g.g^{-1}.day^{-1}$, over 7 size grade treatments (Table. 28). There was a significant different in ML producing a lower RGR compared to other treatments. RGR increased as treatments containing higher WHC increased (Fig. 36).

Table 28. The relationship between relative growth rate (RGR) on 7 size grade (SG) treatments.

Treatment	WHC (% Vol)	RGR* ($g.g^{-1}.day^{-1}$)
S	87.61	1.207[ab]
M	65.17	1.245[ab]
L	41.36	1.155[a]
SM	86.11	1.394[a]
SL	75.28	1.399[a]
ML	49.81	1.073[b]
SML	80.35	1.282[ab]
C	49.57	1.126[ab]
Mean	66.91	1.251

Means with the same letter are not significantly different (95% confidence interval).
*LSD = 0.30

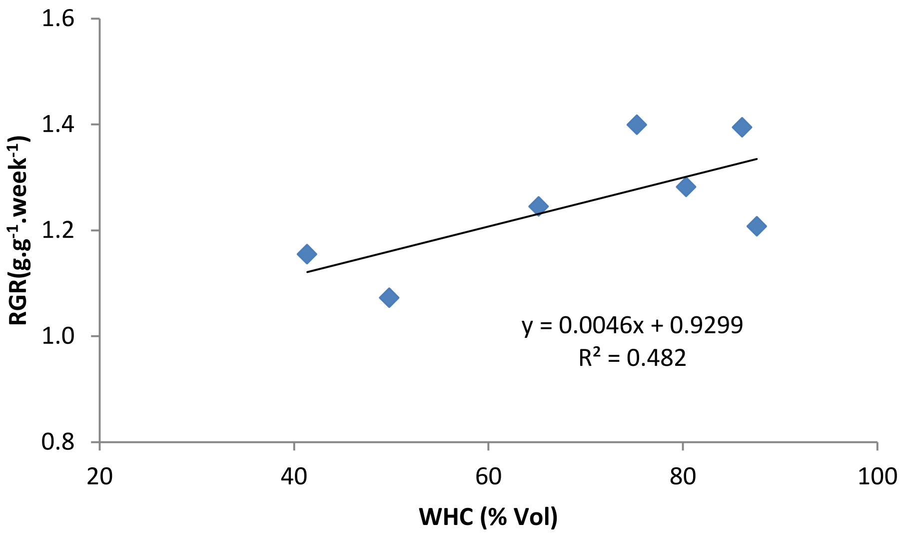

Fig. 36. The relative growth rate (RGR) compared against size grade treatments with various WHC (% Vol).

4.7.2 Leaf area ratio (LAR)

Leaf area ratio varied between 309.4 $cm^{-3}.g^{-1}$ and 333.0 $cm^{-3}.g^{-1}$, over 7 size grade treatments (Table. 29). There was no significant difference in size grade treatments. LAR decreased as treatments containing higher WHC increased (Fig. 37).

Table 29. The relationship between leaf area ratio (LAR) on 7 size grade (SG) treatments.

Treatment	WHC (% Vol)	LAR* ($cm^{-3}.g^{-1}$)
S	87.61	309.4[a]
M	65.17	313.4[a]
L	41.36	327.9[a]
SM	86.11	311.6[a]
SL	75.28	323.8[a]
ML	49.81	333.0[a]
SML	80.35	330.0[a]
C	49.57	314.8[a]
Mean	66.91	321.3

Means with the same letter are not significantly different (95% confidence interval).
*LSD = 27.55

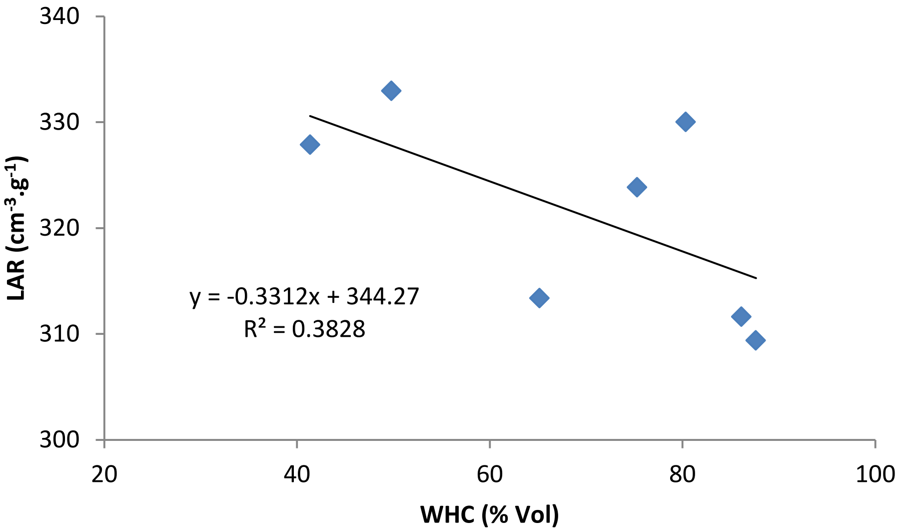

Fig. 37. The leaf area ratio (LAR) compared against size grade treatments with various WHC (% Vol).

4.7.3 Net assimilation rate (NAR)

Net assimilation rate varied between 3.23 $g.cm^{-2}.week^{-1}$ and 4.47 $g.cm^{-2}.week^{-1}$, over 7 size grade (Table. 30). There was a significant difference in size grade treatments. Size grade SM produced a higher NAR compared to L, ML and C. NAR increased as treatments containing higher WHC increased (Fig. 38).

Table 30. The relationship between net assimilation rate (NAR) on 7 size grade (SG) treatments.

Treatment	WHC (% Vol)	NAR* ($g.m^{-2}.week^{-1}.10^{-3}$)
S	87.61	3.91^{ab}
M	65.17	3.99^{ab}
L	41.36	3.52^{b}
SM	86.11	4.47^{a}
SL	75.28	4.37^{ab}
ML	49.81	3.23^{b}
SML	80.35	3.90^{ab}
C	49.57	3.60^{b}
Mean	66.91	3.91

Means with the same letter are not significantly different (95% confidence interval).
*LSD = 1.16

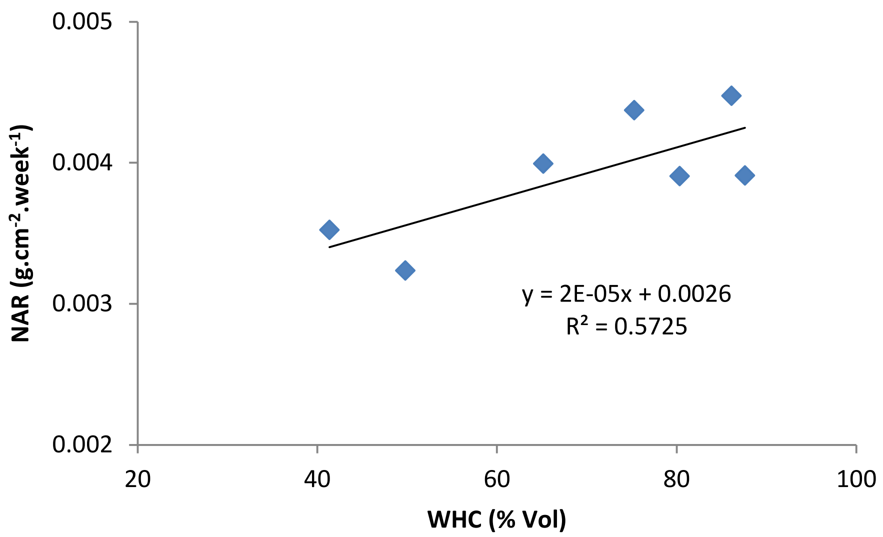

Fig. 38. The net assimilation rate (NAR) compared against size grade treatments with various WHC (% Vol).

4.8 Correlations

4.8.1 AFP vs WHC (HK)

With a slope of -0.87 together with a R^2 of 0.98, a clear correlation exists between air filled porosity and water holding capacity. Water holding capacity decreases as air filled porosity increases (Fig. 39).

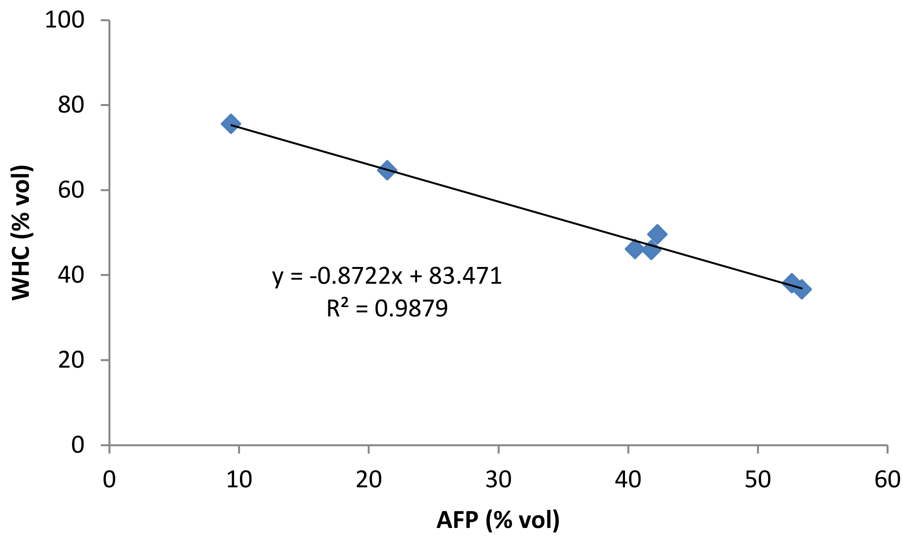

Fig. 39. The correlation between AFP (air filled porosity) and WHC (water holding capacity).

4.8.2 AFP vs WHC (SG)

With a slope of -1.21 together with a R^2 of 0.98, a clear correlation exists between air filled porosity and water holding capacity. Water holding capacity decreases as air filled porosity increases (Fig. 40).

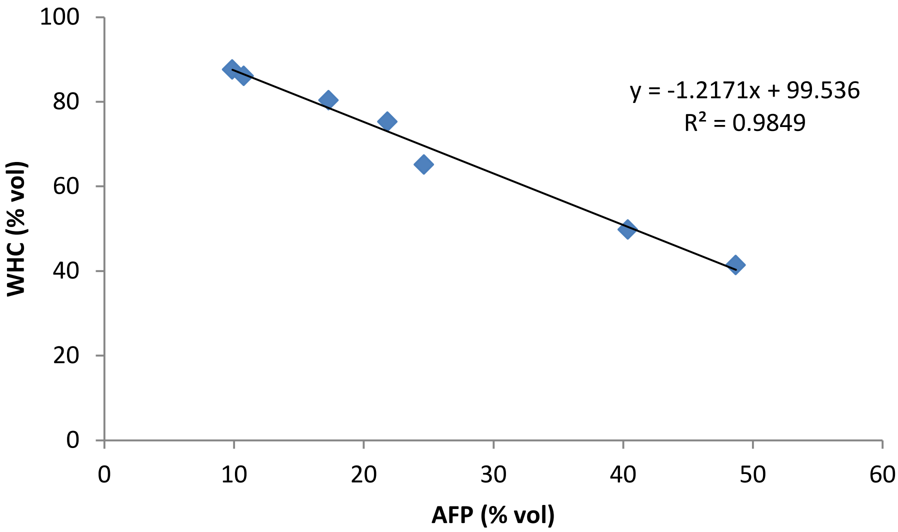

Fig. 40. The correlation between AFP (air filled porosity) and WHC (water holding capacity).

4.8.3 WHC vs Yield (SG)

The relationship between the second tomato yield trial and second growth analysis trial was tested. A clear correlation exists between yield and relative growth rate (RGR) for both irrigations treatments (Fig. 41). Although both irrigation treatments have similar increasing trends, the 3 irrigation treatment performs better in terms of yield gained compared to the 6 irrigation.

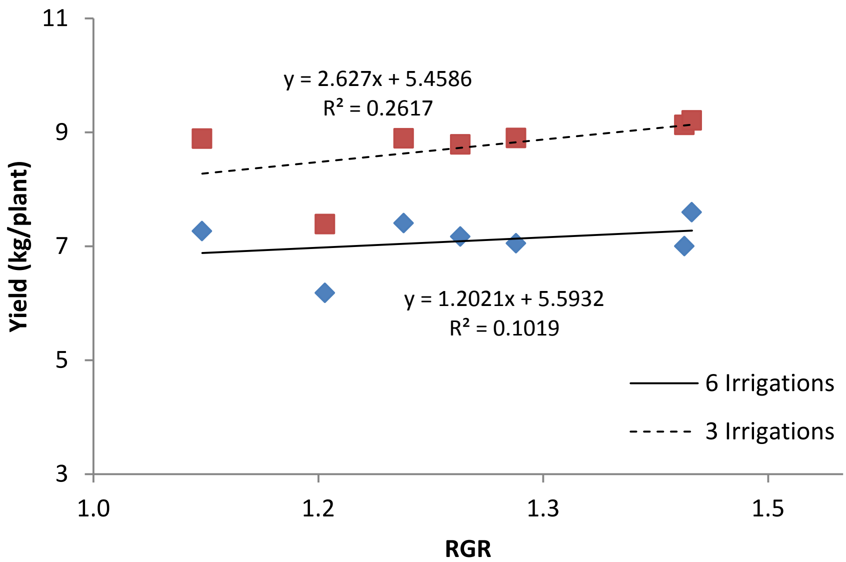

Fig. 41. The correlation between RGR (relative growth rate) and yield per plant (Kg). Harvest 2 data, SG source.

CHAPTER 5: DISCUSSION

5.1 Tomato yield trial

Two or three weeks after the winter tomato crop established, they got blossom end rot. Both tomato yield trials (SG and HK) suffered a calcium deficiency when fruit were roughly the size of a cherry tomato. As a result, the population size shrunk about 40%. The percentage of total yield affected by blossom end rot, due to calcium deficiency, is not known. Conditions in winter are more favourable for blossom end rot compared to greenhouse conditions in summer. Statistical analysis does not include data related to weather conditions. In hindsight this would have been a helpful tool and should have been analysed to better explain conditions favourable to BER.

The average yield for the winter yield trial was 2.38and 2.14 kg per plant for HK and SG data (Table. 6; Table. 9) while the average yield for the summer yield trial was 7.69 and 7.92 kg per plant (Table. 12; Table, 15). Fruit numbers for the summer yield trial was almost double that of the winter yield trial. The same relationship was true for mean fruit weight.

Possible causes for differences between winter and summer yield data are;

1. Blossom end rot (calcium deficient nutrition)
2. Seasonal variations (greenhouse heating/venting conditions)
    a. Greenhouse design in combination with supplementary heating resulted in condensation forming on the inside of the glasshouse as well as hot spots within certain portions of the greenhouse.
3. Cultivar selection (i.e. traditional vs. hybrid seed)
    a. Traits found in hybrid seed may account for greater fruit numbers and mean fruit weight but most importantly total fruit yield.
4. Improved cultural practices (winter yield experience).

Yields for the winter yield trial were much lower than the summer yield trial, points were scattered and according to LSD t tests and slopes, results suggest no significant differences occur for total yield per plant, fruit number per plant, and mean fruit weight per plant. Further discussion will only include results obtained from the summer yield trial.

There were significant differences in coir size grade treatments. Size grade P1 (HK) and S (SG) were significantly higher in their water holding capacities (section 4.1) and as a result produced significantly higher total yields per plant and total fruit number per plant. However, comparing mean fruit weight per plant, there appeared to be no clear relationship with water holding capacity. Of all trends examined total yield for both HK (Fig. 18) and SG (Fig. 21) data was the most reliable. A clear increasing total yield trend exists along size grade treatments as their water holding capacities increase. Thus coir mixes which contain higher ratios of smaller size particles (highest water holding capacity) produce greater total yields. There was no reliable trend when comparing fruit numbers while the trend for mean fruit weight was consistently horizontal for both HK and SG data, i.e. no water holding capacity effect.

Irrigation clearly had an effect on HK data and most of SG data. On average the 3 irrigation treatment produced a higher total yield, fruit number and mean fruit weight for HK data while fruit number produced no significant difference when comparing SG data. Once again differences were there most reliable when comparing irrigation treatments and total yield.

For both size grade and irrigation treatment it appears that the ability of coir to retain moisture (WHC) is more important than its drainage capabilities (i.e. air filled porosity). This argument was further strengthened due to a fault in the irrigation system. As stated in Section 3.3 an error in irrigation resulted in the 3 irrigation treatment actually received three times greater volume compared to the 6 irrigation treatments. Initially it was thought that by doubling the frequency of irrigation (6 irrigation treatment) better aeration would result and in turn higher yield data. But in fact the 3 irrigation better suited treatments highest in WHC.

It can however be argued that if a greater volume of irrigation was supplied to the 6 irrigation, as was the 3 irrigation, an aeration effect may well have been possible. Although results suggest that treatments high in WHC produce the highest yield it is still feasible that treatments lower in WHC could perform better with the correct irrigation frequency, which is not yet known. Considering large grade particles have the highest air filled porosity (see section 4.1) and in turn the most easily available water, supplying a crop with such parameters would most likely produce better results compared to treatments containing only a high water holding capacity when growing a specific crop like tomato. It is therefore the moisture retention/release relationship which requires further development rather than relying on treatments containing the highest WHC. Literature suggests that anoxic conditions, which will most likely occur in high WHC, are detrimental to root proliferation and the onset of root borne diseases/pathogens.

There are possibly two ways of approaching the moisture retention problem;

1. Introduce a smaller grade of coir that has a larger water holding capacity, regardless of irrigation treatment, as we know treatments high in WHC perform naturally better.
2. Introduce a large grade of coir, which has smaller water holding capacity, with improved irrigation scheduling such as lower quantity of irrigation but at a much higher frequency.

5.1.1 Tx (time to x percentage of total harvest) parameters

Tx parameters covers the time taken to reach a specific percentage of total yield. Values are based on cumulative yield data. The two parameters tested was the time to 50% total harvest (Q2) and inner quartile range (IQR). Time to 50% harvest (Q2) measures the first 50% while the IQR measures the difference between Q3 (75%) and Q1 (25%).

There were significant differences in coir size treatments for both coir sources over Q2 and IGR data. It appears that in general the mixed grades took longer reaching Q2 and IQR. More important was the relationship between irrigation treatments and Q2 and IQR data. There was a significant difference between irrigation treatments. Considering that total yield and mean fruit weight per plant was significantly lower in the 6 irrigation treatments it is not surprising that the days required to reach Q2 and IGR were lower. This relationship can be observed with both HK and SG data. Another possibility is that the 3 irrigation was water stressed compared to the 6 irrigation treatment as observed by the significantly lower mean fruit weight per plant. In hindsight a pressure bomb, measuring leaf water potential, could have shown any apparent stress.

5.2 Growth Analysis

The first bioassay trial produced mixed results. There were significant differences in all 3 responses measured (RGR, LAR and NAR) in terms of coir size grade treatment. There was a clear relationship between WHC and RGR for the HK data but not for the SG data. Furthermore the HK data suggests that as WHC increases, the RGR decreases while for the SG data the opposite is true. HK data showed a significant difference in pot height for both RGR and NAR but no significant difference for SG data. Due to contradictions between HK and SG data it can be safe to assume that growth analysis 1 did not accurately describe any relationship between size grade and pot height treatment.

Results obtained from the first growth analysis were entirely useless. As well as statistical analysis, there was a clear visual difference between the two pot heights tested. Short pots appeared to suffer from anoxia following the emergence of the first true leaves. Seedlings appeared stunted, with a clear reduction in root architecture (results not shown) compared to tall pots. These differences in short pots may be due to water table levels. The water table in both pots were identical, however the proportion of media above either water table were clearly different. The proportion of media above the water table was significantly greater in tall pots than in small pots. The contact between particles and water molecules was strong for both pot heights but because of a lower pot height, the seedlings in short pots were almost always submerged in the water table. Air and gas exchange was clearly limited. As a consequence, the newly developed leaves turned yellow and a reduction in root architecture occurred. Statistically there appears to be little difference in height treatment when comparing relative growth rate. Perhaps if seedlings were left to grow for a further week prior to harvesting there would be clearer differences in tall vs. short pots.

Due to advances in technique and improved weather conditions, similar to the differences between winter and summer yield trials, it is more likely that if there are any significant differences it would be found in the second growth analysis trial.

Due to visual differences in pot height in the first bioassay trial, it was concluded that overall, tall pots performed better than short pots, the theory being that if tall pots are used, considering that both pot heights had identical water table levels, the media above the water table will act as a sponge and drag water up the profile as required. Roots are able to proliferate freely with the inclusion of air in the media compared to being in an anoxic state during root development.

The second growth analysis trial showed significant differences in RGR and NAR. Size grade ML produced a lower overall RGR compared to most other treatments while grade SM produced a significantly higher NAR compared to L, ML and C. The differences in growth analysis 2 do not relate to that of the summer yield trial.

Including only tall pots in the second growth analysis resulted in few significant differences between treatments which may be attributed to advances in technique. These advances include;

1. A second watering was applied in the morning above the pots to preserve the contact between particles and water molecules, ensuring adequate water supply, root development and improved nutrient availability
2. Another improvement was made in the sowing of seeds. Seeds were sown in rockwool plugs and transplanted into pots when the first true leaves appeared. This method ensured root development was not sacrificed due to transplanting. The root system was clearly intact when transferring into pots compared to the method used in the first trial.

These small improvements in experimental design, and weather, meant that more reliable data were produced with larger r^2 values. Data points were not as "cluttered" as was the case in the first growth analysis trial.

Although not much could be said for differences in RGR, LAR and NAR in terms of coir size grade treatments, there was in all cases a clear trend when comparing against WHC. The trend (Fig. 36) suggests that as water holding capacity increases so does relative growth rate. In other words the difference between initial and final growth (i.e. period of growth) is directly related to water holding capacity.

Leaf area ratio, or the proportion of biomass invested in leaf area, is also directly related to water holding capacity. The trend (Fig. 37) suggests that as water holding capacity increases the leaf area ratio decreases. In other words the leafiness of a plant can be determined by water holding capacity.

Net assimilation rate, or the difference between total photosynthesis and total respiration, is not an independent characteristic but rather the result of both RGR and LAR (Fig. 9). Indirectly the trend (Fig. 38) suggests that as water holding capacity increases so does net assimilation rate.

5.3 Correlations

A correlation was performed between AFP and WHC. The high r^2 value, obtained by a line of best fit, indicates a strong correlation between AFP and WHC. Both sources of coir, HK and SG, showed the same trend with very similar r^2 values. The objective of such a correlation was to find out whether AFP could be replaced by WHC for statistical analysis with the understanding that the one was near to the inverse of the other. This correlation highlights that both AFP and/or WHC can be used as the explanatory variable when comparing tomato yield and growth analysis as a response variable. Theoretically it is possible to produce media with three different sets of characteristics;

1. High AFP high WHC,
2. High AFP low WHC,
3. Low AFP high WHC.

AFP may be more important when considering environmental conditions such as winter, high frequency irrigation, limited air flow, or pot depth. WHC, however, may be more important when environmental conditions favour higher temperatures, limited irrigation, increased air flow and shallow pot depths.

A second correlation was undertaken to measure the relationship between bioassay data and the tomato yield trial. The second bioassay RGR (relative growth rate) data was used together with the second of the two tomato yield trials. The second trials for both produced more consistent, reliable results compared to the first of the trials. The addition of a trend line indicates a relationship between yield and RGR. An increasing trend occurs for both irrigation treatments as both have identical WHC but different yields per plant. The trend line indicates that as RGR is increased so does yield per plant. This trend could be useful if large numbers of treatments need to be limited without investing in a large scale yield trial on many treatment possibilities.

5.4 Coir source

Two coir sources were used throughout the course of both tomato yield and growth analysis trials. The differences in results comparing the two coir sources are possibly contributed to;

1. Greenhouse design
2. Physical properties of coir sources
3. The nature of the coir.

The layout of the greenhouse during both tomato yield trials was identical. Coir sources were treated as two distinctly separate experiments within the same greenhouse. They both consisted of a randomised complete block design (RCBD). Due to the suns position in the greenhouse, the proximity of plots from the door, and distance from the heating source there will inevitably be differences in yield data.

Although physical properties for both coir sources were determined using the same method. The size grade source was sieved thoroughly so as to only include certain particles sizes within each treatment. Sieving occurred prior to determining physical properties such as water holding capacity. The same cannot be said with the Hong Kong source. Samples were provided, pre-graded to unknown specifications from which physical properties were determined. According to the size grade distribution, Chapter 4.7, the Hong Kong (HK) sourced coir contained particles of varying size grades for both P1 and P3. The grades were therefore not consistent like the Size Grade (SG) sourced coir.

The nature of either coir source is not fully known or understood. The Hong Kong (HK) source is visually very different from the Size Grade (SG) source. Prior to comparing sources based on numerical evidence, there was a striking difference between the two sources of coir; the first notable difference being the texture of the coir and second difference being the colour of the coir.

CHAPTER 6: CONCLUSION

6.1 Tomato yield trial

Regardless of size grade, irrigation treatment had a significant effect on most of the yield parameters tested. As a result, it is recommended that improvements be made to irrigation scheduling rather than solely developing treatments with increased water holding capacities. As highlighted in Chapter 1, air/gas exchange through media is vitally important for successful root expansion as well as for nutrient uptake. Improving the root environment through better air exchange and providing adequate moisture is perhaps the key to improved crop yield when using coir as a soilless growing media.

Although irrigation treatment has made a significant difference in yield paramaters (i.e. total yield and fruit number), the importance of water holding capacity/air filled porosity within the same irrigation treatment should not be ignored. A clear linear relationship was found between water holding capacity and yield.

There is no doubt that improvements can be made to fully assess the potential of using coir, with its physical properties, for use as a soilless growing media

6.2 Growth analysis

The bioassay trial or plant growth analysis trial was firstly implemented into the study to compare various performance parameters (i.e. RGR, LAR, NAR) between various coir treatments. It was later observed that perhaps a plant growth analysis could be used as a type of bioassay to predict responses based on explanatory variables. If a trend exists between RGR and WHC it could most likely predict the response (yield per plant) based on plant growth analysis variables (RGR). An initial full growth trial will need to be undertaken to roughly build the model. Once the model has been established predictions can be drawn without the need of numerous full growth trials. The idea being that if for example the WHC of a media can be increased what would the projected yield obtained compared to a bioassay model which has given a trend line and some indication as to the outcome. Not only is this method shorter but also time conserving. Once the model is established it may be used repeatedly until a time when media choice changes or production practices change resulting in parameters outside the control of the model.

The first bioassay trial highlighted the difficulties and level of detail that needs to be implemented to successfully produce reliable results. It appears that a number of factors determine the success of an experiment whether these factors were thought of before the experimental design or not. Practise and an attention to detail is what ultimately led to the improved second bioassay trial

6.3 Correlations

Data obtained from the first correlation indicates that both AFP and WHC can be used as an explanatory variable. The only difference being is that one will have an increasing trend as the other will have a decreasing trend. The fact that a correlation exists between WHC and AFP is not surprising. With everything remaining equal it can be safe to say that as water exits through a profile it will be replaced by air and vice versa. The amount of air/gas and water in this soilless profile differ according to their physical characteristics. However, what remains the same regardless of physical properties is the air water ratio. The strong r^2 value provides evidence of such a relationship with this particular media type.

The second correlation was undertaken to see what relationship exists between the bioassay data and the tomato yield trial. Even though a strong correlation does not exist between the two measured it does however appear that an increasing trend exists between the two. The bioassay trial has a number of implications. Ideally growers and/or researchers will be able to complete a bioassay trial prior to a larger scale growth trial. This technique will reduce the number of treatments of narrow down the treatments of interest based on predicted yields. Considering this model was developed based on coir it may not be applicable to other soilless media types. However, the concept of completing such a bioassay, regardless of media chosen, will be of value when trying to exclude unnecessary treatments in full scale growth trials.

6.4 Coir source

The tomato yield and growth analysis trial were methods used to determine whether there are any significant differences in particle size using indicators such as total yield, fruit numbers, relative growth rate, etc. These studies were not intended to determine differences between coir sources. In order to test differences in coir source, both sources need to be graded in similar fashions as to compare a common variable rather than trying to explain a variable in the presence of other uncontrollable variables. Much research has been completed on coir from various locations which highlight that there are indeed differences in coir source.

The difference in texture and colour may account for differences in yield, among other parameters measured. Perhaps these visual differences are due to their age, geographical location or a combination of the two. The age of the coir highlights whether the time between grading the coir from the long fibrous strands and the time it reaches the grower have any impact on;

1. Structure (biological breakdown due to nitrification)
2. Stability (i.e. hysteresis)

The geographical location of the coir could account for;

1. Salt content (the amount of salt present in the coir and whether that makes any significant difference.)
2. Annual rainfall and temperature (to leach or not to leach (with calcium) is the question). Does annual rainfall make any difference to uncovered stockpiled coir? Does coir begin composting in favourable conditions?

CHAPTER 7: COMMENTS AND FUTURE DEVELOPMENTS

It has become clear that, while initially a set strategy was put into place to measure the impact size grade particles had on yield, a number of additional problems had been created or discovered which were not thought of prior to investigating. The following chapter attempts to highlight the problems faced during the completion of this study as well as some areas which can be improved upon as well as additional research ideas which could build upon the knowledge obtained from this study.

The first problem faced when completing this study was simply inexperience when implementing theory into practise. This point was highlighted when comparing the first tomato yield trial with the second. A simple error of not checking if calcium was present in the irrigation system resulted in a reduction in the population size. Human error resulted in unreliable data and subsequent loss of any reliable treatment effects. This error resulted in a dramatic reduction in crop yield which could break a horticultural business as their return for product would dramatically decrease not to mention strains on confidence in supply between grower and retailer.

Learning from the first tomato harvest trial, adequate calcium was provided during the second tomato yield trial. A second, equally basic mistake was made during the second tomato yield trial. This time irrigation treatments were intended to provide the same quantity of irrigation within a 12 hour period but instead one irrigation treatment delivered 3 times that of the other. Considering the mistake, in combination with additional alternative strategies, an improved irrigation strategy will include;

- Improved irrigation schedule
    - Irrigating 6 times per day at the higher rate of 800ml rather than 250ml used in the previous studies. However, leachate will ultimately determine the exact volume that should be applied.
    - Water pressure regulator at source (tap) to ensure compensators work correctly at each plot location. The lesson learnt here is not to assume compensators work, even when new.

- Irrigation could possibly be based on;
    - TDR (Time Domain Reflectometer)
        - Is this method of irrigation more reliable/true than a light meter? How many TDR's are required? What about greenhouse position? Is evaporative cooling technology a more reliable option for monitoring conditions, in particular pot temperature? The cost of implementing such technology may be too expensive.
    - Radiation meter
        - High radiation levels increase heat in greenhouse. Is there a correlation between greenhouse temperature and light levels? Is there a correlation between TDR and light meter? Is this correlation specific to particular physical characteristics of soilless media? Can we make a model specific to coir and their corresponding physical characteristics? Do chemical characteristics make any difference to irrigation scheduling?
    - Temperature/ leaf temperature
        - Is leaf temperature an accurate account of moisture status in pot/media?
    - Leaching
        - Measure the volume of leachate to determine water usage.
        - Measure water nutrient status 3 times through each phase (cumulative yield; Chapter 3.2). Could it be possible to make a custom nutrient solution based on size grade, based on whether particle size affect nutrient uptake?

Most of the points highlighted above appear to rather include a list of questions rather than set strategies. Although true, the point is there are a number of strategies which could work but have not been tested through the use of coir. Strategies may change depending of a number of factors such as weather conditions, cultivar selection or simply the availability of equipment.

There were also a number of challenges and changes faced when completing a plant growth analysis. The first being the simple task of germinating tomato seed ready for transplanting. After a number of attempts, it was clear that it was better practice to sow seeds individually into rockwool plugs rather than sowing many in a seed tray. The problem arose when trying to transplant small seedlings while not disturbing their fragile root system. What materialised was inconsistent seedling height, due to delayed root establishment in random pots. The following list includes points which may be of interest if developing the plant growth analysis into a bioassay;

- Further develop Bioassay
    - Is ebb and flow the most suitable irrigation system for such studies over sustained periods between destructive harvests? Does this point matter if the growth period was roughly 4 weeks from 1st and 2nd harvest rather than the 2 weeks in this study?
    - Test graded media, preferably coir, with higher WHC and lower WHC to what was used in this study. Does it follow the model developed in this study? What is the maximum WHC allowed for the model to hold true? Does the bioassay model describe all stages of crop growth or only seedling stage or only vegetative/fruiting stage and is there a difference? How do we measure that difference effectively at low cost?
    - Can this bioassay be used for other soilless media in use today? What about peat, is there a correlation with coir? Can media of various source and structure be compared using a bioassay when each is difference in particle size and physical properties? Can we grade multiple soilless media types at identical or similar WHC to one another and compare those in a bioassay? Will the results be identical given they all have the same physical properties and if not what factors are affecting the coir bioassay model? Suitability for a soilless media type to become

productive may be determined by more than WHC. Perhaps the age of soilless media has a significant difference on performance even though the physical properties are the same.

Apart from using coir in this study, it may be of interest in other sectors of the horticultural industry. One sector gaining popularity, due to its conservative methodology, is aquaponics. For any soilless media to become successful it needs to contain characteristics which favour the initiation and subsequent development of specific crops. One of these characteristics includes the nature water holding capacity and/or air filled porosity play on the root environment. The underlying logic in aquaponics is the use of fish waste to provide nutrition to an edible/saleable crop. A system could be developed which takes advantage of graded coir as an ideal soilless media component of an aquaponic system with specific water/air ratio requirements.

Another area of interest gaining popularity, due to increased concerns over peat, is the development of composts. Coir could be added to composts to either increase their water holding capacity (with the inclusion of Small size grade particles) or increase the air/gas exchange by including large size grade particles. The only problem with adding coir into composts is; one of the reasons why composts are gaining popularity is the simple fact that it can be sourced locally while coir will have to be imported into the country which in some ways defeats the point. Besides composting, the addition of clay soils into coir to manipulate physical properties is one area of interest. The theory being that the inclusion of clay will improve the water holding characteristics rather than including peat to coir to produce the same effect.

CHAPTER 8: REFERENCES

Abad, M., Fornes, F., Carrion, C., Noguera, V., Noguera, P., Maquieira, A., et al. (2005). Physical properties of various coconut coir dusts compared to peat. *HortScience 40*:2138-2144.

Arenas, M., Vavrina, C., Cornell, J., Hanlon, E., & Hochmuth, G. (2002). Coir as an alternative to peat in media for tomato transplant production. *HortScience 37*:309-312.

Chen, Y., Banin, A., & Ataman, Y. (1980). Characterization of particle pores, hydraulic properties and water-air-ratios of artificial growth media and soil. *Proceedings of the 5th international congress of soilless culture* (pp. 63-82). Wageningen, The Netherlands: ISOSC.

Coolong, T. (2012). *Vegetable production guide for commercial growers, 2012-2013*. Cooperative extension services. University of Kentucky. College of agriculture. Lexington, KY.

CVPG (2002). *Greenhouse Tomato*. Commercial vegetable production guides. North Willamette Research and Extension Center. Oregon State University.

De Boodt, M., Verdonck, O., & Cappaert, I. (1972). Method for measuring the waterrealease curve of organic substrates. *Acta Horticulturae*, *37*:2054-2062.

De Koning, A.N.M. (1994). *Development and dry matter distribution in glasshouse tomato: a quantitative approach*. Thesis, Wageningen Agricultural University, Wageningen, The Netherlands.

DeKock, P.C., Inkson, R.H.E., & Hall, A. (1982). Blossom end rot of tomato as influence by truss size. *Journal of Plant Nutrition*, *5*:57-62.

Duggan-Jones, D.I. (2011). *Effects of particle size grading on the physical characteristics of coconut coir*. Unpublished Postgraduate Diploma thesis, Massey University, Palmerston North, New Zealand.

Ehret, D.L., & Ho, L.C. (1986). Effects of osmotic potential in nutrient solution on diurnal growth of tomato fruit. *Journal of Experimental Botany*, 37:1294-1302.

Evans, M.R., Konduru, S., & Stamps, R.H. (1996). Source variation in physical and chemical properties of coconut coir dust. *HortScience, 31*:965-967.

FAO. (2010). *FAO statistical database*. Accessed March, 2012. FAO, Rome, Italy.

Foale, M. (2005). An introduction to the coconut palm. In P. Batugal., R. Rao & J. Oliver (Eds.), *Coconut Genetic Resources* (pp. 1-12). International Plant Genetic Resources Institute – Regional Office for Asia, the Pacific and Oceania (IPGRI-APO), Serdang, Selangor DE, Malaysia.

Fornes, F., Belda, R.M., Abad, M., Noguera, P., Purchades, R., Maquieira, A., et al. (2003). The microstructure of coconut coir dusts for the use as alternatives to peat in soilless growing media. *Australian Journal of Experimental Agriculture 43*:1171-1179.

Grierson, D., & Kader, A.A. (1986). Fruit ripening and quality. In J.G. Atherton & J.Rudith (Eds.), *The tomato crop: A scientific basis for improvemen*t (pp.241-280). Chapman & Hall, New York.

Grimwood, E. (1976). *Coconut palm products: Their processing in developing countries*. FAO, Rome, Italy.

Heuvelink, E., & Dorais, M. (2005). Crop growth and yield. In E. Heuvelink (Eds.), *Tomatoes*. Cambridge: CAB International.

Hickman, G.W. (1998). *Commercial greenhouse vegetable handbook*. ANR Publications.

Hillel, D. (2008). *Soils in the environment: Crucible of terrestrial life*: Elsevier Academic Press.

Ho, L.C. (1999). The physiological basis for improving tomato fruit quality *Acta Horticulturae, 487*:33-40.

Hunt, R. (1978) *Plant growth analysis*. Studies in biology no. 96. London: Edward Arnold.

Hunt, R. (1982) *Plant growth curves: The functional approach to plant growth analysis*. London: Edward Arnold

Hunt, R. (2003). Growth analysis, individual plants. In B. Thomas., D.J. Murphy & D. Murray (Eds.), *Encyclopaedia of applied plant sciences* (pp.588-596). London: Academic Press.

Iwasaki, Y. (2008). Root zone aeration improves growth and yields of coir-cultured strawberry (*Fragaria Ananassa* Duch.) during summer. *Acta Horticulturae*, *779*:251-254.

Jeyaseeli, D.M., & Raj, S.P. (2010). Physical characteristics of coir pith as a function of particle size to be used as soilless medium. *American-Eurasian Journal of Agricultural & Environmental Science, 8*:431-437.

Jones, B.J. (2008). *Tomato plant culture*: In the field, greenhouse, and home garden. NW,USA: CRC Press.

Kennedy, G.G. (2003). Tomato, pests, parasitiods, and predators: Tritrophic interactions involving the Genus *Lycopersicum*. *Annual Review of Entemology 48*:51-72.

Kirkham, B. (2005). Principles of soil and plant water relations: Elsevier Academic Press

Kriedermann, P.E. (2003). Growth analysis: a quantitative approach. In B. Atwell., P. Kriedermann & C. Turnbull (Eds.), *Plants in action: adaptation in nature, performance in cultivation* (pp. 186-220). South Yarra, Australia: Macmillan publishers.

Lai, R., & Shukla, M.K. (2004). Principles of soil physics. New York: Marcel Dekker.

Luckwill, L. (1943). *The genus Lycopersicum*: historical, biological, and taxonomic survey of the wild and cultivated tomato. Aberdeen, Scotland: Aberdeen University Press.

Lindhout, P. (2005). Genetics and breeding. In E. Heuvelink (Ed.), *Tomatoes* (pp.21-52). Cambridge: CAB International.

Miyazaki, T. (2006). Water flow in soils: Taylor and Francis

Myers, J. (2006). What can I do to ensure that my tomato flowers are pollinated? *Organic Garden, 53*:29.

Nelson, P.V., Oh, Y.M., & Cassel, D.K. (2004). Changes in physical properties of coir dust substrates during crop production. *Acta Horticulturae*, *644*:261-268.

Nobel, P.S. (2009). Physicochemical and environmental plant physiology: Academic Press

Noguera, p., Abad, M., & Martinez, J. (1997). Physical and chemical properties of coir waste and their relation to plant growth. *Acta Horticulturae, 450*: 365-373.

Noguera, P., Abad, M., Purchades, R., Maquieira, A., & Noguera, V. (2003). Influence of particle size on physical and chemical properties of coconut coir dust as container medium. *Communications in Soil Science and Plant Analysis, 34*:593-605.

OMAFRA (2001). *Growing greenhouse vegetables*. Publication 371 (pp. 116). Toronto, Canada: Ontario Ministry of Agriculture, Food and Rural Affairs.

Or, D., & Wraith, J.M. (2002). Soil water content and water potential relationships. In Warrick, A.W. (Ed.), *Soil physics companion* (pp 49-84): CRC Press.

Peet (1992). Fruit Characteristics. In B.J Jones (Ed.), *Tomato plant culture* (pp. 108-114). FL, USA: CRC Press.

Peet, M.M., & Willits, D. (1995). Role of excess water in tomato fruit cracking. *HortScience, 30*: 65-68.

Peet, M.M., & Welles, G.W.H. (2005). Greenhouse tomato production. In E. Heuvelink (Ed.), *Tomatoes*. Cambridge: CAB International.

Perera, L., Russell, J.R., Provan, J., & Powell, W. (2003). Studying genetic relationships among coconut varieites/populations using microsatellite markers. *Euphytica, 00*: 1-8.

Pill, W.G., Lambeth, V.N., & Hinckley, T.M. (1978). Effect of nitrogen form and level on ion concentration, water stress and blossom end rot incidence in tomato. *Journal of the American Society for Horticultural science, 103*:265-286.

Pokorny, F.A., Gibson, P.G., & Dunavent, M.G. (1986). Prediction of bulk density of pine bark and/or potting media from laboratory analyses of individual components. *Journal of the American Society for Horticultural science. 111*: 8-11.

Prasad, M., & Chualain, D.N. (2004). Relationship between particle size and air space of growing media. *Acta Horticulturae*, *648*: 161-166.

Raviv, M., & Mordechai, S. (1988). A suggested modification in the extraction procedure and expression of EC values of growth media. *Acta Horticulturae*, *221*:445-452.

Raviv, M., Lieth, J.H., Burger, D.W., & Wallach, R. (2001). Optimization of transpiration and potential growth rates of 'Kardinal' rose with respect to root-zone physical properties. *Journal of the American Society for Horticultural science, 126*: 638-645.

Raviv, M., Wallach, R., Silber, A., & Bar-Tal., A. (2002). Substrates and their analysis. In D. Savvas & H. Passam (Eds.), *Hydroponic production of vegetables and ornamentals* (pp.25-101). Athens, Greece: Embryo Publications.

Salisbury, F.B., & Ross, C.W. (1992). *Plant physiology*: Wadswoth Pub. Co.

Salveit, M.E. (2005). Fruit ripening and fruit quality. In E. Heuvelink (Ed.), *Tomatoes* (pp.145-170). Cambridge: CAB International.

Saure, M.C. (2001). Review: Blossom-end rot of tomato (*Lycopersicon esculentum* Mill.) – a calcium- or a stress-related disorder? *Scientia Horticulturae,* 90:193-208

Schilmiller, A.L., Last, R.L., & Pichersky, E. (2008). Harnessing plant trichome biochemistry for the production of useful compounds. *The Plant Journal, 54*:702-711.

Snowdon, A.L. (1990). *Post-Harvest diseases and disorders of fruits and vegetables Volume 2*: Mason Publishing

Van den Ende, J. (1971). Extraction methods for the determination of major elements in greenhouse soils and potting culture media. *Acta Horticulturae, 29*: 125-140.

van Dam, J.E.G. (2002). *Coir processing technologies: Improvement in drying, softening, bleaching and dyeing coir fibre/yarn and printing coir floor coverings*. Rome, Italy: FAO.

van Dam, J.E.G., van den Oever, M.J.A., & Keijsers, E.R.P. (2003*). Production process for high density high performance binderless boards from whole coconut husk.* Industrial Crops and Products 20 (2004): 97-101.

Vavrina, C., Armbrester, K., Arenas M., & Pena, M. (1996). Coconut coir as an alternative to peat media for vegetable transplant production. *Station Report-Vegetal, 4*.

Warncke, D.D. (1990). Testing artificial growth media and interpreting the results. In: R.L. Westerman, (Ed.), *Soil testing and plant analysis*. 3rd ed. – SSSA Book Series no.3. Soil Science Society of America.

West, C., Briggs, G.E., & Kidd, F. (1920). Methods and significant relations in the quantitative analysis of plant growth. *New Phytologist, 19*:200-207.

Yu, H., Kowalski, S.P., & Steffens, J.C. (1992). Comparison of polyphenol oxidase expression in glandular trichomes of *Solanum* and *Lycopersicon* species. *Plant Physiology, 100*: 1885-1890.

APPENDIX 1: EXAMPLE STATISTICAL ANALYSIS

Yield trial

Total yield

```
Call:
lm(formula = TotalYldPP ~ Treatment * Irrigation + Block, data =
data)

Residuals:
    Min      1Q  Median      3Q     Max 
-0.9214 -0.3905  0.0000  0.3905  0.9214 

Coefficients:
                         Estimate Std. Error t value Pr(>|t|)    
(Intercept)                7.0886     0.5740  12.349 1.48e-08 ***
TreatmentM                 1.4050     0.7843   1.792   0.0965 .  
TreatmentML                1.5100     0.7843   1.925   0.0763 .  
TreatmentS                 1.5150     0.7843   1.932   0.0755 .  
TreatmentSL                1.8250     0.7843   2.327   0.0368 *  
TreatmentSM                1.7450     0.7843   2.225   0.0444 *  
TreatmentSML               1.5150     0.7843   1.932   0.0755 .  
Irrigation6               -1.2000     0.7843  -1.530   0.1500    
Block2                     0.5929     0.2964   2.000   0.0668 .  
TreatmentM:Irrigation6    -0.4250     1.1091  -0.383   0.7078    
TreatmentML:Irrigation6   -0.4300     1.1091  -0.388   0.7045    
TreatmentS:Irrigation6    -0.2900     1.1091  -0.261   0.7978    
TreatmentSL:Irrigation6   -0.4100     1.1091  -0.370   0.7176    
TreatmentSM:Irrigation6   -0.9300     1.1091  -0.839   0.4169    
TreatmentSML:Irrigation6  -0.6450     1.1091  -0.582   0.5708    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.7843 on 13 degrees of freedom
Multiple R-squared: 0.7808,  Adjusted R-squared: 0.5447 
F-statistic: 3.307 on 14 and 13 DF,  p-value: 0.01893

Analysis of Variance Table

Response: TotalYldPP
                     Df  Sum Sq Mean Sq F value    Pr(>F)    
Treatment             6  6.5276  1.0879  1.7688   0.18275    
Irrigation            1 18.9916 18.9916 30.8777 9.278e-05 ***
Block                 1  2.4604  2.4604  4.0002   0.06683 .  
Treatment:Irrigation  6  0.4991  0.0832  0.1352   0.98905    
Residuals            13  7.9957  0.6151                      
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Study:

LSD t Test for TotalYldPP 

Mean Square Error:  0.6150571
```

Irrigation, means and individual (95 %) CI

	TotalYldPP	std.err	replication	LCL	UCL
3	8.744286	0.2556025	14	8.19209	9.296481
6	7.097143	0.1752907	14	6.71845	7.475835

alpha: 0.05 ; Df Error: 13
Critical Value of t: 2.160369

Least Significant Difference 0.6403783
Means with the same letter are not significantly different.

Groups, Treatments and means

a	3	8.744
b	6	7.097

Study:

LSD t Test for TotalYldPP

Mean Square Error: 0.6150571

Treatment, means and individual (95 %) CI

	TotalYldPP	std.err	replication	LCL	UCL
L	6.7850	0.5889043	4	5.512750	8.057250
M	7.9775	0.6577661	4	6.556483	9.398517
ML	8.0800	0.5037030	4	6.991816	9.168184
S	8.1550	0.4970832	4	7.081117	9.228883
SL	8.4050	0.5417487	4	7.234623	9.575377
SM	8.0650	0.7714651	4	6.398351	9.731649
SML	7.9775	0.5715239	4	6.742798	9.212202

alpha: 0.05 ; Df Error: 13
Critical Value of t: 2.160369

Least Significant Difference 1.198038
Means with the same letter are not significantly different.

Groups, Treatments and means

a	SL	8.405
a	S	8.155
a	ML	8.08
a	SM	8.065
ab	M	7.978
ab	SML	7.977
b	L	6.785

Time to 50% harvest

```
Call:
lm(formula = Q2 ~ Treatment * Irrigation + Plot, data = tx)

Residuals:
   Min     1Q Median     3Q    Max 
-5.714 -1.786  0.000  1.786  5.714 

Coefficients:
                         Estimate Std. Error t value Pr(>|t|)    
(Intercept)                30.714      2.425  12.665 1.09e-08 ***
TreatmentM                  4.500      3.313   1.358   0.1975    
TreatmentML                 7.500      3.313   2.264   0.0414 *  
TreatmentS                  4.000      3.313   1.207   0.2488    
TreatmentSL                 6.000      3.313   1.811   0.0933 .  
TreatmentSM                 7.500      3.313   2.264   0.0414 *  
TreatmentSML                7.000      3.313   2.113   0.0545 .  
Irrigation6                -4.500      3.313  -1.358   0.1975    
Plot2                       3.571      1.252   2.852   0.0136 *  
TreatmentM:Irrigation6     -4.500      4.686  -0.960   0.3544    
TreatmentML:Irrigation6    -4.000      4.686  -0.854   0.4088    
TreatmentS:Irrigation6     -0.500      4.686  -0.107   0.9167    
TreatmentSL:Irrigation6    -2.000      4.686  -0.427   0.6765    
TreatmentSM:Irrigation6    -6.000      4.686  -1.280   0.2228    
TreatmentSML:Irrigation6   -3.500      4.686  -0.747   0.4684    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 3.313 on 13 degrees of freedom
Multiple R-squared: 0.8077,  Adjusted R-squared: 0.6005 
F-statistic: 3.899 on 14 and 13 DF,  p-value: 0.009547

Analysis of Variance Table

Response: Q2
                     Df Sum Sq Mean Sq F value    Pr(>F)    
Treatment             6  95.00   15.83  1.4423   0.27177    
Irrigation            1 386.29  386.29 35.1872 4.969e-05 ***
Plot                  1  89.29   89.29  8.1331   0.01361 *  
Treatment:Irrigation  6  28.71    4.79  0.4359   0.84215    
Residuals            13 142.71   10.98                      
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Study:

LSD t Test for Q2

Mean Square Error:  10.97802 

Irrigation,  means and individual ( 95 %) CI

        Q2  std.err replication      LCL      UCL
3 37.71429 1.268505          14 34.97385 40.45472
6 30.28571 0.587681          14 29.01611 31.55532

alpha: 0.05 ; Df Error: 13
```

```
Critical Value of t: 2.160369

Least Significant Difference 2.705459
Means with the same letter are not significantly different.

Groups, Treatments and means
a      3     37.71
b      6     30.29

Study:

LSD t Test for Q2

Mean Square Error:  10.97802

Treatment,  means and individual ( 95 %) CI

       Q2  std.err replication      LCL      UCL
L   30.25 1.314978           4 27.40916 33.09084
M   32.50 2.629956           4 26.81833 38.18167
ML  35.75 2.750000           4 29.80899 41.69101
S   34.00 1.779513           4 30.15560 37.84440
SL  35.25 3.682730           4 27.29395 43.20605
SM  34.75 3.497023           4 27.19514 42.30486
SML 35.50 2.958040           4 29.10954 41.89046

alpha: 0.05 ; Df Error: 13
Critical Value of t: 2.160369

Least Significant Difference 5.06145
Means with the same letter are not significantly different.

Groups, Treatments and means
a      ML    35.75
a      SML   35.5
ab     SL    35.25
ab     SM    34.75
ab     S     34
ab     M     32.5
b      L     30.25
```

Growth Analysis

Relative growth rate

```
Call:
lm(formula = RGR ~ Treatment + Block, data = data)

Residuals:
     Min       1Q   Median       3Q      Max 
-0.42713 -0.08819  0.03750  0.12400  0.35175 

Coefficients:
             Estimate Std. Error t value Pr(>|t|)    
(Intercept)   1.20263    0.12190   9.866 2.45e-09 ***
TreatmentL    0.02825    0.14701   0.192   0.8495    
TreatmentM    0.11825    0.14701   0.804   0.4302    
TreatmentML  -0.05375    0.14701  -0.366   0.7183    
TreatmentS    0.08050    0.14701   0.548   0.5898    
TreatmentSL   0.27250    0.14701   1.854   0.0779 .  
TreatmentSM   0.26775    0.14701   1.821   0.0828 .  
TreatmentSML  0.15550    0.14701   1.058   0.3022    
Block2       -0.15588    0.10395  -1.499   0.1486    
Block3       -0.08375    0.10395  -0.806   0.4295    
Block4       -0.06488    0.10395  -0.624   0.5393    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.2079 on 21 degrees of freedom
Multiple R-squared: 0.3544,	Adjusted R-squared: 0.04694 
F-statistic: 1.153 on 10 and 21 DF,  p-value: 0.373

Analysis of Variance Table

Response: RGR
          Df  Sum Sq  Mean Sq F value Pr(>F)
Treatment  7 0.39953 0.057075  1.3204 0.2894
Block      3 0.09872 0.032906  0.7613 0.5284
Residuals 21 0.90772 0.043225               

Study:

LSD t Test for RGR 

Mean Square Error:  0.04322456 

Treatment,  means and individual ( 95 %) CI

        RGR    std.err replication       LCL      UCL
C   1.12650 0.05785830           4 1.0061771 1.246823
L   1.15475 0.14518917           4 0.8528126 1.456687
M   1.24475 0.07476338           4 1.0892710 1.400229
ML  1.07275 0.05534645           4 0.9576508 1.187849
S   1.20700 0.10436874           4 0.9899533 1.424047
SL  1.39900 0.04090232           4 1.3139390 1.484061
SM  1.39425 0.07688452           4 1.2343599 1.554140
SML 1.28200 0.17975585           4 0.9081772 1.655823

alpha: 0.05 ; Df Error: 21
```

Critical Value of t: 2.079614

Least Significant Difference 0.3057264
Means with the same letter are not significantly different.

Groups, Treatments and means

a	SL	1.399
a	SM	1.394
ab	SML	1.282
ab	M	1.245
ab	S	1.207
ab	L	1.155
ab	C	1.126
b	ML	1.073

APPENDIX 2: PHOTOS OF SUMMER YIELD TRIAL

Photo. 1. Hybrid Albaron seeds were propagated in rockwool cubes on an ebb and flow system until such time as the roots began emerging from the base of the cube.

Photo. 2. A week later on the 2nd of September, seedlings were transferred to their plastic bags containing the 7 size grade treatments.

Photo. 3. Seedlings established and ready for wire support.

Photo. 4. On the 3rd October 2011 flowering was underway and supported by string.

Photo. 5. A month and a half later, on the 23rd November 2001, fruit began ripening and plants were topped when they reached the top wire of 2m.

Photo. 6. With harvesting was well underway. King fruit were not removed and fruit thinning ignored. No chemical sprays were used throughout the growth trial. Biological control agent (*Encarsia formosa*) was used to control aphid populations, and bumblebees were introduced to aid pollination.

APPENDIX 3: PHOTOS OF GROWTH ANALYSIS 2(SG)

Photo. 7. This photo was taken a week after the first harvest when 1st true leaves appeared

Photo. 8. This photo was taken prior to the second destructive harvest.

APPENDIX 4: PAPER PRESENTED AT: INTERNATIONAL CONFERENCE & EXHIBITION ON SOILLESS CULTURE 2012 (SHANGHAI, CHINA)

Effect of physical characteristics of coir on the productivity of greenhouse tomatoes

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Keywords: air filled porosity, water holding capacity, easily available water, bioassay, yield, particle size

Abstract

Coir is a relatively new growing media, and little information is known of the relationship between particle size and particle size distribution on crop productivity. Particle size significantly affects the physical properties of coir, particularly the air-water relationships. An experiment was designed to compare the yield, water use efficiency and RGR (relative growth rate) of a tomato (*Solanum lycopersicum*) crop grown in coir using a range of particle sizes. Seven treatments based on combinations of small (s), medium (M) and large (L) sized particles, together with a commercial ungraded coir dust. Two irrigation (low and high) frequencies were used. The seven treatments are based on particle size with differences in WHC (water holding capacity). A bioassay will be used to compare tomato yield and RGR. The physical properties, governed by particle size, have an effect on tomato yield. As treatments increase in WHC so does yield. An upward linear relationship exists between WHC and yield gained per plant. A relationship was also found between the bioassay and tomato yield trial. Similar to the tomato yield trial, as WHC increased so did the RGR. The relationship between WHC and RGR may have commercial implications for both soilless media manufacturers and growers which require specific physical properties in terms of water and air availability for particular crop types.

INTRODUCTION

Coir is a by-product of the coconut industry. Coconut palm (*Cocos nucifera*) is cultivated in many parts of the world. The main producers of coconut, and coir, are tropical countries such as Indonesia, Philippines and India. Indonesia provides a third of the world's coconuts while globally 62 Million tonnes are produced (FAO, 2010). Coir is the remains left after the extraction of the coconut fruit and long fibrous coconut husk for the production of other products such as rope and mats. A potential large amount of waste product (coir) may therefore be of horticultural interest.

While there are vast quantities of coir available the technique used to process coir vary by location. This variation has created coir with differences in quality and subsequently changes in their physical and chemical properties (Konduru et al., 1999;

Noguera et al., 2000). The physical properties of coir have been well researched over the past twenty years (Evans et al., 1996; Noguera et al., 2003; Jeyaseeli and Raj, 2010). Research into coir has primarily focused on source and their corresponding physical and/or chemical properties. Not only are the physical properties of coir different among countries but also within the same region. Evans et al., (1996) found significant differences in bulk density, air-filled pore space, water filled pore space, and total pore space from five Philippine sources of coir. It may be fair to compare different sources to one another if all producers of coir use the same techniques for processing. In fact, majority of what is being compared through previous coir source studies is the processing technique used and given a false indication of coir quality. In addition, results obtained from previous research may become obsolete when processing technique change. Ideally producers of coir would use the same technique regardless of their geographical location. As this is not the case at present, another method needs to be implemented which can actually produce viable results. With that said, apart from differences in physical properties, other characteristics which are unique to coir from a specific region or coconut variety may influence its suitability for horticultural use. At present our understanding of such detail is limited.

To successfully measure the performance of coir a common trait needs to be found between all coir sources. Physical properties are common characteristic which can define coir. The physical property which can easily be compared, which directly affects the performance on crops, is the WHC (water holding capacity) or AFP (air filled porosity). Determining physical properties prior to use is vitally important (Verdonck et al., 1983) for all media substrates. Once the crop has established in the media there is little which can be done to improve the characteristics for optimal crop growth. Growing crops in different sources of coir and then comparing their performance cannot be taken as a true representation of coir.

Although it can be argued that simply comparing physical properties and ignoring the chemical properties of coir does not accurately describe the true nature of coir. The chemical properties of coir can be manipulated easily throughout the duration of the crop cycle which cannot be said for the physical properties. It is true that microbial activity causes a change in the physical properties of coir during a crop cycle (Handreck, 1993a and 1993b). This however will not form part of this research.

This research will focus on how physical properties of coir directly relate to crop yield. In particular how coir with varying physical properties, such as WHC, relates to overall crop yield. In addition, a bioassay (growth analysis) will be used to model seedling growth and how it relates to overall crop yield.

MATERIALS AND METHODS

Experiments were carried out on compressed packaged coir sourced from Sri-Lanka. Compressed coir needed to be fully hydrated to separate particles and oven dried at 60°C prior to further use. Coir was sieved into 3 size grades (S for fractions measuring less than 0.85mm, M for fractions between 0.85mm and 1.40mm and L for fractions between 1.40mm and 2.36mm). Fractions measuring larger than 2.36mm was removed. A further 4 size grades (SM, SL, ML and SML) were produced by mixing equal weight portions of S, M and L. Separating coir into fractions allows media of distinct physical properties (Table. 1) to be tested as opposed to raw coir of varying physical properties. Separating into distinct size grades will aid in the processing of coir to better meet the goals of the grower, in particular those which require specific physical properties in terms of water and air availability for particular crop types.

Water and Air properties

The water holding capacity was defined using a slightly modified method used by de Boodt et al., (1972). The modification uses two slotting disks containing holes, located beneath the core, which regulates the flow of liquid exiting the core rather than a sandbath.

Bioassay

Pots measuring 70 mm in height containing 0.2 L media were placed on an ebb and flow system throughout the duration of the analysis. The experimental design was a randomised complete block with 2 plots, 4 blocks and 7 size grades. An EC of 2.2 was maintained throughout the experiment. The bioassay (growth analysis) took place on the 7th November 2011. This trial involved sowing seeds using the same technique as the tomato yield trial with the exception of not placing them into larger rockwool cubes. Emerged seedlings were transplanted from rockwool grow plugs into pots. Two seedlings were placed into each pot.

A destructive harvest took place after the first week of growth and once again a week later. Leaf area, stem dry weight and leaf dry weight were measured for all treatments. Treatments were compared to one another using the RGR (relative growth rate). LAR (leaf are ratio), NAR (net assimilation rate) and root dry weight were also recorded (data not shown).

Tomato yield trial

A growth trial was conducted during the spring/summer months of 2011/2012. Tomato (*Lycopersicon esculentum*) cv. Albaron seeds propagated in rockwool on August 2nd 2011 and placed on an ebb and flow system. Seedlings were two weeks old before placing them into larger rockwool cubes. Once seedling reached approximately 15cm in height, on the 26th of August 2011, they were moved to the greenhouse where they were placed two plants per processed coir grow bag. Grow bags consisted of the 7 size grade treatments at 650g/bag. Each bag contained the same weight of media regardless of the volume it occupied. An A and B standard tomato solution, injected via a Dosatron to maintain an EC of 2.2, through a drip nozzle placed on every plant. Two irrigation treatments, high and Low frequency, were installed. The high solution was irrigated twice as often as the Low solution. The low frequency irrigation treatment received 2.5 times the amount of irrigation the high treatment received. The experimental design was a randomised complete block with 2 replications, 2 blocks, 2 irrigation treatments and 7 size grade treatments (Table.1). Chemical pest and disease control was not used in this experiment. *Encarsia formosa* was introduced regularly to control whitefly populations. Bumblebees were used to facilitate pollination. As biological control was used, bumblebees were able to successfully pollinate throughout the flowering period without interruption.

The first harvest commenced on the 24th of November 2011 and continued for a further 12 weeks. Tomatoes were harvested three times a week for the first 7 weeks followed by twice a week for the next 3 weeks and then once a week for the remaining

2 weeks. The number of fruit, together with their weight, was recorded for the harvest period.

RESULTS AND DISCUSSION

Bioassay

Comparing the performance of coir with differing WHC through growth analysis required a sound technique which was achieved after much practice. The first attempt, consisting of 2 pot heights combined with direct sowing, produced inconsistent performance (data not shown). After some practise and improved technique the bioassay experiment produced reliable results. Amongst other parameters measured, relative growth rate (RGR) was compared against differing WHC (Fig. 1). As WHC increased so RGR increased. Average RGR ranged from 1.1 to 1.4 ($g.g^{-1}.day^{-1}$). Growth analysis produced an upward linear trend consistent with that of the growth trial (Fig. 2).

Tomato yield trial

Tomato yield ranged from 5.92 to 8.75 (kg) per plant. An upward linear trend was observed between WHC and yield per plant (Fig. 2). As WHC increased, or as AFP decreased, weight per plant increased. The low frequent irrigation treatment produced greater yield compared to the high frequent irrigation. Although nutrition was applied at a low frequency the overall amount delivered to the plant was higher. Initially it was predicted that delivering less irrigation more frequently would increase yield as aeration was improved. Thus however was not true for this growth trial. It appears increased WHC improves yield greater than the amount of aeration in the profile. The ability of media, in this case coir, to retain moisture between irrigations produces greater yield compared to frequent less irrigation (Fig. 2).

A linear relationship exists between RGR and tomato yield (Fig. 3). Yield increases as RGR increases. Low and high irrigation share the same trend as both have the same RGR.

CONCLUSIONS

This study suggests that particle size, with different physical properties, produce differences in yield. An important factor highlighted is the importance of water and the relationship with particle size. Producers of soilless media talk about the importance of aeration in their media and how this improves production. Although the importance of aeration to roots in the profile is well understood questions need to be asked as to when the importance of water in the profile exceeds that of air.

Of interest was the similarity between yield gained per plant and RGR. The combination of these two experiments highlights an important relationship which could be a useful tool for further growth trials for soilless media. Theoretically researchers could first complete a growth analysis which predicts potential yield without having to complete a full growth trial. Results also indicate that particle size in particular WHC, can be used to guide media manufacturers of coir and possibly other soilless media such as peat as mentioned by Naasz and Bussieres (2011).

In conclusion, results of this study highlight the importance of quantifying physical characteristics when producing soilless media. The importance of WHC is highlighted in both the growth trial and bioassay.

LITERATURE CITED

de Boodt, M., Verdonck, O. and Cappaert, I. 1974. Method for measuring the waterrelease curve of organic substrates. *Acta Hort*. 37: 2054-2062.

Evans., M.R., Konduru, S. and Stamps, R.H. 1996. Source variation in physical and chemical properties of coconut coir dust. *HortScience* 31: 965-967.

FAO. 2010. FAO statistical yearbook 2010. *FAO*, Rome.

Handreck, K.A. 1993a. Properties of coir dust and its use in the formulation of soilless potting media. *Communications in Soil Science and Plant Analysis*. 24: 349-363

Handreck, K.A. 1993b. Immobilization of nitrogen in potting media. *Acta Hort*. 342: 121-125.

Jeyaseeli, D. and Raj, S.P. 2010. Physical characteristics of coir pith as a function of its particle size to be used as soilless medium. *American-Eurasian J. Agric. & Environ. Sci* 8(4): 431-437.

Konduru, S., Evans, M.R. and Stamps, R.H. 1999. Coconut hust and processing effects on chemical and physical properties of coconut coir dust. *HortScience* 34: 88-90.

Naasz, R. and Bussières. 2011. Particle sixes related to physical properties of peat-based substrates. *Acta Hort*. 893: 971-978.

Noguera, P., Abad, M., Noguera, V., Puchades, R., Maquieira, A. and de Jager, A. 2000. Coconut coir waste, a new and viable ecologically-friendly peat substitute. *Acta Hort*. 517: 279-286

Noguera, P., Abad, M., Puchades, R., Maquieira, A. and Noguera, V. 2003. Influence of particle size on physical and chemical properties of coconut coir dust as container medium. *Communications in Soil Science and Plant Analysis* 34: 593-605.

Verdonck, O., Penninck, R. and de Boodt, M. 1983. The physical properties of different horticultural substrates. *Acta Hort*. 150: 155-160

Tables

Table 31. WHC (water holding capacity), RGR (relative growth rate) and tomato yield produced from different size graded coir and two irrigation treatments.

Treatment	Size Grade (mm)[1]	WHC (% vol)	RGR ($g.g^{-1}.day^{-1}$)	Tomato yield(kg/plant) 3 irrigations	Tomato yield(kg/plant) 6 irrigations
S	<0.85	87.61	1.21	8.90	7.41
M	0.85>1.40	65.17	1.24	8.79	7.17
L	1.40>2.36	41.36	1.15	7.39	6.18
SM		86.11	1.39	9.13	7.00
SL		75.28	1.40	9.21	7.60
ML		49.81	1.07	8.89	7.26
SML		80.35	1.28	8.90	7.05

[1]Treatments SM, SL and ML contain 50% weight of each major size grade. Treatment SML contains 33% weight of each of the 3 major size grades.

Figures

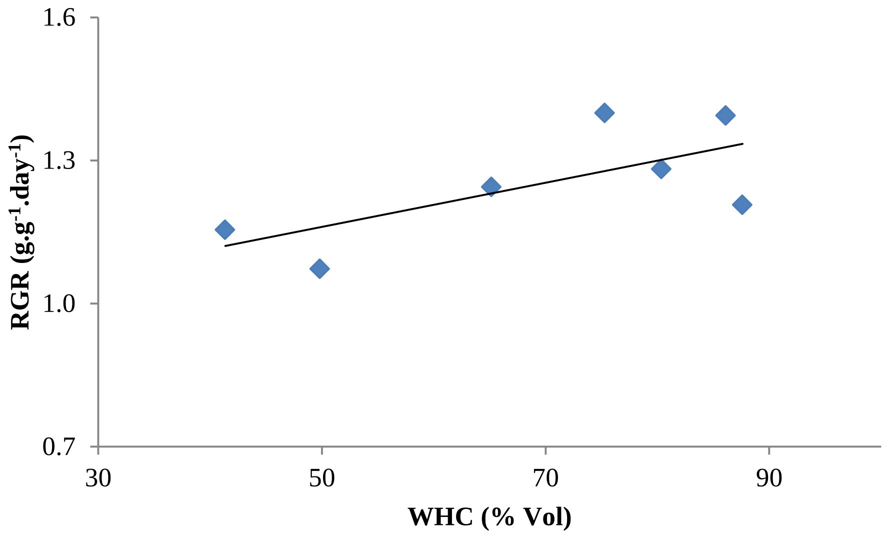

Fig. 1. Relationship between water holding capacity (WHC) and relative growth rate (RGR) obtained through a bioassay.

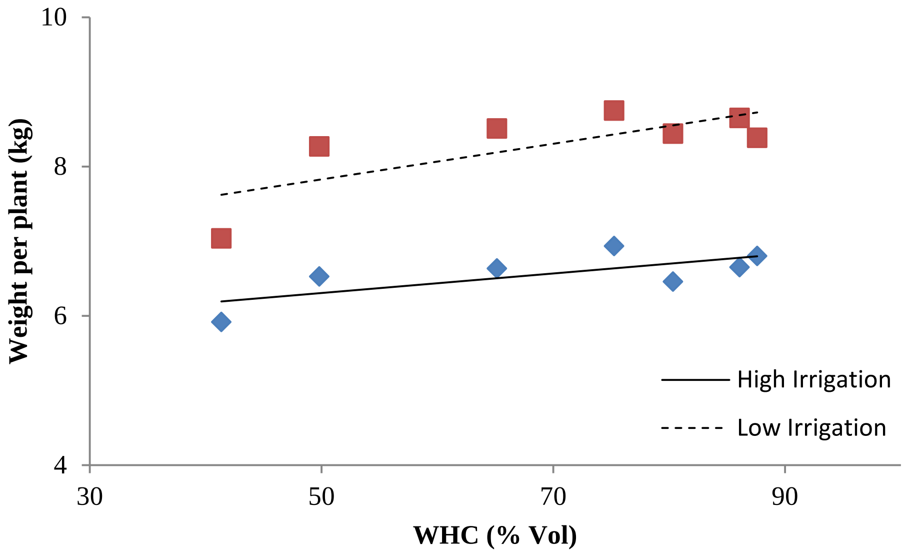

Fig. 2. Relationship between water holding capacity (WHC) and yield obtained between two irrigation treatments. High irrigation refers to high frequency (i.e. 6 irrigations per day) while low irrigation refers to 3 irrigations per day.

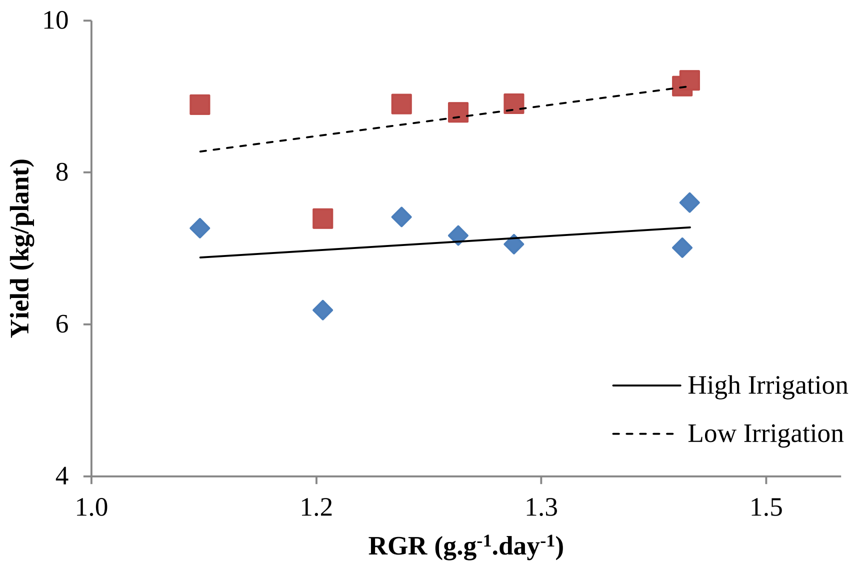

Fig. 3. Relationship between the bioassay and yield generated from the tomato yield trial. High irrigation refers to high frequency (i.e. 6 irrigations per day) while low irrigation refers to 3 irrigations per day.